ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

DESIGN OF SMART ELECTRONIC ADULT DIAPER

M.Sc. THESIS

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Department of Electronics and Communication

Electronics Engineering Programme

JUNE 2022

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

AKILLI ELEKTRONİK ERİŞKİN ALT BEZİ TASARIMI

YÜKSEK LİSANS TEZİ

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Name-surname, a M.Sc. student of İTU Graduate School student ID 504161237, successfully defended the thesis/dissertation entitled "DESIGN OF SMART ELECTRONIC ADULT DIAPER", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my family and my valentine,

FOREWORD

Nowadays, with the development of technology, we can easily do things that we could not do before or that we did very difficult in our lives. Solutions in the field of health and patient care can be given as examples of studies in this direction.

Every technological development actually arises out of a need. Scientists and engineers produce solutions to meet the needs. Afterwards, improvements are made to facilitate this solution.

In order to understand the need, it is necessary to experience the need personally or to witness and empathize with a person in need. Experiencing the emotion or feeling the emotion both enables to move forward without giving up for the solution and also provides the emergence of a real solution that can be easily used.

Adult diapers and bladder pads have also emerged as a result of people's urinary/fecal incontinence due to biological or psychological problems. If urinary incontinence is a temporary and manageable process, it will not be a problem for adults. However, if the person using the adult diaper or bladder pad is old, or even an elderly person in need of care, this situation can lead to psychological and medical problems if not kept under control. It requires the attention of family members or a caregiver to keep it under control. This creates the need for patient care, which is a very demanding and patient process.

People who pass by, chat with, and interact with you during the day may be able to use adult diapers or bladder pads. This is something that people often hesitate to say. Maybe (I would hope not) you will have to use it one day and then you will understand the situation that those people went through.

From the other point of view, do we know which patients are in what pain in the houses we are walking on their streets right now? Or have we ever thought? Especially with the increase in dementia, the need for patient care has increased. The combination of these diseases due to old age with urinary/fecal incontinence causes the person to be excluded from social life. In addition to staying out of social life, having to constantly use adult diapers due to urinary/fecal incontinence and needing someone to change the adult diapers causes psychological problems such as loss of self-confidence and loss of joy of life, and/or medical problems such as diaper rash.

Frankly, I was one of those people who lived unaware of these problems. Words such as urinary/fecal incontinence, adult diapers, dementia, etc. did not exist in my life. Until 2010, when my grandfather had a cerebral hemorrhage as a result of an accident. Fortunately, he was able to continue his life as a result of medical interventions. But, unfortunately, he suffered from dementia due to a cerebral hemorrhage. Because of dementia, he sometimes didn't even realize what he was doing. He even disappeared once. As a result, he had to continue his life in need of care.

When I saw the life of my grandfather, I began to understand what those people were going through. Sometimes we need to stop and empathize with the lives of the people around us, and even find solutions that will make their lives easier if possible.

My motivation and purpose in starting this project have been to offer a solution to make the lives of people like my grandfather easier. But, shortly after I started the project, I lost my grandfather. Still, I have had a purpose to keep the project going. In addition to the problems witnessed, I continued and completed this project, taking into account the problems experienced by other people as a result of my research. I couldn't do this project for my grandfather, but I hope it will benefit the life of every adult who has to use adult diapers.

June 2022

Ramazan KARAHALİL
(Electronics Engineer)

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To my dear girlfriend, who has always been with me in my education life, in my thesis work, and in my social life, who has always supported me and increased my motivation,
To my friends who always support me by sharing their knowledge and opinions with me both in my master's courses and in my thesis work,
To the companies I worked for that allowed me to attend lectures and thesis meetings during my master's degree,
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Finally, I would like to express endless thanks and respect to my advisor Assoc. Prof. Dr. Mustafa Berke YELTEN, and my gratitude to Assoc. Prof. Dr. Onur FERHANOĞLU and Assoc. Prof. Dr. Y. Dağhan GÖKDEL for serving in my thesis committee.

June 2022 Ramazan KARAHALİL
(Electronics Engineer)

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ABBREVIATES

AFH	: Adaptive Frequency Hopping
BLE	: Bluetooth Low Energy
CMOS	: Complementary Metal Oxide Semiconductor
EDR	: Enhanced Data Rate
FI	: Fecal Incontinence
FIT	: Future Internet of Things
GSM	: Global System for Mobile Communications
IDE	: Integrated Development Environment
IoT	: Internet of Things
IP	: Internet Protocol
LED	: Light Emitting Diode
M2M	: Machine to Machine
NFC	: Near Field Communication
RF	: Radio Frequency
RFID	: Radio Frequency Identification
RH	: Relative Humidity
SEAD	: Smart Electronic Adult Diaper
SMS	: Short Message Service
SPI	: Serial Peripheral Interface
SPP	: Serial Port Protocol
SSP	: Synchronous Serial Port
TCP	: Transmission Control Protocol
TPINOC	: The Person in Need of Care
UFI	: Urinary/Fecal Incontinence
UI	: Urinary Incontinence
USA	: United States of America
Wi-Fi	: Wireless Fidelity
WSN	: Wireless Sensor Network

SYMBOLS

%RH	**:** Relative Humidity Value
°C	**:** Celcius
g/gr	**:** Gram
GHz	**:** Giga Hertz
H	: Hour
Hz	**:** Hertz
KB	**:** Kilo Byte
kg	**:** Kilogram
L	**:** Litre
m	: Minute
mg	**:** Miligram
MHz	**:** Mega Hertz
ml	**:** Mililitre
ms, msc	: Milisecond
pH	**:** Potential of Hydrogen
s	: Second
V	**:** Volt
Ω	**:** Ohm

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DESIGN OF SMART ELECTRONIC ADULT DIAPER

SUMMARY

Nowadays, technology is now in almost every aspect of our lives and people can quickly adapt to new technologies. Technology, which develops day by day as a result of the work of academics, scholars, researchers and engineers, creates new areas for itself every day. In this thesis, which we set out with the philosophy that every technological development arises from needs and every new need are occured by technological developments, we designed the Smart Electronic Adult Diaper.

In this thesis, all the processes of a Smart Electronic Adult Diaper design have been explained in detail, respectively. In addition to a scientific study, a product design process has also been presented in the thesis. Every stage of the thesis work, from the idea phase to the prototype phase, from artificial tests to real tests, has been handled and analysed in detail. During the thesis study, electronics, communication, computer, medicine, biology, chemistry and psychology sciences have been taken as references and the design has been carried out in the light of these sciences.

The first part of the thesis is the introduction part. In the introduction, some preliminary information has been shared to make the thesis work more understandable. Information about the purpose of realization of the thesis and how this purpose emerged has been given. The terms and definitions mentioned in the next steps of the thesis have also been clarified in the introduction. In addition, the roadmap of the thesis study has been explained in detail in this section.

The next part of the thesis is a literature search. In the literature research, every factor, criterion, parameter and problem that is within the scope of the thesis study has been investigated and conveyed in detail. In the design of the Smart Electronic Adult Diaper, every criterion, parameter and feature has been presented by researching it from various aspects with multiple sciences. Multiple fields of electronics, communications, computers, medicine, biology, chemistry and psychology have been used, sometimes for reference and sometimes as inspiration. The process from the development of technology to wearable technologies is mentioned. Afterwards, information about adult diapers, their types, and usage areas have been given. In addition, the factors and problems that cause adult diaper use and the problems experienced by users during adult diaper use have also been examined in detail. In the last part of this section, the advantages and disadvantages of the studies carried out so far and shared in the literature for the detection of urinary and fecal incontinence have been mentioned. Sensors/systems that detect urinary/fecal incontinence have been examined in detail in terms of use and application.

In the next section, pre-tests performed to compare the sensors/systems mentioned in the studies in the literature have been presented. Since almost all of the studies in the literature have been carried out for the detection of urinary incontinence, urinary incontinence has been simulated in pre-tests. The advantages and disadvantages of each sensor/system have been determined in this section, where similar sensors/systems in the studies mentioned in the literature are tested. Studies separated

as sensor material and sensor layer have been tested with various liquids (water, salt solution (artificial urine) and real urine) in various volumes (50 ml, 100 ml and 250 ml). The data obtained as a result of the tests have been analyzed and the advantages and disadvantages of each sensor/system have been compared.

In the next section, which is entered into the design part of the thesis, each parameter affecting the design has been examined in detail. The objectives of each design and the reasons for each selected component have been explained in detail. In the design, the user and caregiver experience has been taken into account, as well as the applicability and usability of the designs and components. Components and communication features have been explained in detail.

In the hardware/software design part of the thesis, hardware design and software design have been explained step by step. It is clearly seen in this section which steps the design process goes through in order. The advantages of each design have been explained according to both the user and their caregivers.

The tests carried out to see the effect of our design and system have been presented in the next section. The tests carried out in this section have been carried out under similar conditions to the tests carried out in the pre-tests. The tests presented here have shown the advantages and disadvantages of our design versus studies in the literature.

In order to see whether this thesis study has succeeded, as it is desired for every study to reach its real purpose, real actual use tests have been presented in the last part. In this section, not only urinary incontinence but also fecal incontinence tests have been presented. Test data has been analysed to see the stability, reliability and speed of the system and the analysis results have been shown.

Many people are faced with the problem of urinary/fecal incontinence without realizing it. Especially in these situations, such as dementia patients, people may experience biological problems in the case of urinary/fecal incontinence. In addition to biological problems, they may also experience psychological problems. Depending on the environment the person is in and the people he lives with, there may be situations up to psychological violence. In order to prevent or at least minimize the problems experienced by people, the "Smart Electronic Adult Diaper" project has been carried out. With this project, the instant status of the person will be able to be followed by the caregivers or family members who are responsible for him/her, through sensors, processors and various auxiliary modules. Even in cases of urinary/fecal incontinence, notification will be sent to these people. In this way, both the caregivers/family members will be able to intervene immediately and the biological and psychological problems that the person may experience will be prevented.

With the Smart Electronic Adult Diaper Design thesis, we present a design that we believe can be beneficial biologically and psychologically for people suffering from urinary/fecal incontinence. Moreover, we believe that SEAD will facilitate the lives of both people suffering from urinary/fecal incontinence and the caregivers or family members who are responsible for caring for these people.

AKILLI ELEKTRONİK ERİŞKİN ALT BEZİ TASARIMI

ÖZET

Günümüzde teknoloji artık hayatımızın hemen hemen her alanında yer almaktadır ve insanlar yeni teknolojilere hızla adapte olabilmektedir. Akademisyenler, bilim insanları, araştırmacılar ve mühendislerin çalışmaları sonucunda günden güne gelişim gösteren teknoloji her geçen gün kendine yeni alanlar da yaratmaktadır. Her teknolojik gelişim ihtiyaçtan doğar ve teknolojik gelişmeler yeni ihtiyaçlarımızı yaratır felsefesi ile yola çıktığımız bu tez çalışmasında Akıllı Elektronik Erişkin Alt Bezi (SEAD) tasarımını gerçekleştirdik.

Bu tez çalışmasında bir Akıllı Elektronik Erişkin Alt Bezi tasarımının tüm süreçleri sırasıyla detaylı bir şekilde aktarılmaktadır. Bilimsel bir çalışmanın yanı sıra aynı zamanda bir ürün tasarım süreci de tez süresince anlatılmaktadır. Tez çalışmasının fikir aşamasından prototip aşamasına, yapay testlerden gerçek testlere kadar her aşaması detaylı bir şekilde işlenmektedir ve analiz edilmektedir. Tez çalışması süresince elektronik, haberleşme, bilişim, tıp, biyoloji, kimya ve psikoloji bilimleri referans alınmakta ve bu bilimler ışığında tasarım gerçekleştirilmektedir.

Tez çalışmasının ilk kısmında giriş bölümü yer almaktadır. Giriş bölümünde tez çalışmasının daha anlaşılır olması açısından bazı ön bilgiler paylaşılmaktadır. Tezin gerçekleştirilme amacı ve bu amacın nasıl ortaya çıktığı ile ilgili bilgiler verilmektedir. Tezin devamında gerçekleşen adımlarda bahsedilen terim ve tanımlar da giriş bölümünde açıklanmaktadır. Ayrıca tez çalışmasının yol haritası bu bölümde detaylı bir şekilde açıklanmaktadır.

Tez çalışmasının sonraki kısmında literatür araştırması yer almaktadır. Literatür araştırmasında tez çalışmasının kapsamına giren her etken, kriter, parametre ve sorun detaylı bir şekilde araştırılmakta ve aktarılmaktadır. Akıllı Elektronik Erişkin Alt Bezi tasarımında her kriter, parametre ve özellik çeşitli bilimler ile çeşitli açıdan araştırılarak aktarılmaktadır. Elektronik, haberleşme, bilgisayar, tıp, biyoloji, kimya ve psikoloji bilimlerinin çeşitli alanlarından bazen referans bazen de ilham alınarak yararlanılmaktadır. Teknolojinin gelişiminden giyilebilir teknolojilere gelen süreçten bahsedilmektedir. Sonrasında erişkin alt bezleri, çeşitleri ve kullanım alanları hakkında bilgi verilmektedir. Ayrıca, erişkin alt bezi kullanımına neden olan etkenler ve sorunlar ile erişkin alt bezi kullanımı sırasında kullanıcıların yaşadığı sorunlar da detaylı bir şekilde incelenmektedir. Bu bölümün son kısmında ise idrar kaçırmanın tespit edilebilmesi için şimdiye kadar yapılan ve literatürde paylaşılan çalışmalardan avantajları ve dezavantajları ile birlikte bahsedilmektedir. İdrar kaçırmayı tespit eden sensör veya sistemler kullanım ve uygulama açısından detaylıca incelenmektedir.

Sonraki kısımda literatürdeki çalışmalarda bahsedilen sensörleri/sistemleri karşılaştırmak için gerçekleştirilen ön testler sunulmaktadır. Literatürdeki çalışmaların geneli idrar kaçırmanın tespiti için gerçekleştirilmiş olmasından dolayı ön testler de idrar kaçırmayı simüle etmek üzerine gerçekleştirilmektedir. Literatürde bahsedilen

çalışmalardaki sensörlerin/sistemlerin benzerlerinin test edildiği bu kısımda her sensörün/sistemin avantajları ve dezavantajları tespit edilmektedir. Sensör malzemesi (iletken iplik ve iletken mürekkep) ve sensör katmanı (1-Katmanlı ve 2-Katmanlı) olarak ayrılan çalışmalar çeşitli hacimlerdeki (50 ml, 100 ml ve 250 ml) çeşitli sıvılar (su, tuz solüsyonu (suni idrar) ve gerçek idrar) ile test edilmektedir. Testler sonucunda elde edilen veriler analiz edilerek her sensörün/sistemin avantajları ve dezavantajları karşılaştırılmaktadır.

Tez çalışmasının tasarım kısmına girilen sonraki kısımda tasarıma etkiyen her bir parametre detaylıca incelenmektedir. Yapılan her tasarımın amaçları ve seçilen her komponentin nedenleri detaylıca açıklanmaktadır. Tasarımda kullanıcı ve hastabakıcı deneyimi göz önüne alındığı gibi kullanıcı ve hastabakıcıların istekleri de değerlendirilmiştir. Ayrıca, tasarımların ve komponentlerin uygulanabilirliği ve kullanılabilirliği de ele alınmaktadır. Komponentler, tasarım ve haberleşme özellikleri detaylıca açıklanmaktadır.

Tez çalışmasının donanım ve yazılım tasarımı kısmında donanım tasarımı ve yazılım tasarımı adım adım açıklanmaktadır. Tasarım süreçlerinin sırayla hangi adımlardan geçtiği bu kısımda açıkça aktarılmaktadır. Donanım tasarımı aşamasında komponentlerin yetişkin bezi üzerindeki yerleşimleri, komponent yerleşimleri seçilirken dikkat edilen kriterler ve özellikler, elektronik karta bağlanan tüm sistem bileşenlerinin nasıl bağlandığı ve bu bağlantı yöntemlerinin nasıl ve neden seçildiği detaylı bir şekilde açıklanmıştır. Yazılım tasarımında kullanılan arayüzler, kütüphaneler, kod blokları ve yazılım mantığı detaylı bir şekilde açıklanmaktadır. Donanım ve yazılımın birlikte nasıl çalışacağını belirlediğimiz algoritma tasarımı kısmında ise Akıllı Elektronik Erişkin Alt Bezi'nin çalışma mantığı diyagramlarını oluşturduk. Algoritma tasarımı bu bölümde detaylı bir şekilde açıklanmakta ve görsel ile gösterilmektedir. Her tasarım aşamasında Akıllı Elektronik Erişkin Alt Bezi'nin getirdiği avantajlar hem kullanıcı hem de kullanıcıya bakmakla yükümlü olan kişiler açısından açıklanmaktadır.

Gerçekleştirdiğimiz tasarım ve sistemin etkisini görmek amacıyla gerçekleştirilen testler sonraki kısımda sunulmaktadır. Bu kısımda gerçekleştirilen testler ön testlerde gerçekleştirilen testler ile benzer koşullarda gerçekleştirilmektedir. 50 ml, 100 ml ve 250 ml hacimlerindeki su, tuz solüsyonu (suni idrar) ve gerçek idrar sıvıları ile Akıllı Elektronik Erişkin Alt Bezi test edilmektedir. Testler sonucunda elde edilen veriler analiz edilerek Akıllı Elektronik Erişkin Alt Bezi'nin çalışma performansı, tepki hızı, güvenilirliği ve kararlılığı literatürde gerçekleştirilen çalışmalarda sunulan sensörlerin ön testlerdeki sonuçlarına göre karşılaştırılmaktadır. Testler sonucunda karşılaştırmalı analizler ile Akıllı Elektronik Erişkin Alt Bezi'nin diğer sensörlere göre üstün avantajlarından bahsedilmektedir.

Sonraki bölümde Akıllı Elektronik Erişkin Alt Bezi'nin fiili kullanımı sırasında ihtiyaç duyacağı karar matrisleri belirlenmektedir. Hem nem hem de sıcaklık değerlerini elde edebilen Akıllı Elektronik Erişkin Alt Bezi, elde ettiği verilere göre karar vermek için limit değerlere ihtiyaç duymaktadır. İhtiyaç duyulan limit değerlerin belirlenebilmesi için sensörümüz iki farklı pozisyonda iken ölçümler alınmıştır. Birinci pozisyon sensörümüzün Akıllı Elektronik Erişkin Alt Bezi'nin donanım tasarımı aşamasında belirlenen sensör yerleşim yerinde olması, ikinci pozisyon ise sensörümüzün insan vücuduna yapışık bir şekilde yer almasıdır. Elde edilen sonuçlar ile gerçekleştirilen analizler sonucunda Akıllı Elektronik Erişkin Alt Bezi'nin fiili kullanımı sırasında hem kararlı bir şekilde veri sağlayabileceği hem de yanlış uyarılar vermeyecek şekilde güvenilir kararlar verebileceği sınır değerler belirlenmiştir. Akıllı Elektronik Erişkin Alt Bezi'nin limit değerleri belirlenirken sensörümüzün insan vücudundaki nem ve sıcaklık değişimlerinden nasıl izole edildiği ve değişimlerden etkilenmediği detaylıca açıklanmaktadır.

Her çalışmanın gerçek amacına ulaşması istendiği gibi bu tez çalışmasının da gerçek amacına ulaşıp ulaşmadığına görmek için son kısımda gerçek fiili kullanım testleri sunulmaktadır. Bir önceki bölümde belirlenen limitler kullanılarak Akıllı Elektronik Erişkin Alt Bezi'nin çalışma performansı, güvenilirliği ve kararlılığı fiili kullanımda test edilmektedir. Bu kısımda sadece idrar kaçırma değil, aynı zamanda dışkı kaçırma sonuçları da sunulmaktadır. Fiili kullanımda ne zaman idrarın ne zaman dışkının geleceği belirsizdir. O yüzden idrar kaçırma testleri kısa sürede yapılsa dışkı kaçırma testleri süre ve detaylı izleme isteyen bir süreç olarak gerçekleşmiştir. Hatta dışkının sıvı içermeyecek şekilde sert gerçekleştiği ve de dışkının sıvı şekilde gerçekleştiği testleri yapma fırsatımız da olmuştur. Akıllı Elektronik Erişkin Alt Bezi'nin her türlü sıvıyı tespit edebilmesi sayesinde güvenilir ve kararlı bir şekilde idrar kaçırmanın tespit edilebildiği kanıtlanmaktadır. Akıllı Elektronik Erişkin Alt Bezi'nin hem iletkenlikten bağımsız olarak sıvıyı tespit edebilmesi hem de sadece nemi değil aynı zamanda sıcaklığı ölçebilmesi sayesinde dışkı kaçırmanın her türünün güvenilir ve kararlı bir şekilde tespit edilebildiği kanıtlanmaktadır.

Günümüzde birçok kişi farkında olmadan idrar/dışkı kaçırma problemi ile karşı karşıyadır. Özellikle demans hastaları gibi hastaların yaşadığı bu durumlarda kişiler idrar/dışkı kaçırma durumunda biyolojik olarak sorunlar yaşayabilmektedir. Biyolojik problemlere ek olarak psikolojik olarak rahatsızlık da yaşamaktadırlar. Kişinin bulunduğu ortama ve beraber yaşadığı kişilere bağlı olarak da psikolojik şiddete varan durumlar da yaşanabilmektedir. Kişilerin yaşadığı problemlerin engellenmesi ya da en azından bu durumları minimize etmek amacıyla "Akıllı Elektronik Erişkin Alt Bezi" tasarımı gerçekleştirilmiştir. Bu tasarım ile sensörler, işlemciler ve çeşitli yardımcı modüller vasıtasıyla kişinin anlık durumu hastabakıcılar veya bakmakla yükümlü olan aile bireyleri tarafından takip edilebilecektir. Hatta idrar ve dışkı kaçırma durumlarında bu kişilere bildirim gönderilecektir. Bu sayede hem hastabakıcılar veya aile üyeleri hemen müdahale edebilecek hem de kişinin yaşayabileceği biyolojik ve psikolojik problemlerin önüne geçilmiş olacaktır.

Akıllı Elektronik Erişkin Alt Bezi Tasarımı tez çalışması ile idrar ve dışkı kaçırmadan muzdarip olan insanlara biyolojik ve psikolojik açılardan faydalı olabileceğine ve hem idrar ve dışkı kaçırmadan muzdarip olan insanların hem de bu insanlara bakmakla yükümlü olan hastabakıcı veya aile üyelerinin hayatlarını kolaylaştırabileceğine inandığımız bir tasarımı sunmaktayız.

1. INTRODUCTION

This thesis study has been carried out with the aim of presenting a useful technology to people by taking electronics, communication, computer, medicine, biology, chemistry and psychology sciences as a reference. During the thesis study, various fields of each science have been used, sometimes by reference and sometimes by inspiration.

In order to present a useful technology to people, the subject of the adult diaper has been chosen as the main subject of the thesis. While it varies by country and region, there are countless people today suffering from urinary/fecal incontinence. Although urinary/fecal incontinence is known as a frequent problem in the elderly, it is also seen in young adults due to various biological or psychological reasons. With the development of technology and medicine, while the average life expectancy of people increases, the rate of diseases related to old age also increases. Likewise, the increase in people's anxiety levels due to various social problems triggers psychological and biological disorders. In addition, with the genetic modification of foods, new biological diseases have emerged that did not occur in previous centuries. These and similar new events directly or indirectly play an active role in increasing urinary/fecal incontinence disorders. Therefore, the demand for adult diapers is increasing and the adult diaper market is increasing day by day. If dementia etc. as people with diseases also suffer from urinary/fecal incontinence, these people become in need of care. The need for patient care has also increased the demand for patient care personnel and nursing homes.

The development of the market has led to various requests and demands in this field. Adult diapers produced and marketed with classical methods only serve to trap urine or feces and they don't let them overflow. For ordinary adults, this method may be somewhat sufficient. Because these people can change their diapers or get help to change the diaper after they have unintentionally urinated or defecated. However, disabled people, those who do not feel neural due to various biological or psychological reasons, and dementia etc. people who are unaware of what they are doing due to illness cannot change their diapers and cannot notify someone for help after they have unintentionally urinated or defecated. Such persons must be under the control of a family member or a caregiver. The family member or the caregiver should constantly check the diaper condition and change it if necessary. Unfortunately, this process, which is very gruelling, cannot always be realized. People suffering from urinary/fecal incontinence also burn out and experience psychological problems in the process. They are even exposed to physical and/or psychological violence depending on the behaviour of their family member or caregiver.

A periodic control method is generally chosen for a diaper change. However, the frequency of periodic control and the time are critical. Because the time at which the person wets or soils the diaper is not known. Exposure of human skin with urine or feces for a certain period of time causes various problems. Delayed diaper changes cause these problems and cause the person to catch a new disease. At this point, there is a need to get information about when the diaper is wet or dirty. This thesis study has been carried out for this purpose and the "smart electronic adult diaper" has been designed.

The solution and design presented in this thesis is a product that can be used by adults of all ages. With the design presented in this thesis, we offer solutions to more than one problem that people are suffering. Ordinary adults will be able to follow urine or feces activity instantly thanks to this design, and they will be able to record the urinary/fecal incontinence times, frequency, etc.. They will be able to obtain such information and share it with their doctors if needed. Although they can change their own diapers, those who do not feel urinary/fecal incontinence for various biological or psychological reasons will receive information as an instant notification in case of urinary/fecal incontinence thanks to this design and will be able to change the diaper without experiencing any medical problems. Likewise, it will be able to record the urinary/fecal incontinence times, their frequency, etc.. They will be able to obtain such information and share it with their doctors if needed. For people who need help and care, a family member or caregiver will be notified instantly when urinary/fecal incontinence happens. The family member or caregiver receiving the notification will ensure that the necessary diaper change is made as soon as possible. In this way, medical diseases caused by late diaper changes will be prevented. Moreover, there will be no need for constant control by a family member or caregiver and time loss will be avoided. In addition, since the patient will interact at a minimum time during this process, it will also prevent the patient from experiencing psychological problems. In addition, since the urinary/fecal incontinence times are recorded, family members or caregivers can see these data, their frequency, etc.. They will be able to obtain such information and share it with the patient's doctors if needed.

Each step of the study has been carried out in order, and in each chapter, various topics have been discussed and the process has been conveyed (Figure 1.1). As you progress through the thesis, you will have the opportunity to look at each chapter from different perspectives. In order to clearly convey why the design details of the product that will come out as a result of the thesis work are realized, the sections have progressed in a design process that progresses with technical details.

In the next chapter, chapter 2, the literature research of the project will be mentioned. We will make the subject more understandable in order to go into the details of the project by talking about the ongoing developments which are related to the thesis work from the past to the present.

After mentioning the development of technology and the introduction of the Internet into our lives, how the concept of the Internet of Things (IoT) came into our lives and the usage areas of IoT will be mentioned. The sectors and areas where IoT is used the most will be mentioned and the future and opportunities of IoT in this field will be discussed. With the development of the IoT, the field of wearable technology, which is one of the concepts that entered our lives, will also be mentioned.

We will move away from technology for a bit and talk about the adult diaper, which is the main product of the thesis work. It will discuss why people need this product by showing the types of adult diapers.

Afterwards, we will talk about a few of the health problems suffered by people who have to use diapers. Diaper dermatitis will be the first of these and by explaining dermatitis, why the dermatitis occurs and its types will be mentioned. In the thesis study, diaper dermatitis will be tried to be explained sufficiently in order to understand dermatitis during the evaluation of the studies we have done to prevent dermatitis. Likewise, by talking about dementia patients, the problems suffered by dementia patients will be discussed. The effects of urinary/fecal incontinence, which is the last health problem we will talk about, and the root causes that cause urinary/fecal incontinence will be mentioned. Understanding the problems experienced by people suffering from urinary/fecal incontinence will make the solution of the thesis study most helpful.

In the last part of the literature chapter, we will talk about smart diapers. In this area, we will try to talk about not only adult diapers but also all of the studies carried out to detect urinary/fecal incontinence as much as possible. Here you can find studies on baby diapers, children's clothes, etc. there will be work as well. Then the sensor type, sensor material, electronics module, target audience, etc. in the sub-headings, the advantages and disadvantages of the studies will be discussed in detail.

In chapter 3, we will make various pre-tests according to the examinations made during the literature research. Data comparisons will be made by testing the sensor types and sensor materials specified in the literature with various liquids in various volumes. The data analyses performed in this section will give us various clues for SEAD.

In chapter 4, we will enter upon the SEAD design and discuss the selection stages of each design component. In this section, we will proceed by giving information about every detail from the user/caregiver experience to the communication features of the system. It will be discussed how the diaper design is selected so that the user experience of patients and caregivers are at the highest level and how the sensor and electronic modules are selected to give the most reliable and stable results. The characteristics of each design component will be determined to make the thesis work more useful.

In chapter 5, the step-by-step phases of SEAD design will be discussed. While progressing through the design phases, both hardware and software stages will be discussed in detail. In this chapter, while progressing through the product design process, it will also be mentioned how the thesis work was developed. During the design process of the thesis, the experiences, needs and complaints of the people who have to use adult diapers and the family members or caregivers who are responsible for the care of those who use adult diapers were taken into consideration.

In chapter 6, the tests before the final of the thesis work will be discussed. In this section, similar to section 3, the system will be tested with various volumes of various fluids. The obtained data will be compared with other sensor data in the literature. We will discuss the advantages and disadvantages of SEAD compared to other smart diaper studies.

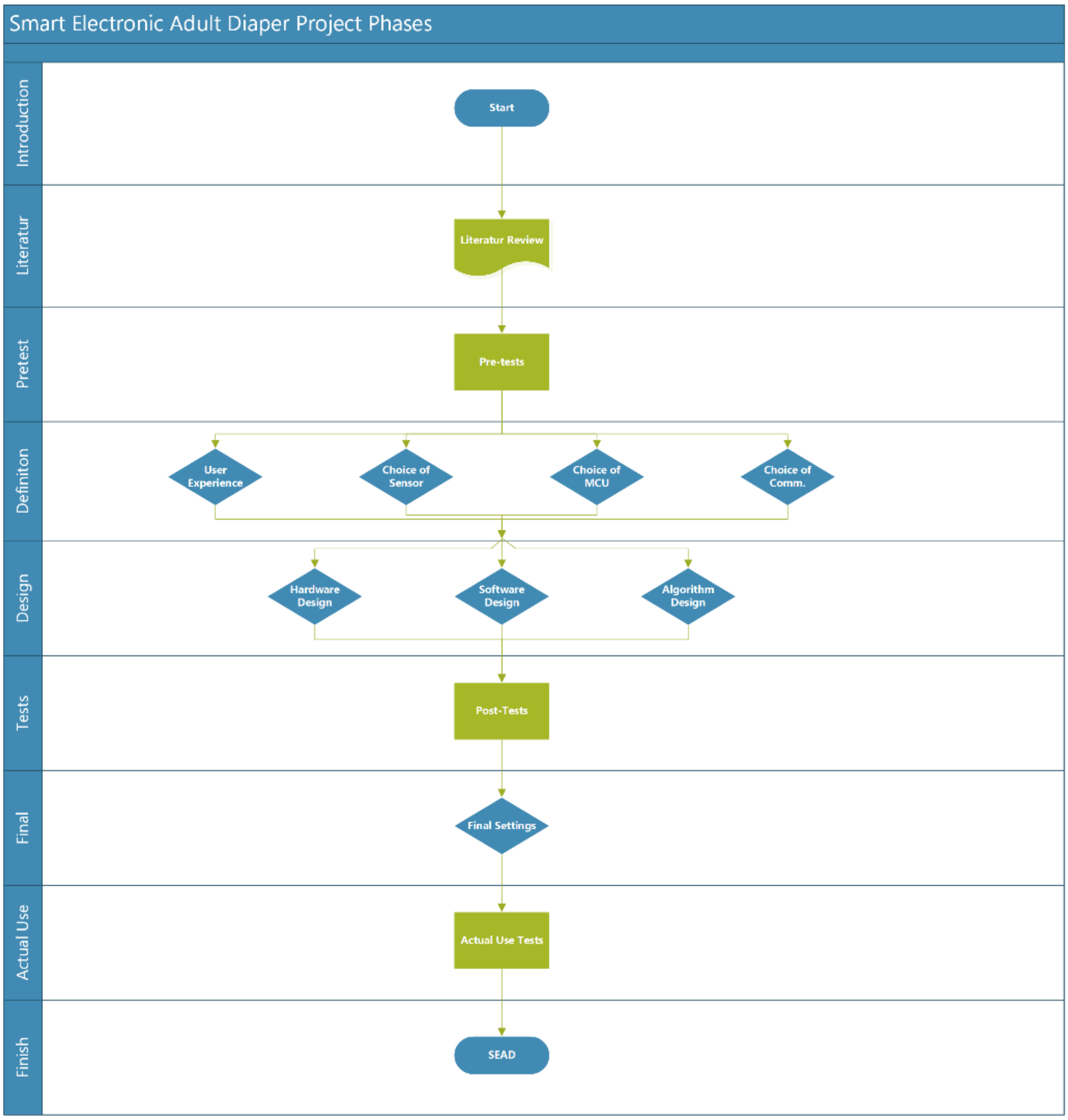


Figure 1.1 : Project Phases of SEAD

In the 7th chapter, the determination of the limit values will be discussed. Which limit values SEAD will have in case of actual use will be decided in this section.

In chapter 8, actual use tests will be discussed. In this section, the data and warnings provided by SEAD in case of actual use and the test results obtained will be examined in detail.

Chapter 9 will be the conclusion part of the thesis. In the conclusion part, the thesis work will be handled as a progressive process from the beginning to the end. We will talk about the achievements we have experienced in the process from the creation of the SEAD idea to the creation of SEAD. We will also talk about the opportunities and benefits that SEAD offers to users and family members/caregivers. Afterwards, we will have finalized our thesis by briefly talking about our next roadmap for the development of SEAD.

2. LITERATUR REVIEW

2.1 Development of Technology

With the development of technology, numerous studies have been made and continue to be made in order to make people's lives easier. Especially innovative and creative technologies find use in many areas of life. The development in technology constantly creates a new field for itself and innovative technologies are created for these new fields (Figure 2.1).

The concept of "Machine-to-Machine (M2M) Communication Technology" has emerged with the application of "Radio Frequency Identification (RFID)" technology in the industry to ensure the traceability of a product or service. The emergence of Internet-based technologies has led to the emergence of internet-based manufacturing, measuring machines, networked sensor arrays and surveillance systems, and new forms of traceability [1].

Figure 2.1 : End Users and Applications of IoT [2]

The "Internet of Things (IoT)", which has entered our lives with the spread of the internet, is an evolution of M2M that increases what device connectivity can achieve at both the consumer and enterprise level. IoT occurs when the object system is integrated into the internet domain, allowing such an object to be connected continuously. Another advantage of this phenomenon is that such objects continue to be uniquely identified in a network even in the vast world of the internet. The IoT environment interconnects and shares data from inanimate objects, but this can also include sensors associated with living "entities" such as people, animals, and plants [3]. Biomedical devices that can transmit such information to health institutions autonomously and in real-time while monitoring life parameters can be shown as an example of IoT applications. Moreover, there are biomedical devices that can diagnose faster and intervene in case of abnormal values with data analysis on life parameters [4]. The ubiquitous sensing enabled by Wireless Sensor Network (WSN) technologies is present in many areas of modern daily life. It offers the ability to measure, analyze and understand environmental indicators from natural resources to urban environments. Powered by the recent development of various technologies such as RFID, NFC and sensors, IoT is the next revolutionary technology in transforming the internet into a fully integrated Future Internet of Things (FIT) [5].

With the development of technology, the emergence of new areas, the emergence of new needs of people and the change of habits, IoT has created many different areas for itself (Figure 2.2) [6].

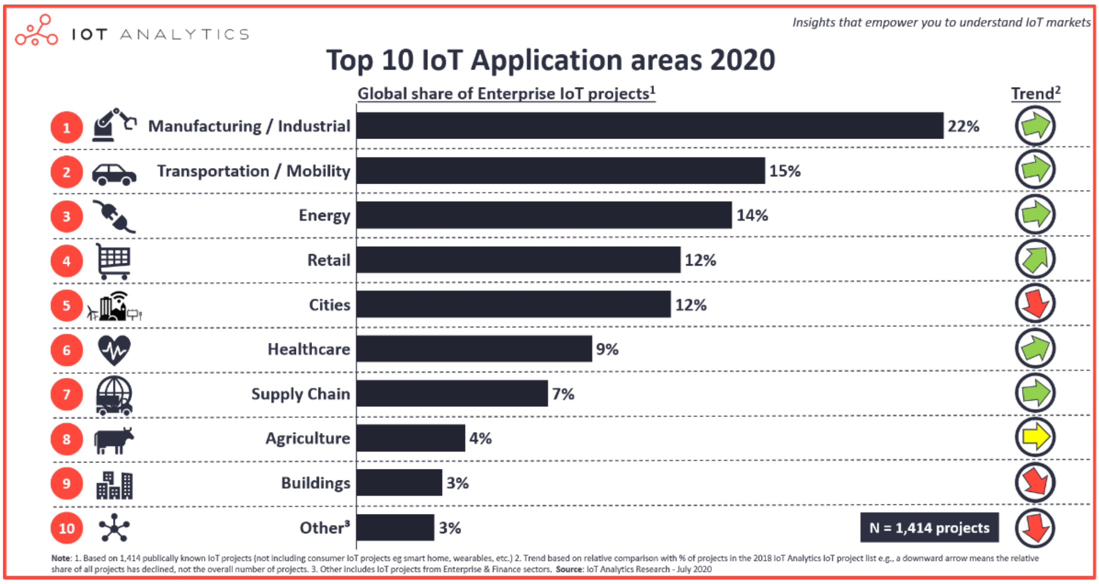


Figure 2.2 : IoT Application Areas [6]

Developments in IoT continued with the invention and development of new sensors for needs. With the development of the IoT, countless data have started to be received from the sensors. The problems that arise due to the storage problem of countless data have been resolved as a result of the invention of Cloud Technology. The freedom to receive unlimited data depending on the infrastructure has also provided a wide area for designers.

Nowadays, IoT technology is used in numerous fields (Figure 2.3). Industry, production, supply chain, home appliances, automation systems, network systems, defence industry, consumer electronics, medical devices are the leading areas of these fields. Nowadays, there is hardly any area where IoT is not used. Moreover, with the development of technology, IoT will continue to find new areas for itself.

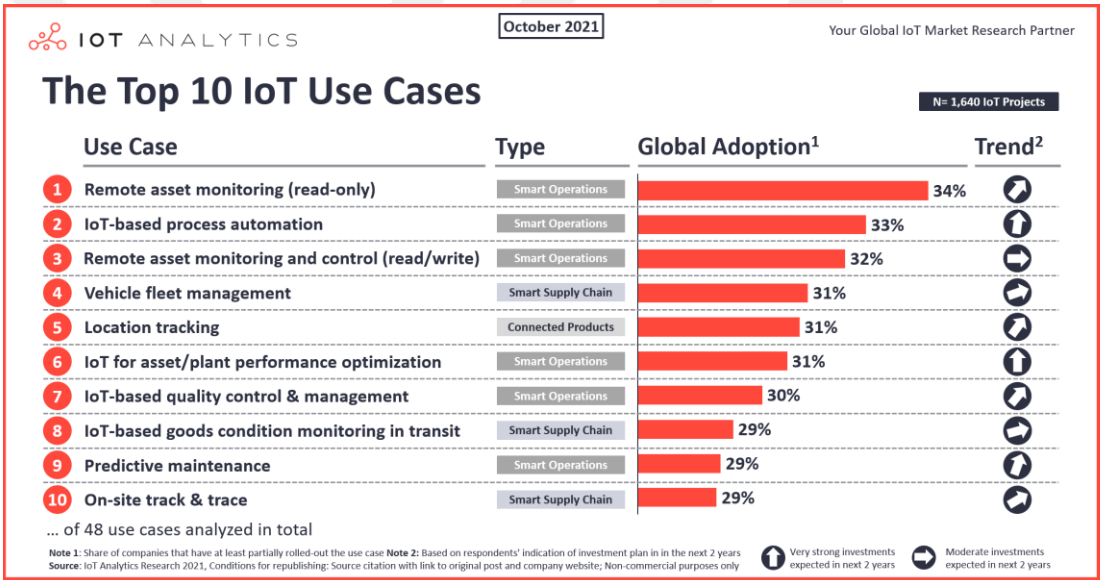


Figure 2.3 : IoT Use Cases [6]

2.2 Wearable Technology

With the development of technology and IoT, a new field called "wearable technologies" has emerged (Figure 2.4). Wearable technology aims to control people's vital and physical conditions. Wearable technology products have emerged to meet the demands of people who want to access information while on the move, not in a fixed place. Although it appeared in the beginning to monitor the movement data of athletes, wearable technologies that can be used by every person have emerged and continue to emerge. Besides, this technology, which is offered to everyone, has started to turn into a fashion among people. Fashion has also added new areas such as aesthetics and comfort to wearable technology. As a result, the view that fashion and technology should be used together has emerged to provide functionality, aesthetics and comfort at the same time [7].

Figure 2.4 : Wearable Technology Examples [8]

Wearable technology products are in many cases designed as specialized electronic monitoring devices synchronized to a computer to monitor data over a period of time wirelessly. Afterwards, with the introduction of smartphones into our lives, the need for computers disappeared. With cloud technology, it has been possible to monitor data from any device at any time. IoT has started to take an important place in our daily use with the fashion of wearable technology. Rings, smart glasses, smartwatches, wristbands, bracelets, etc. They are state-of-the-art wearable computers that can be integrated into different ways into various parts of the objects used such as. Advances in wearable technology have given consumers the ability to monitor nearly every aspect of their daily lives [9,10].

The increasing interest in mobile devices that can be used independently of the location in recent years signals that the demand for such technologies will continue to increase in the coming years. In parallel with the development of new tablet and smartphone models, wearable technologies such as smartwatches, smart bracelets, and virtual glasses are becoming more and more common among users and are gradually taking their place in daily life. The wearable technology sector, which is expected to get stronger through the combination of internet services and wearable technologies, is expected to gain a considerable market share by continuing to attract the attention of both businesses and users in the coming years [11].

2.3 Adult Diaper

A diaper is a protective garment that is used in cases where the person unwittingly and unintentionally wetting or soiling their clothes and/or bed. The situation where the person unwittingly and unintentionally wetting or soiling usually occurs in three situations; babyhood period, senescent period and periods of biological problems. As it is known, a baby diaper designed and developed for babies is used during infancy. Special diapers called adult diapers are used in old age and periods of biological problems, and in this thesis, we will work on adult diapers.

An adult diaper or adult nappy is a diaper made and designed to be worn by a person with a body larger than an baby or child. Adult diapers can be necessary for adults with a variety of conditions, such as incontinence or dementia. Adult diapers are manufactured in a variety of ways, including those that look like traditional diapers, underpants, and pads that look like sanitary napkins (Figure 2.5). Super absorbent polymer is primarily used to absorb body wastes and fluids [12].

Adult diapers help individuals who face daily problems, whether they are suffering from dementia, urinary/fecal incontinence or health impairment. Not having complete autonomy over your body's actions can be a humiliating and embarrassing experience. Especially in the senescent period, the fact that this situation is not due to biological problems but due to old age and dementia has also shown that these people experience psychological depression. In addition, dermatitis etc. can occur if urinary/fecal incontinence stays in the cloth or the adult diaper(if used) for a long time and is not changed health problems may occur.

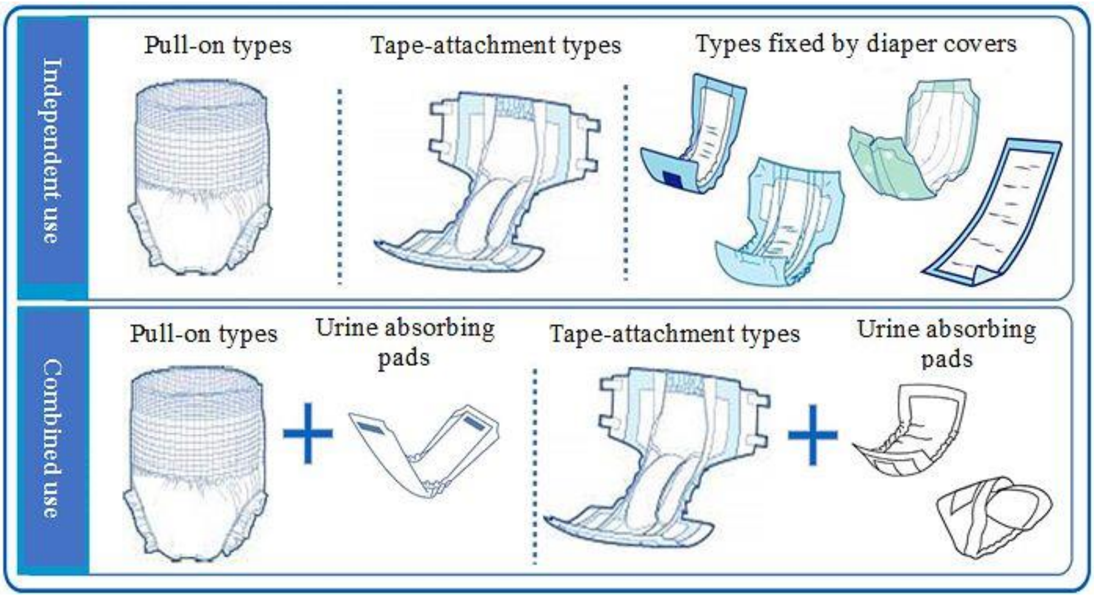


Figure 2.5 : Usage Types of Adult Diaper [13]

2.4 Diaper Dermatitis

Diaper dermatitis is a medical term used to describe an acute inflammatory skin reaction in the diaper area (Figure 2.6). It is caused by the damage caused by pee or poop to the skin in the diaper area when urinary or faecal activity occurs in the diapers. It happens especially when the diaper change takes place late. Diaper dermatitis is the most common dermatological disorder of infancy and results in a large number of visits to physicians each year. The incidence in infants is up to 35%, depending on the age of the infant, family care and environmental conditions. Diaper dermatitis peaks between the 9th and 12th months of infants [14-17].

Although the general view is that diaper dermatitis (or diaper rash in colloquial speech) is thought to be a problem in infants, recent studies have revealed that diaper dermatitis also occurs in adults. Diaper dermatitis is not just a problem in babies and can occur in people of any age who wear diapers. Although the prevalence rate of diaper dermatitis in adults is not known yet, it is thought to be especially common in the elderly. Studies conducted in some countries can reveal an average number with a sample study. E.g; Studies conducted in the USA show that approximately 13 million American adults suffer from diaper dermatitis. From a different point of view, considering the increase in the number of sales of companies that design and produce adult diapers, it is predicted that the number of people who may suffer from diaper dermatitis will increase [18-20].

Figure 2.6 : Five Degrees of Diaper Rash [21]

Generally, diaper dermatitis is thought to be a reaction to friction, moisture, urine or faeces in the adult diaper area. Recommended methods of treatment generally include increasing the frequency of adult diaper changes, using super-absorbent disposable adult diapers, and applying barrier ointments or creams to the skin against urine and faeces. Here, it is critical to increasing the frequency of changing adult diapers both hygienically and in order to prevent the problem. It is recommended to replace it immediately if possible. The other two methods are recommended when it is not possible to detect when the adult diaper is wet or soiled or when it is not possible to change the diaper frequently [22-24].

2.5 Dementia

Dementia is a disease that causes the loss of reasoning ability as a result of damage to executive functions due to old age. Dementia is an important public health problem as it is one of the most common diseases in the elderly (Figure 2.7). People with dementia usually need to be cared for by someone. This person may be a member of the family or a caregiver. Some dementia patients even stay in nursing homes. Who the person responsible for caring for a dementia patient is and where the patient lives vary according to each country. E.g; In studies conducted in the United Kingdom, it has been determined that nearly half of the patients live in nursing homes. Caregivers have critical roles for dementia patients who have psychological problems as well as biological problems [25-28].

Dementia has numerous negative consequences for dementia patients in daily life. Especially the problems that affect the quality of life can cause both biological and psychological problems. E.g; Urinary and faecal incontinence, which is an important factor for the quality of life, is more common in people with dementia [29].

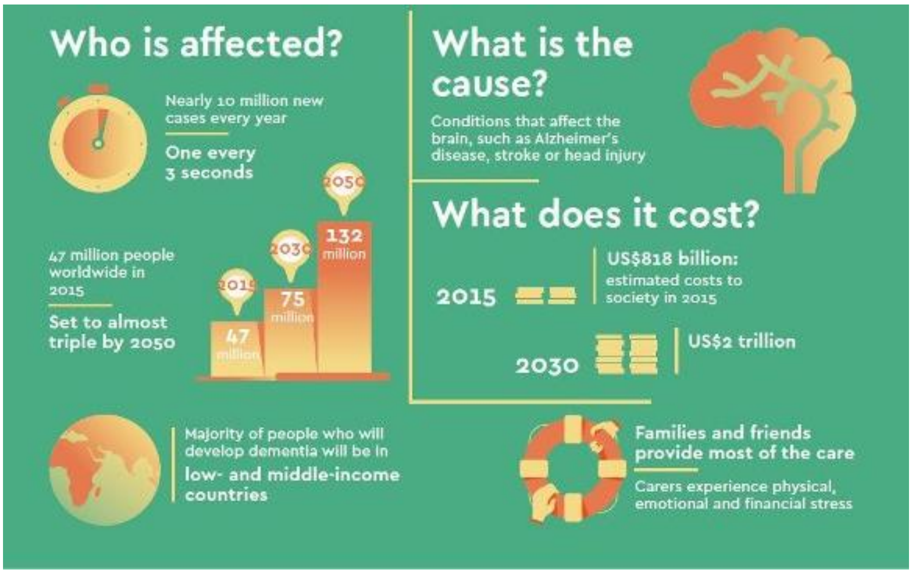


Figure 2.7 : Information about Dementia [30]

2.6 Urinary and Fecal Incontinence

Urinary and fecal incontinence is a disorder that occurs due to biological or psychological problems and affects daily life, general health and quality of life. It can cause embarrassment and loss of self-confidence in people. In addition, if the incontinence in these people is due to old age and is permanent, there is a possibility of rejection by their family members. It often results in them being sent to a nursing home because they need care [31-33].

The rates of being at home and being in a nursing home for people with urinary and/or fecal incontinence vary according to gender, age and country. The prevalence of those who have urinary and/or fecal incontinence at home is not known exactly. In nursing homes, studies conducted in nursing homes can provide clear data, as their health status is recorded and people are kept under control. Urinary incontinence prevalence is approximately 50% in nursing homes and approximately 30% in fecal incontinence. It is thought that the prevalences are so high because the majority of people staying in nursing homes are elderly. However, it should not be forgotten that there are young people and adults who live at home and suffer from urinary and fecal incontinence due to biological and/or psychological factors, although they are not old [34-37].

2.7 Smart Diaper

Textiles are used in almost every aspect of our daily life, especially as clothing. The shrinking of electronic devices with the development of technology has paved the way for the use of electronic devices in textiles. As a part of wearable technology, smart clothes have emerged and new smart clothes continue to emerge. Researchers from electronics and communication, software, textile and materials engineering have worked together to carry out different studies for smart clothes called e-textile [38-40].

Considering the problems in Clause 2.4, Clause 2.5 and Clause 2.6, there is a need for a smart diaper design that detects urinary and fecal incontinence for both afflicted people and their caregivers or family members. In the literature, there are researches and studies on the diaper to notify when it is wet or soiled. However, the vast majority of them have been studied for baby diapers. The vast majority of the rest have been studied for children and adolescents. Studies on adult diapers are very rare and limited in number. Smart diapers in the literature generally consist of sensor(s) unit, electronic microprocessor unit, receiver/transmitter communication unit, battery unit structures integrated on adult diapers.

2.7.1 Sensors

2.7.1.1 Conductive threads

The method of creating sensors with embroidery is one of the methods used in smart diapers. By using conductive threads, various sensor structures can be created for use in various garments. In some studies in the literature, conductive threads are used by the embroidery method to make moisture sensors. The operating logic in moisture sensors made with conductive threads is that sweat or urine accumulates between two conductive paths, resulting in a short-circuit (Figure 2.8). As a result of short-circuit, the circuit is completed and operations are performed depending on the circuit structure and algorithm [41-44].

The success of sensors made with conductive threads embroidered in detecting sweat and urine has been the idea to use this sensor to detect urinary incontinence. Various sensor studies have been carried out in the literature by leaving appropriate distances between the embroidered conductive thread paths. Since the urine of a healthy person has a conductive content, urine can transmit electrical signals. Due to urinary incontinence, the urine starts to accumulate between the embroidered conductive thread sensor pathways as the urine reaches the diaper/clothes and thus the sensor, and then the sensor pathways become short-circuited and urinary incontinence is detected.

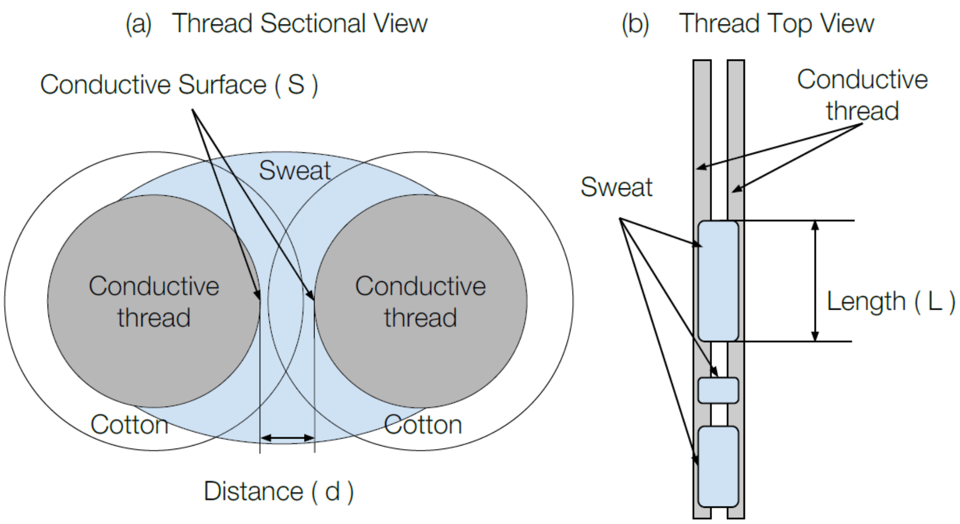


Figure 2.8 : The conductivity model of the embroidery method [45]

In studies in the literature, embroidered sensors made of conductive threads have been designed in different structures according to what they detect. There are also changes in the designs of embroidered conductive thread sensors for detecting urinary incontinence. Parameters such as sensor geometries, embroidery density, sensor path width, sensor path length, the conductive thread used, etc., lead to the diversity of sensors. This diversity also affects the performance, quality and reliability of the sensors.

Some examples of the studies in the literature of embroidered sensors made of conductive threads are shown in Figure 2.9. As can be seen from the figure, there are geometrical differences between the sensors. In addition, when we go into the details of the studies, we see that the conductive thread content, embroidery density, embroidery width, sensor path length and distances between the sensor paths vary.

Briedis et al. (2017) [46] have presented a sensor that detects children's enuresis. As can be seen from the sensor structure shown as "Briedis et al. (2017)" in the figure above, the sensor was obtained by sewing the conductive thread as embroidery. In addition, the electrical connections of the processor that process the sensor's output and other components are also provided with embroidered conductive thread paths. In addition to the sensor, the system includes a processor, a buzzer and a battery. The sensor and system were embroidered on a child's underwear. The working logic of the system is as follows; If the child wets the bed at night (enuresis/urinary incontinence), urine accumulates between the conductive paths of the sensor and short-circuits the sensor. The electrical energy provided by the battery reaches the processor by following the path completed by the urine. The processor processes the incoming signal and activates the buzzer. The buzzer beeps loudly, waking the child who is wetting the bed and making him/her go to the toilet. It is claimed that children who constantly wake up like this will stop wetting the bed. It is said that the sensor embroidered on the underwear can be disjointed from the system, washed and reused.

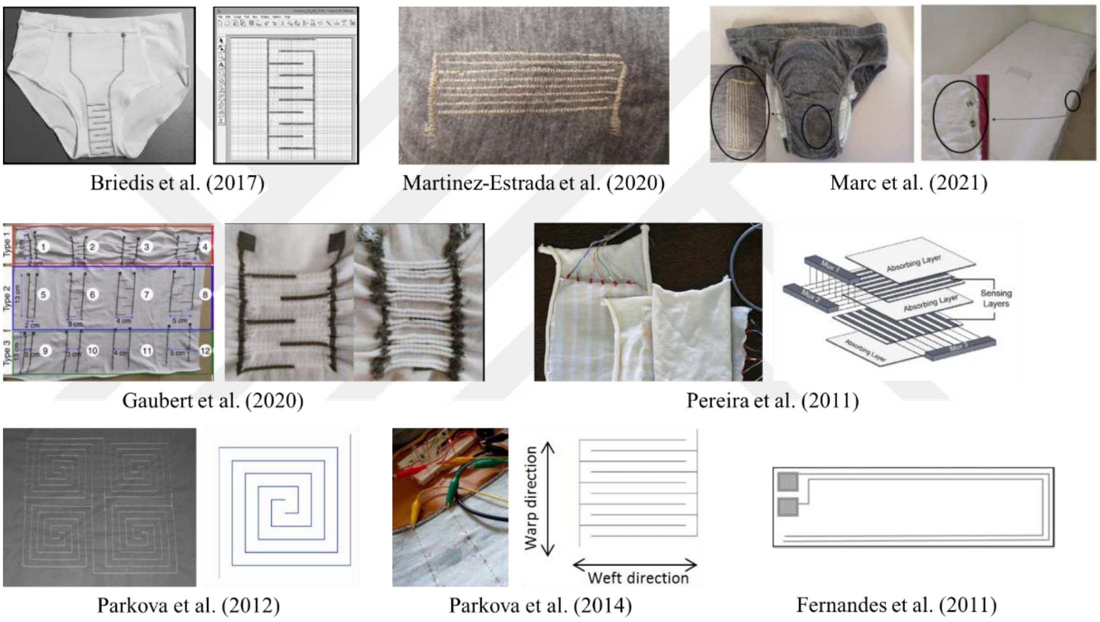


Figure 2.9 : The embroidered sensors made of conductive threads in the literature

Similarly, in Martinez-Estrada et al. (2020) [47] have presented a sensor that detects children's enuresis. As can be seen from the sensor image shown as "Martinez-Estrada et al. (2020)" in the figure above, the sensor was obtained by sewing the conductive thread as embroidery. However, there is no information about the system other than the sensor. That is, there is no information about the processor and other components that process the output of the sensor and their connections. The designed sensor is embroidered on a child's underwear. The working logic of the system is explained in two ways. Firstly, when the child wets the clothes (enuresis/urinary incontinence), urine accumulates between the conductive paths of the sensor and short-circuits the sensor. Thus, the sensor detects urinary incontinence. Secondly, if the child wears a diaper inside the sensor underwear, urine accumulates in the diaper when the child wets the diaper (enuresis/urinary incontinence). In the study, the capacitive value of the sensor on the underwear decreases when the diaper is wet and urine accumulates in the diaper. If the decreasing capacitive value falls below the determined limit value, urinary incontinence is detected. In other words, the sensor can also be used as a capacitive sensor. In addition, it is claimed that notifications can be sent to the smartphone via Bluetooth with a processor, but there is no information about this system in the article.

Marc et al. (2021) [48] have presented a sensor that detects general-purpose urinary incontinence. As it can be seen from the sensor images shown as "Marc et al. (2021)" in the figure above, the sensor can be applied to both underwear and bedsheet. Also, as can be seen, the sensor was obtained by sewing the conductive thread as embroidery. In fact, the sensor application on underwear is the same as the sensor application mentioned in Article 2. In this study, we see that the same sensor is also applied to the bedsheet. The working logic of the system is explained in the same way in two ways. First, when the person wets the bed or clothes (enuresis/urinary incontinence), urine accumulates between the conductive paths of the sensor on the underwear or bedsheet, thus short-circuiting the sensor. Thus, the sensor detects urinary incontinence. Secondly, if the person wears a diaper, urine accumulates in the diaper when the person wets the diaper (enuresis/urinary incontinence). In the study, the capacitive value of the sensor on the underwear or bedsheet decreases when the diaper is wet and urine accumulates in the diaper. If the decreasing capacitive value falls below the determined limit value, urinary incontinence is detected. In other words, the sensor can also be used as a capacitive sensor. In addition, it is claimed that information can be sent to the computer via Wi-Fi with an electronic circuit. It is stated that data can be tracked with the use of an external application.

Gaubert et al. (2020) [49] have presented a sensor that detects children's enuresis. As can be seen from the sensor images shown as "Gaubert et al. (2020)" in the figure above, the sensor was obtained by sewing the conductive thread as embroidery. In the study mentioned in the article, a few sensor geometries were tried by diversifying parameters such as sensor length, distances between sensor paths, etc., and it was decided to continue with it by choosing one of these sensors. The selected sensor was applied to a child's underwear. In the system mentioned together with the sensor, in addition to the sensor, there are an electronic circuit, a buzzer and a battery. The working logic of the system is as follows; When the child wets the clothes at night (enuresis/urinary incontinence), urine accumulates between the conductive paths of the sensor and short-circuits the sensor. The electrical energy provided by the battery reaches the processor by following the path completed by the urine. The processor processes the incoming signal and activates the buzzer. The buzzer beeps loudly, waking the child who is wetting the clothes and making him/her go to the toilet. Also, in order to silence the alarm, it is necessary to remove the snap fasteners between the sensor and the electronic circuit, which requires an effort to wake them up. It is claimed that children who constantly wake up like this will stop wetting the bed. It is said that the sensor embroidered on the underwear can be washed after disconnecting it from the electronic circuit and the sensor can be used again. The necessity to disconnect the electronic circuit from the sensor in order to silence the alarm also provides an advantage in terms of this point. The necessity of removing the electronic circuit every time the underwear is dirty prevents the electronic circuit from being accidentally thrown into the washing machine with the underwear.

Pereira et al. (2011) [50] have presented a sensor that detects general-purpose urinary incontinence. As can be seen from the sensor images shown as "Pereira et al. (2011)" in the figure above, the sensor was obtained by embroidering conductive thread on two different layers. The designed sensor paths are vertical in one layer and horizontal in the other layer. In both layers, the conductive paths in the same layer are independent of each other. There is an absorbent surface between the two layers. The working logic of the system is in two ways; Urine accumulates in the diaper when the person wets the diaper (enuresis/urinary incontinence). Firstly, with the absorption of urine by the absorbent surface, a conductive path is formed between the two layers and the sensor detects urinary incontinence. Secondly, as the urine is absorbed by the absorbent surface, the capacitance value between the two layers decreases. When the decreasing capacity value falls below the determined limit value, urinary incontinence is detected. With the help of the fact that the conductive paths in the two layers are independent of each other, it is possible to detect where the wetness is in the diaper with an external computer program. In fact, the purpose of the study is to detect pressure ulcers in patients who have been constantly bedridden. However, it has been shown that urinary incontinence can also be detected.

Parkova et al. (2012) [51] have presented a sensor that detects children's enuresis. As can be seen from the sensor structure shown as "Parkova et al. (2012)" in the figure above, the sensor was obtained by sewing the conductive thread as embroidery. In the system, in addition to the sensor, there is an electronic circuit and a buzzer. The sensor design was realized as two different solutions, both for a child's underwear and a bedsheet. Moreover, the sensor is designed as both spiral type and comb type. While the sensor size on the underwear is small, the sensor size on the bed sheet is designed wide to cover the entire area where the child can wet the bed. The working logic of the system is as follows: If the child wets the underwear or the bed at night (enuresis/urinary incontinence), urine accumulates between the conductive paths of the sensor in the underwear or bed sheet, thus short-circuiting the sensor. The processor processes the incoming signal and activates the buzzer. The buzzer beeps loudly, waking the child who is wetting the underwear/bed and making him/her go to the toilet. It is claimed that children who constantly wake up like this will stop wetting underwear/bed. It is stated that the sensor, which is processed into underwear or bedsheet, can be disconnected from the electronic system, washed and reused.

Parkova et al. (2014) [52] have presented a sensor that detects children's enuresis. As can be seen from the sensor structure shown as "Parkova et al. (2014)" in the figure above, the sensor was obtained by sewing the conductive thread as embroidery. In the system, in addition to the sensor, there is a processor and an LED. The sensor is embroidered on fabric and is in prototype form. The working logic of the system is as follows: The system reads the resistance value of the sensor. In the initial state, the resistance between the conductive paths has an infinite value. In case the fabric gets wet with urine, the resistance value decreases due to moisture. When enough urine is reached on the line, there will be a short-circuit between the conductive paths and only the resistance value due to the content of the conductive threads will remain. When the resistance value falls below the predetermined limit value, the processor detects urinary incontinence. Afterwards, the LED is energized by the processor and a visual warning is given. Unlike other studies, a visual warning has been given in this study, not audial. On the other hand, it is also said that it can be turned into an audible warning by changing the buzzer with the LED.

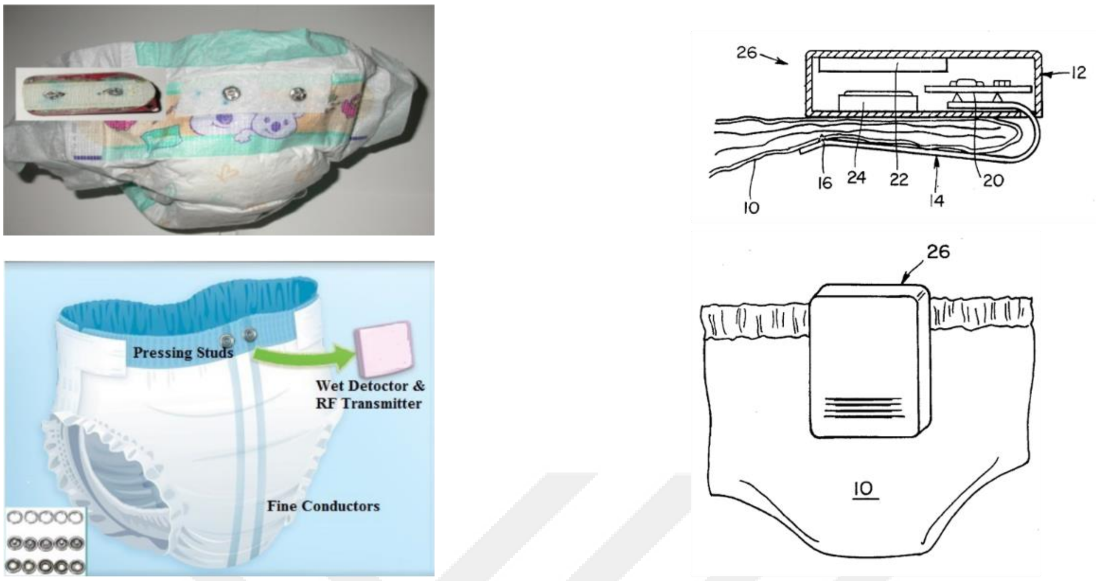
Fernandes et al. (2011) [53] have presented a sensor designed for people who use continence pads. The sensor shown as "Fernandes et al. (2011)" in the figure above was obtained by sewing the conductive thread as embroidery. The sensor can detect the leakages. In the system, in addition to the sensor, there is an electronic circuit, a vibration unit and a coin cell. The sensor is embroidered on underwear and the sensor paths are designed to reach all the edges of the bottom of the underwear. In addition, cotton fabric is embroidered on the sensor to prevent accidental short-circuiting of the sensor paths as a result of folding the underwear. The electronic system is placed on the upper part of the underwear. The working logic of the system is as follows: In the case of urinary incontinence, urine accumulates in the continence pad. If the urine starts to overflow from the continence pad, the urine starts to spill into the underwear. At this stage, the urine that starts to accumulate in the underwear short-circuits the conductive paths of the sensor and the energy supplied by the battery is sent to the processor. The processor processes the incoming signal and operates the vibration unit. The vibration unit integrated into the underwear vibrates and warns the user and allows him to go to the toilet etc. and change the continence pad immediately. Unlike other studies, the system gives not audial or visual but feeling warning. Because the aim of the study is to warn adults who suffer from urinary incontinence and have to use a continence pad before the urine passes through the underwear and spreads to the clothes in case the continence pad overflows. Thus, a situation that will embarrass them in society is prevented.

2.7.1.2 Conductive wires

One of the methods used in smart diapers is the use of conductive wires. Various sensor structures that detect moisture or urine can be created using conductive wires for use in clothes/diapers. In some studies in the literature, conductive wires have been used in smart diapers to detect urinary incontinence. The working logic of moisture/urine sensors made with conductive threads is that sweat or urine accumulates between the two conductive paths, causing a short-circuit. Since the sweat or urine of a healthy person has a conductive content, sweat or urine can transmit electrical signals. As a result of the short-circuit, the circuit is completed and operations are performed depending on the circuit structure and algorithm. Obviously, they have the same operating logic as sensors made with conductive threads.

In studies in the literature, sensors made of conductive wires to detect urinary incontinence generally have the same design although their electronic systems differ.

These sensors, which are generally designed as two parallel and long paths, can be seen in Figure 2.10.



Simik et al. (2014) Nair (1996)

Figure 2.10 : The sensors made of conductive wires in the literature

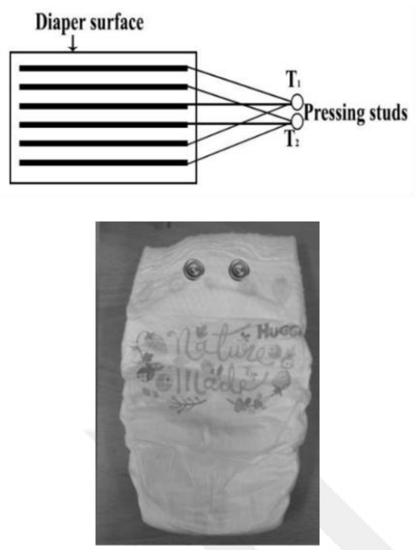
Simik et al. (2014) [54] have presented a sensor that detects babies' urinary incontinence. As can be seen from the sensor structure shown as "Simik et al. (2014)" in the figure above, the sensor consists of two parallel conductive wires running straight from the front of the diaper to the bottom. By connecting to the electronic system with pressing studs, the smart diaper system is completed. In addition to the sensor, the system includes an electronic circuit, an RF transmitter, a buzzer and a flat battery. The sensor and system are applied to a diaper. The working logic of the system is as follows: In the case of enuresis/urinary incontinence, urine accumulates between the conductive paths of the sensor and short-circuits the sensor. The electrical energy provided by the battery reaches the processor by following the path completed by the urine. The processor processes the incoming signal in two ways. In the first algorithm, the processor runs the buzzer. The buzzer beeps loudly and gives audible information to the parent. In the second algorithm, the processor sends an SMS to the determined GSM number with the help of the RF transmitter. In this way, if the parent is too far away from the baby to hear the buzzer, they can be informed via SMS. The electronic system is removed from the dirty diaper and the dirty diaper is directly thrown into the trash together with the sensor. Although the sensor is not reusable, the electronic system is reusable.

Nair (1996) [55] has presented a sensor that detects bedwetting for infants. As can be seen from the sensor structure shown as "Nair (1996)" in the figure above, the sensor consists of two parallel conductive wires that start from the front of the diaper and straight down to the bottom. Sensors are connected to the electronic system on the front of the diaper with hooks and the smart diaper system is completed. In the system, in addition to the sensor, there is an electronic circuit, a buzzer and a battery. The sensor and system are applied to a diaper. The working logic of the system is as follows: In the case of urinating in the diaper, urine accumulates between the conductive paths of the sensor and short-circuits the sensor. The electrical energy provided by the battery reaches the processor by following the path completed by the urine. The processor processes the incoming signal and activates the buzzer. The buzzer beeps loudly and gives audible information to the parent. In addition, in the study, the times when the infant peed in the diaper are recorded. The recorded times the infant pees are analyzed and the next pee time is calculated. In this way, it is aimed to give a warning before the time to pee and direct the infant to the toilet before peeing. Thus, the infant receives toilet training.

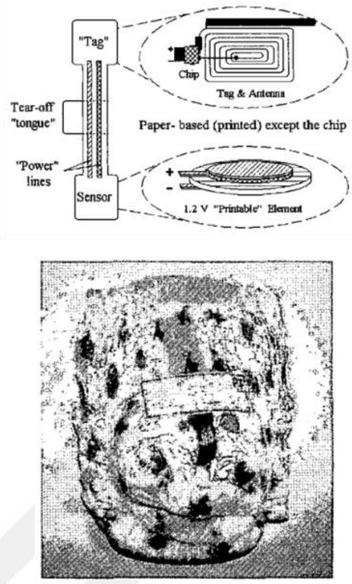
2.7.1.3 Printed sensor

Another method used in smart diapers is the use of printed sensors. Printed sensors are usually obtained by printing on fabrics, clothes, diapers, etc., using conductive ink. Depending on the type of place printed, they can be used for different purposes. The success of the printed sensors used to detect sweat led to the idea that this sensor could also be used to detect urinary incontinence. Various sensor studies have been carried out in the literature by keeping appropriate distances between the paths of the printed sensor consisting of conductive ink. Due to bedwetting/enuresis/urinary incontinence, when the urine reaches the diaper/clothes and thus the sensor, urine starts to accumulate between the printed sensor paths, and then the sensor paths are short-circuited and incontinence is detected. As you can see, it has the same operating logic as the other sensors mentioned above.

Printed sensors have been designed in different structures in studies in the literature. Parameters such as sensor geometries, sensor path width, sensor path length, the content of conductive ink used, etc., lead to the variety of sensors. This diversity also affects the performance, quality and reliability of the sensors. Some examples in the literature of printed sensors are shown in Figure 2.11. As can be seen from the figure, there are differences between the sensors.



Rahman et al. (2017)



Siden et al. (2004)

Figure 2.11 : The printed sensors made of conductive ink in the literature

Rahman et al. (2017) [56] have presented a sensor that detects urinary incontinence for dementia patients or mental retardation people. As can be seen from the sensor structure shown as "Rahman et al. (2017)" in the figure above, the sensor has 6 parallel conductive paths obtained by printing conductive ink. These 6 paths are connected to pressing studs, one (+) and one (-) respectively. In this way, it has been aimed to cover the entire diaper. In the system, in addition to the sensor, there is an electronic circuit and a battery. The connection between the electronic system and the sensor is provided by pressing studs. The sensor and system are applied to a diaper. The working logic of the system is as follows: When the person wets the diaper (urinary incontinence), urine accumulates between the conductive paths of the sensor and short-circuits the sensor. Initially, the resistance between the conductive paths is infinite, but as a result of the short-circuit, the resistance value decreases gradually. After the resistance value falls below a certain value, the electrical energy provided by the battery reaches the processor by following the paths completed by the urine. The processor processes the incoming signal and sends a signal to the phone via Bluetooth.

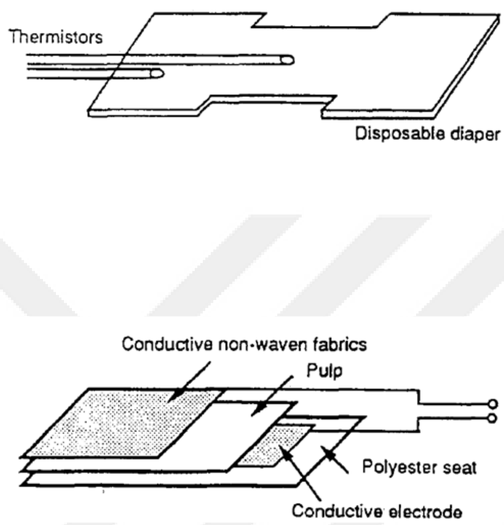
Siden et al. (2004) [57] have presented a sensor that detects bedwetting for hospitalized persons. As can be seen from the sensor structure shown as "Siden et al. (2004)" in the figure above, the sensor has 2 parallel conductive paths with a layer between them obtained by printing conductive ink. There is an RF transmitter at the start of this sensor. The working logic of the system is as follows: When the person wets the diaper (urinary incontinence), urine accumulates between the conductive paths of the sensor and short-circuits the sensor. The short-circuited sensor activates the RF transmitter located on the front of the diaper. The activated RF transmitter sends the signal to the receiver which at a central location, notifying that the diaper is wet.

2.7.1.4 Conductive fabrics

Another method used in smart diapers is the use of conductive fabric that covers the entire diaper. This sensor, which arises due to the inability of the sensors made with conductive materials to cover the entire diaper, consists of conductive fabrics along the top and bottom of the absorbent surface of the diaper and an absorbent surface as a layer between these fabrics. In some studies in the literature, conductive fabrics have been used in smart diapers to detect urinary incontinence. The working logic of humidity/urine sensors made with conductive fabric is that sweat or urine accumulates in the layer between two conductive fabrics and short-circuit occurs between two conductive fabrics. Since the sweat or urine of a healthy person has a conductive content, sweat or urine can transmit electrical signals. As a result of the short circuit, the circuit is completed and operations are performed depending on the circuit structure and algorithm. Obviously, the sensor made with conductive fabric has the same operating logic as the other sensor types mentioned above.

Although the electronic systems of the sensors made of conductive fabrics to detect urinary incontinence in the studies in the literature differ, in general, the sensor designs are similar. Figure 2.12 shows the design of a study of one of these sensors.

Tamura et al. (1993) [58] have presented a sensor that detects urinary incontinence for elderly people. As can be seen from the sensor structure shown as "Tamura et al. (1993)" in the figure above, the sensor was obtained by using a non-conductive layer between two conductive layers. In the system, in addition to the sensor, there is a circuit consisting of two thermistors and a transmitter. The sensor and system are embroidered on a diaper. The working logic of the system is as follows: When the person wets the diaper (urinary incontinence), urine accumulates in the absorbent surface between the conductive layers of the sensor and short-circuits the sensor. The short-circuited sensor activates the transmitter and sends a signal to an external receiver. Another feature specified in the system is that it measures the temperature difference of the circuit made with thermistors. When the temperature difference measured by the thermistor on the front of the diaper and the thermistor on the inside of the diaper is 0.5 C, the thermistor circuit activates the transmitter and sends a signal to the receiver.



Tamura et al. (1993)

Figure 2.12 : The sensor made of conductive fabric in the literature

2.7.1.5 Evaluation of the sensors

As can be seen, various sensor designs made with various materials have been carried out in order to detect urine. Table 2.1 shows the comparison according to the sensor materials used in the studies in the literature. Each sensor design and sensor content has advantages and disadvantages.

In sensors made with conductive threads, there are generally two different types of conductive threads. The first is a type of conductive thread obtained by covering an ordinary thread with conductive material. The second is the type of conductive thread obtained by mixing the materials used to obtain the ordinary thread and the conductive material and making it into a conductive thread. The main difference between these types of conductive thread is revealed during operation. In order for the sensor made with the threads covered with conductive material to transmit the signal, it is sufficient for the conductive liquid to enter between the roads, while the sensor made with the threads mixed with the conductive material must first absorb the conductive liquid in order to transmit the signal. Conductive material covered thread can transmit the signal over the surface of the thread immediately. In the thread where the conductive material is mixed, the conductive material can be located inside as well as outside. So, the sensor made of threads mixed with the conductive material may respond later than the sensor made of conductive threads covered with the conductive material.

Table 2.1 : Comparison of Studies According to Sensor Materials.

Study	Sensor Material
Briedis et al. (2017)	Conductive Threads
Martinez-Estrada et al. (2020)	
Marc et al. (2021)	
Gaubert et al. (2020)	
Pereira et al. (2011)	
Parkova et al. (2012)	
Parkova et al. (2014)	
Fernandes et al. (2011)	
Simik et al. (2014)	Conductive Wires
Nair (1996)	
Rahman et al. (2017)	Printed Sensor (Conductive Ink)
Siden et al. (2004)	
Tamura et al. (1993)	Conductive Fabrics

On the other hand, one of the most important issues in sensors made with conductive threads is durability. In particular, sensors designed to be reusable may not be able to show their original performance after washing. Moreover, in order to clean the urine thoroughly, the sensors that are washed at high speed, high temperature and using detergent in devices such as washing machines may be damaged. After a few washes, problems such as fringing, loosening and even breaking of the conductive paths can be seen. In case of fringing and loosening, wrong warnings may occur as the sensor paths may accidentally connect with each other. The disconnection of the conductive paths and the permanent disconnection of the conductive paths with the electronic system may cause the sensor to become unusable. The sensors must be designed in such a way that they do not experience these and similar problems. However, it has been determined that sensors made with conductive threads are deformed by temperature and washing. For this reason, it has been stated that the sensors made of conductive threads can be used as disposable rather than reusable [59,60].

In addition, another problem with sensors made with conductive threads is the difficulty of connecting to electronic components. Direct soldering of conductive threads to electronic components is not possible. In some studies, the legs of electronic components are connected by knotting or wrapping the conductive thread well. However, this method is not suitable for reliability. Unstable connections may cause contactless. Moreover, depending on use, loosening of the connections may also occur. This situation also causes instability. Similar problems can be experienced in studies where the connection of the electronic system and the sensor is made with pressing studs. The poor connecting of the conductive thread and the pressing studs affects the reliability of the system.

Sensors made with conductive wires have been preferred in some studies because they are stable and reliable in signal transmission. However, two problems come to the fore in sensors made with conductive wires. Firstly, sensor designs made with conductive wires are usually in the form of two parallel paths, since wires cannot be easily embroidered like threads. The fact that it is only in the form of two parallel paths causes the diaper or underwear to not cover all the places where urine can come from. So, there is a risk of failing to detect urinary incontinence. Secondly, the fact that the conductive wires have a rigid structure compared to other sensor materials may cause discomfort to the users. Therefore, children or dementia patients with urinary incontinence problems may not want to wear the diaper or underwear with the sensor made of conductive wire, or they may want to take it off even if they wear it. In addition, the content of the conductive wire used in sensors made with conductive wires must be chosen very carefully. Since urine is acidic, it can interact with some metals. If the used conductive wire contains at least one of these metals, the urine and the conductive wire will interact and corrosion will occur. Depending on the reaction created by this interaction, unwanted infections may occur in users.

Sensors obtained by printing conductive ink have advantages as well as disadvantages. This sensor, which is obtained by printing the sensor design on a surface such as a fabric, is fast in signal transmission. Because the contact of urine between the sensor paths on the surface is sufficient for signal transmission, it is not necessary for the urine to be absorbed by the material to which the sensor is applied. On the other hand, some important issues should be calculated and analysed carefully during the design process of the sensor and should be considered during the printing of the sensor. Firstly, during the sensor design, the distance between the sensor paths should be as narrow as possible for signal transmission, but in the normal case, the sensor paths should be kept wide enough not to short-circuit. Secondly, the conductive ink chosen as the sensor material should be suitable in accordance with the surface to which it will be applied. For example, if the sensor is to be applied to fabric, a fabric-applicable conductive ink should be selected. Otherwise, the sensor cannot adhere to the fabric and the sensor cannot be used. Thirdly, during printing, the printing and drying processes should be well observed. Otherwise, some problems may occur. For example; sensor design may be suppressed incorrectly, sensor paths may cross each other, sensor paths may be broken, there may be capillary short-circuits between sensor paths, etc. These and similar reasons affect the stability and reliability of the sensor. Since many parameters affect the quality of the sensor, sensors made with conductive ink are one of the sensor types that need the most attention.

Sensors made with conductive fabric are designed to cover all areas of the diaper or underwear to be used, where urine may come. Although there are advantages theoretically, some disadvantages may occur in practice depending on the design. First of all, this sensor, which is obtained by placing the absorbent surface between two parallel conductive layers to cover the entire area, is similar to capacitors in structure. For this reason, it is necessary to prevent the sensor from giving undesirable results due to the capacitive effect. Because of the sensor behaves like a capacitor, the system may be unstable because the capacitance values when the user is standing and sitting can be different. While the distance between the two conductive layers is equal to the thickness of the absorbent surface while the user is standing, pressure is exerted on the absorbent surface while the user is sitting and the thickness of the absorbent surface decreases. Therefore, the capacitance value varies. The variable value may also cause wrong warnings when the specified limit values are exceeded. Secondly, it must be ensured that there is always an absorbent surface between the conductive layers. During use, the conductive layers may be short-circuited as a result of the slipping of the absorbent surface and the system can give wrong warnings. In addition, sensors made with conductive fabrics are quite costly. Since they are not reusable in terms of reliability, it is not cost-effective to apply them in a disposable version.

2.7.2 Electronic unit

In literature research, it is seen that different microprocessors, microcontrollers or various electronic circuits/boards are used in studies to detect urinary incontinence. This differentiation is due to the initiative of the designers. Because, what is expected from the microprocessor, microcontroller or electronic circuit/board is to process the data coming from the sensor and perform the algorithm planned by the designer. The electronic component chosen by the designer changes according to the planned algorithm or design.

Table 2.2 shows the electronic components used in the studies. Since some studies do not provide information about electronic circuits, it is not known which electronic component is used in these studies. However, as can be seen from the table, the electronic components selected in the studies differ.

2.7.3 Signal transmission method

It is as important to process that signal in a way that makes it meaningful as it is to receive the data from the sensor. In the studies in the literature, a component such as buzzer, LED, etc. is used in order to react instantly. In this way, audial, visual, etc. warnings are given. Although such warnings are a good way to warn people who are close, unfortunately, they are not enough to warn people who are far away. Furthermore, in the case of urinary incontinence in studies for adults, giving warnings such as audial, visual, etc. may cause people to experience feelings such as shame and embarrassment in the society or family. Considering all these reasons, various methods are used in order to give warnings to people who are far away and to give these warnings as much as possible without causing shame and embarrassment. Some of the methods used in studies in the literature are shown in Table 2.3. Using these methods, notifications can be sent to a computer or a smartphone screen, and alerts and information can be given to parents, family members or caregivers.

Table 2.2 : Comparison of Studies According to Electronic Unit.

Study	Micropressor / Microcontroller / Electronic Unit
Briedis et al. (2017)	ATTINY13-20PU Microcontroller
Marc et al. (2021)	SAM D21 Microcontroller
Pereira et al. (2011)	NI-USB 6259 Multifunction Data Acquisition Board
Parkova et al. (2012)	TINY11LP Microcontroller
Simik et al. (2014)	DG418DJ Analogue Switch HT12E Encoder HT12D Decoder
Nair (1996)	PIC1654 Microcontroller
Rahman et al. (2017)	nRF51822 BLE Chip
Parkova et al. (2014)	No Chip
Siden et al. (2004)	
Martinez-Estrada et al. (2020)	No Information
Gaubert et al. (2020)	
Fernandes et al. (2011)	
Tamura et al. (1993)	

2.7.4 Power supply

Systems designed to detect urinary incontinence often need energy. This energy is needed for electronic circuits, buzzers, LEDs, etc.. These systems, which are designed as smart diapers, are generally used batteries or coin cells as a power source in wearable technology product structures. It can also be seen that in hospitals and in systems designed for patients who have to stay in bed all the time, access to the power supply is provided depending on the plug. On the other hand, some systems do not need an external power supply according to their design. Table 2.4 shows the power source types used in the studies in the literature. In some studies, information about how energy is provided in the systems is not given.

Table 2.3 : Comparison of Studies According to Transmission Method.

Study	Transmission Method
Martinez-Estrada et al. (2020)	Bluetooth
Rahman et al. (2017)	
Marc et al. (2021)	Wi-Fi & Bluetooth
Simik et al. (2014)	GSM
Siden et al. (2004)	RF
Tamura et al. (1993)	RF
Briedis et al. (2017)	No
Gaubert et al. (2020)	
Pereira et al. (2011)	
Parkova et al. (2012)	
Parkova et al. (2014)	
Fernandes et al. (2011)	
Nair (1996)	

2.7.5 Base

In designs made to detect urinary incontinence, the product and surface on which the system and sensor are applied show diversity. We have seen in the images above that the designs made according to underwear and diaper vary. The base used when detecting urinary incontinence also has an important place. Because the designs are usually made with the logic of short-circuit, resistance measurement and capacitance measurement, the base used must have absorbent and liquid-retaining properties. Moreover, especially in systems made with diapers, the diaper must reliably hold the liquid so that it does not overflow. For the stability and reliability of the system, it is critical for the base to hold the liquid in terms of signal transmission. It has been observed that the bases used in the studies in the literature differ. Table 2.5 shows some base features of the studies in the literature. The base information of some studies has been not shared.

Table 2.4 : Comparison of Studies According to Power Supply Type.

Study	Battery
Briedis et al. (2017)	110 mAh LiPo Battery
Marc et al. (2021)	1200mAh Battery
Gaubert et al. (2020)	3V Coin Cell
Pereira et al. (2011)	Plugged in
Fernandes et al. (2011)	Coin Cell
Simik et al. (2014)	2*1,5V Flat Cell
Rahman et al. (2017)	3,3V Battery
Martinez-Estrada et al. (2020)	No Information
Parkova et al. (2012)	
Parkova et al. (2014)	
Nair (1996)	
Tamura et al. (1993)	
Siden et al. (2004)	Action-Activated Tag

2.7.6 Warning type

The type of warning to be given after detecting urinary incontinence varies according to the design and system. In designed systems, audial and visual warning types are generally chosen in order to react instantly. However, while such alerts are ideal for alerting people nearby, they are not sufficient to alert people far away. Moreover, especially in systems designed for adults and adult children, the use of audial or visual warnings can create a feeling of shame and embarrassment in the family or community.

In some studies, information or notifications are sent to the computer or smartphone in order to both warn the distant people and to give the urinary incontinence situation silently. In studies conducted for hospitals or nursing homes, it can be seen that information can be sent to the computer application. Table 2.6 shows some of the warning types used in the literature. As can be seen, in some studies, more than one warning method has been used.

Table 2.5 : Comparison of Studies According to Diaper Base.

Study	Diaper Base
Briedis et al. (2017)	%95 Cotton %5 Elastane
Martinez-Estrada et al. (2020)	Cotton / Polyester Substrate
Marc et al. (2021)	Mixed Cotton-Polyester (Underwear), Cotton (Sheet)
Gaubert et al. (2020)	Cotton / Elastane Substrate
Pereira et al. (2011)	Cotton Knitted Fabrics
Parkova et al. (2012)	Cotton Fabric Substrate
Parkova et al. (2014)	
Fernandes et al. (2011)	
Siden et al. (2004)	Cellulose-based Substrate
Simik et al. (2014)	No Information
Nair (1996)	
Rahman et al. (2017)	
Tamura et al. (1993)	

2.7.7 Target users

It is very important to identify target users in studies to detect urinary incontinence. The design requirements and design structure may vary according to the target users. For example; the amount of urine between a baby and an adult is very different. Design requirements need to be well evaluated. A good design enables users to use the design/system/product easily, and also provides reliable and stable data. Studies on urine detection in the literature are generally aimed at babies. The studies on urinary incontinence, which is within the scope of this thesis, were generally made for infants or children. Studies on adults and the elderly are rare. Table 2.7 shows some of the target users of the studies in the literature.

Table 2.6 : Comparison of Studies According to Warning Type.

Study	Warning Type
Briedis et al. (2017)	Audible Alarm (Buzzer)
Gaubert et al. (2020)	
Parkova et al. (2012)	
Nair (1996)	
Parkova et al. (2014)	Visual Alarm (LED) Audible Alarm (Buzzer)
Simik et al. (2014)	Audible Alarm (Buzzer) GSM SMS
Martinez-Estrada et al. (2020)	Phone Notification
Marc et al. (2021)	Computer Notification
Pereira et al. (2011)	Computer Application Information
Fernandes et al. (2011)	Vibration
Rahman et al. (2017)	Notification Phone Ringing
Siden et al. (2004)	Alarm/Light Indicator for Hand-Held Device, Calling the Nurse
Tamura et al. (1993)	Visual Alarm (LED) Information

2.7.8 Reusability

Reusability is an important parameter in terms of cost reflected to the customer and the user. In smart underwear/diapers, the cost generally appears in three items. The first is the cost of the material used to build the sensor. The costs of materials such as conductive thread, conductive wire, conductive ink and conductive fabric vary according to their content and quality. The second is the cost of the underwear or diaper used as a base. The cost of underwear and diapers also varies according to their quality. The third is the cost of electronic systems that receive and process the data from the sensor and make it meaningful for users. It is also the biggest cost item in smart diaper/underwear designs.

Table 2.7 : Comparison of Studies According to Target Users.

Study	Target Users
Briedis et al. (2017)	Children
Gaubert et al. (2020)	
Parkova et al. (2012)	
Parkova et al. (2014)	
Simik et al. (2014)	Babies
Nair (1996)	Babies and Children
Martinez-Estrada et al. (2020)	Elderly and Disabled People
Marc et al. (2021)	Patients in Hospitals, Nursing Homes
Pereira et al. (2011)	Disabled and Bed-Rest Patients
Fernandes et al. (2011)	Continence Pad Users
Rahman et al. (2017)	Patients with Dementia and Mental Retardation
Siden et al. (2004)	People in Hospitals and Elderly Care Units
Tamura et al. (1993)	Aged People Who Used A Diaper

Although the cost is often overlooked in scientific research, the cost is a parameter to consider since a smart underwear/diaper is designed to use millions of people suffering from urinary incontinence. Therefore, some studies in the literature have designed sensors as reusable. In general, the sensors applied on the underwear are designed to be reusable because the underwear is reusable. Similarly, the sensors applied on the diaper are designed as disposable because the diaper is disposable. However, it has been observed that the sensors designed as reusable lose performance after a few uses and then the sensors become unusable. When the pros and cons are evaluated, it is seen as the most optimum solution to design the sensor as disposable and electronic systems as reusable. Table 2.8 shows the comparison according to the choice of reusability in the studies conducted in the literature.

Table 2.8 : Comparison of Studies According to Reusability of Sensors.

Study	Reusability of Sensor
Briedis et al. (2017)	Reusable
Martinez-Estrada et al. (2020)	
Marc et al. (2021)	
Gaubert et al. (2020)	
Parkova et al. (2012)	
Parkova et al. (2014)	
Fernandes et al. (2011)	
Pereira et al. (2011)	Disposable
Simik et al. (2014)	
Nair (1996)	
Rahman et al. (2017)	
Siden et al. (2004)	
Tamura et al. (1993)	

2.7.9 Detected incontinence type

In the literature, it has been observed that there is no smart underwear or diaper design study to detect fecal incontinence so far. Table 2.9 shows the comparison according to the incontinence types detected in the studies in the literature. Studies in the literature have been conducted to detect urinary incontinence. Fecal incontinence has generally been studied clinically. It can be thought that the reason for the lack of studies to detect fecal incontinence is that urine and stool usually come together, and therefore detection of urine may be sufficient. However, biologically, stool may come without urine. So, in the case of fecal incontinence, the sensor cannot detect it because only stool occurs.

Moreover, even though the underwear or diaper is dirty, the "underwear/diaper is clean" information is sent to the parents, family members or caregivers who are responsible for the user.

Table 2.9 : Comparison of Studies According to Detected Incontinence Type.

<table>
<tr><th>Study</th><th>Detected Incontinence Type</th></tr>
<tr><td>Briedis et al. (2017)</td><td rowspan="13">Urinary Incontinence</td></tr>
<tr><td>Martinez-Estrada et al. (2020)</td></tr>
<tr><td>Marc et al. (2021)</td></tr>
<tr><td>Gaubert et al. (2020)</td></tr>
<tr><td>Pereira et al. (2011)</td></tr>
<tr><td>Parkova et al. (2012)</td></tr>
<tr><td>Parkova et al. (2014)</td></tr>
<tr><td>Fernandes et al. (2011)</td></tr>
<tr><td>Simik et al. (2014)</td></tr>
<tr><td>Nair (1996)</td></tr>
<tr><td>Rahman et al. (2017)</td></tr>
<tr><td>Siden et al. (2004)</td></tr>
<tr><td>Tamura et al. (1993)</td></tr>
</table>

2.7.10 Comparison of choices

When the studies and designs in the literature as smart diapers or underwear are examined, it is seen that different materials and components are selected and different designs are realized according to the purpose and target user. Comparing the selections across all studies, we obtain Table 2.10. As can be seen from the table, there is diversity in the studies.

Table 2.10 : Comparison of Choices in Studies.

Study	Sensor Material	Electronic Unit	Signal Transmission Method	Power Supply	Base	Warning Type	Target Users	Reusability	Detected Incontinence Type
Briedis et al. (2017)	Conductive Threads	ATTINY13-20PU Microcontroller	No Transmission	Battery	Cotton - Elastane	Audial	Children	Reusable	Urinary Incontinence
Martinez-Estrada et al. (2020)	Conductive Threads	No Information	Bluetooth	No Information	Cotton - Polyester	Phone	Elderly - Disabled People	Reusable	Urinary Incontinence
Marc et al. (2021)	Conductive Threads	SAM D21 Microcontroller	Wi-Fi & Bluetooth	Battery	Cotton - Polyester	Computer	Patients in Hospitals, Nursing Homes	Reusable	Urinary Incontinence
Gaubert et al. (2020)	Conductive Threads	No Information	No Transmission	Coin Cell	Cotton - Elastane	Audial	Children	Reusable	Urinary Incontinence
Pereira et al. (2011)	Conductive Threads	NI-USB 6259 Multifunction Data Acquisition Board	No Transmission	Plugged in	Cotton	Computer	Disabled and Bed-Rest Patients	Disposable	Urinary Incontinence
Parkova et al. (2012)	Conductive Threads	TINY11LP Microcontroller	No Transmission	No Information	Cotton	Audial	Children	Reusable	Urinary Incontinence
Parkova et al. (2014)	Conductive Threads	No Chip	No Transmission	No Information	Cotton	Visual - Audial	Children	Reusable	Urinary Incontinence
Fernandes et al. (2011)	Conductive Threads	No Information	No Transmission	Coin Cell	Cotton	Sensual	Continence Pad Users	Reusable	Urinary Incontinence
Simik et al. (2014)	Conductive Wires	DG418DJ Analogue Switch HT12E Encoder HT12D Decoder	GSM	Flat Cell	No Information	Audial - Phone	Babies	Disposable	Urinary Incontinence
Nair (1996)	Conductive Wires	PIC1654 Microcontroller	No Transmission	No Information	No Information	Audial	Babies and Children	Disposable	Urinary Incontinence
Rahman et al. (2017)	Conductive Ink	nRF51822 BLE Chip	Bluetooth	Battery	No Information	Phone	Patients with Dementia and Mental Retardation	Disposable	Urinary Incontinence
Siden et al. (2004)	Conductive Ink	No Chip	RF	Action-Activated Tag	Cellulose	Device	People in Hospitals and Elderly Care Units	Disposable	Urinary Incontinence
Tamura et al. (1993)	Conductive Fabrics	No Information	RF	No Information	No Information	Visual	Aged People Who Used A Diaper	Disposable	Urinary Incontinence

3. PRE-TESTS FOR SENSOR TYPE SELECTION

In the literature review, we discussed the sensors developed so far and the advantages and disadvantages of these sensors. In this section, we want to experience and see the behaviour of these sensors with tests. Therefore, we will try the conductive ink print sensor and the embroidered thread sensor in the tests.

We will test the conductive ink sensor and the conductive thread sensor using the short-circuit technique. We will create two parallel paths of various shapes. Thus, we will actually have two probes, a positive terminal and a negative terminal. Then we will perform our tests with water, salt solution and urine. We will pour these liquids on the diaper and monitor and record the working performance of the sensors that will be in the diaper.

3.1 Test Liquids

The water will be used to see the performance of sensors when the electrical conductivity is low. As content, pH and conductivity of urine change depending on biological effects, it is an important criterion for us to see the sensor behaviour and response time in case of low conductivity. The salt (NaCl) solution will be used to create artificial urine. Determining the exact composition of the urine and making artificial urine with this composition is a very difficult and very expensive process. Because the content and properties of urine vary according to effects such as gender, age, race, nutrition, drug use, etc. Moreover, even in the same person, urine characteristics can change during the day depending on body functions [61]. Even when explained simply, it has been determined that human urine consists of 95% water, 2% urea, 0.1% creatinine, 0.03% uric acid, and the others (chloride, sodium, potassium, sulfate, ammonium, phosphate, and other ions and molecules) (Table 3.1) [62]. Although detailed descriptions of artificial urine can be found in the literature, only the general electrical conductivity is sufficient for these sensors to be active. Urine has more conductivity than water, so NaCl solution with properties similar to that of urine will be prepared. Nutritional salt containing sodium chloride (NaCl) was dissolved in water to obtain artificial urine. Various urine conductivity values have been reported in the literature [63,64]. According to the reported urine conductivity values, the low conductivity value was chosen to be on the safe side, and the amount of salt that should be added to the water was calculated to obtain this value. As a result of the calculations, approximately 8 gr of salt will be added to each 1 L of water to obtain artificial urine. The (real) urine will be used to see the real effects. Especially considering the acidic effect of urine, the response of the sensors to this acidic effect will be observed.

Table 3.1 : Physiological ranges of compounds in the urine of a healthy person [62]

Property and Composition	Molar Mass (g/mol)	Normal Range in humans (reference age in years)	Molarity (mmol/1.5 L)
Volume		0.8–2 L	
pH		4.5–8.0	
Specific gravity (SG)		1.002–1.030 g/ml (all)	
Osmolality		150–1150 mOsm/kg (>1)	
Urea (CH_4N_2O)	60.06	10–35 g/d (all)	249.750
Uric Acid ($C_5H_4N_4O_3$)	168.11	<750 mg/d (>16)	1.487
Creatinine ($C_4H_7N_3O$)	113.12	Males: 955–2936 mg/d Females: 601–1689 mg/d (18–83)	7.791
Citrate ($C_6H_5O_7^{3-}$)	192.12	221–1191 mg/d (20–40)	2.450
Sodium (Na^+)	22.99	41–227 mmol/d (all)	92.625
Potassium (K^+)	39.10	17–77 mmol/d (all)	31.333
Ammonium (NH_4^+)	18.05	15–56 mmol/d (18–77)	23.667
Calcium (Ca^{2+})	40.08	Males:<250 mg/d Females:<200 mg/d (18–77)	1.663
Magnesium (Mg^{2+})	24.31	51–269 mg/d (18–83)	4.389
Chloride (Cl^-)	35.45	40–224 mmol/d (all)	88.000
Oxalate ($C_2O_4^{2-}$)	88.02	0.11–0.46 mmol/d (all)	0.277
Sulphate (SO_4^{2-})	96.06	7–47 mmol/d (all)	18.000
Phosphate (PO_4^{2-})	94.97	20–50 mmol/d (>18)	23.33

An adult person excretes on average 20 ml of urine per kilogram of body weight in 24 hours. It is between 1 L and 2 L for an adult person. These rates may increase (polyuria) or decrease (oliguria) according to age, gender, nutrition (water consumption, alcohol consumption), environmental conditions (outdoor temperature), physiological movements (muscle work), pathological disorders. The amount of urine may even drop to zero (inability to urinate) or, on the contrary, it may happen involuntarily urinating (urinary incontinence) [65]. An adult person uses the toilet from 4 to 8 times and urinates 100 ml to 500 ml of urine each time. This amount may vary depending on various factors. For example, it has been determined that the amount of urine output per toilet use is high since people in the office environment tend to hold urine while they are working, and the amount of urine per toilet use is low in homes since it is possible to use the toilet comfortably (Figure 3.1) [66]. In addition, due to some biological diseases (prostate, etc.), the bladder cannot hold much urine, and the amount of urine per toilet use may decrease below 100 ml in some cases. Considering all these, 50 ml, 100 ml and 250 ml liquid samples will be used in the tests.

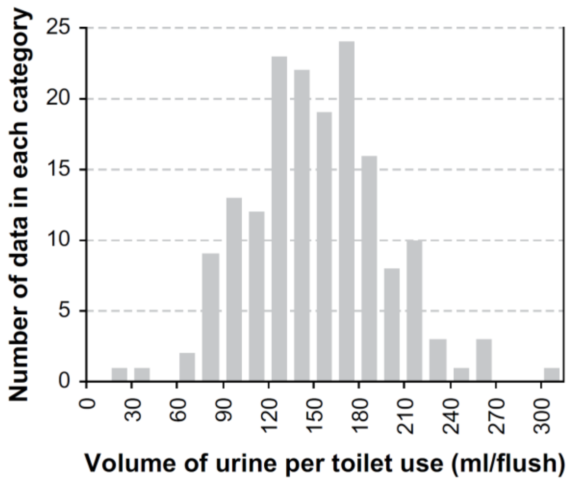


Figure 3.1: Distribution of urine amount per toilet use in homes (ml/flush) [66]

3.2 Test Circuit

We built a simple circuit to see the working performance of the sensors in the tests. Our aim in this circuit is to determine whether wetness is detected and how long it takes. The circuit diagram is shown in Figure 3.2.

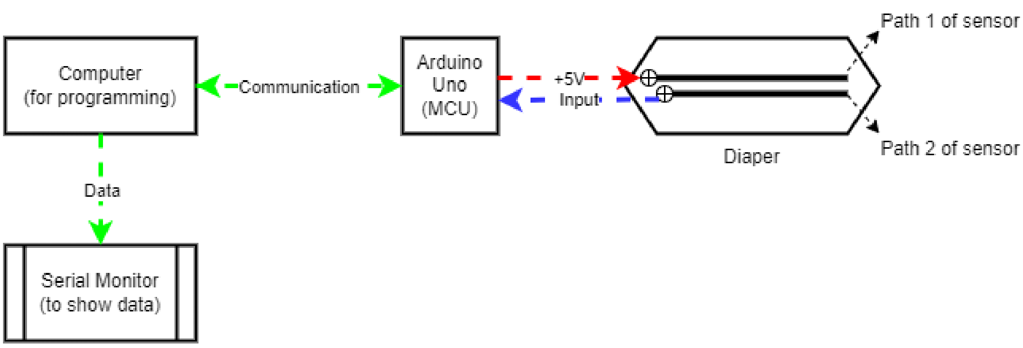


Figure 3.2: Pre-test Circuit Diagram

The equivalent of the sensors in the literature can be thought of as a potentiometer that can have an infinite resistance value. The sensors, which are obtained by keeping two paths separate from each other with a certain distance between them and having different geometric structures, initially have almost infinite resistance. They need a conductive liquid that will provide conduction between the two paths. Depending on the conductivity and amount of the conductive liquid, the sensor resistance starts to decrease from almost infinite value to almost zero value. After a certain time, only the resistance value from the road remains (Figure 3.3).

In addition, it should be noted that the equivalent of sensors in actual use is resistance and capacitive impedance. In other words, sensors have both resistive and capacitive properties. The fact that it consists of parallel paths with an insulating distance between them reveals the capacitive feature. Moreover, the actual situation in which the capacitive feature emerges is that the sensor is made of two layers. The two parallel layers resemble two parallel conductive plates of capacitance, and the absorbing surface resembles the insulating material between two parallel conductive plates of capacitance. This sensor structure reveals the capacitive effect of the sensor. Therefore, in some studies in the literature, urinary incontinence has been detected by measuring this capacitance value. As the liquid comes to the absorbent surface, the capacitance value decreases. The capacitance value drops to zero when sufficient liquid reaches the absorbent surface and a path is formed between the two sensor layers to enable transmission.

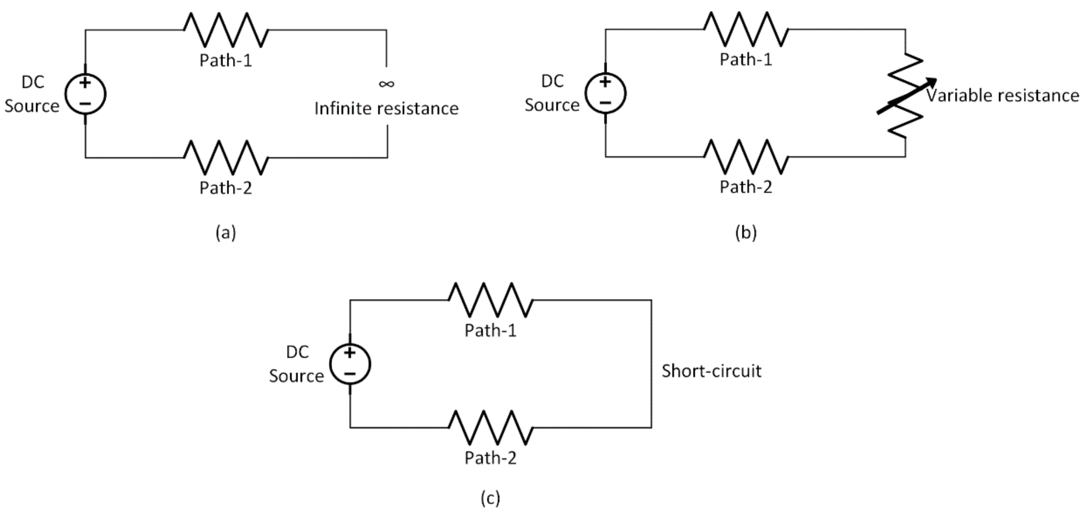


Figure 3.3: Equivalent Resistance of the Sensors in Literature (a) Initially (b) Contact of Conductive Liquid (c) Final Situation

Since our purpose in the tests has been to test whether the sensors detect or not, we wrote the algorithm and code simply (Figure 3.4).

```
/*
  Wetnees Detect Code
  Reads a digital receiveed input from sensor path, prints the result to the Serial Monitor
*/

// digital pin 2 is assigned input to receive sensor path signal.
int wetdetect = 2;

void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
  // make the pin 2 an input:
  pinMode(wetdetect, INPUT);
}

// the loop routine runs over and over again forever:
void loop() {
  // read the input pin:
  int inputstate = digitalRead(wetdetect);
  // print out the state of the input:
  Serial.println(inputstate);
  delay(100);        // delay in between reads for stability
}
```

Figure 3.4: Software of the Pre-test

Since these sensors, which are prepared as two paths in the literature, short-circuited must happen when the diaper is wet, we will test whether these sensor paths are short-circuited. Thus, we send the "1" signal by giving +5 V to one of the sensor paths. The other sensor path will be used as input for the MCU (Arduino Uno). If the input signal is “0”, we will determine that wetness is not detected, and if it is 1, we will determine that wetness is detected. The received input signal value will be printed on the computer screen at 100 ms intervals and will be followed from there. Figure 3.5 shows the working algorithm of the pre-tests.

3.3 Test Diaper

As a matter of course, it is necessary to perform the tests in a real adult diaper in order to experience the real test. Although most of the studies mentioned in the literature have been tested by directly contacting the sensors with the liquids, we believe that the performance in the absorbent adult diaper is more important. In the design of the sensor system, the compatibility of the sensor with every component of the system is as critical as the sensor.

In the tests, an adult diaper with a textile surface, waistband, cotton absorbent surface has been chosen as the adult diaper [67]. While choosing the adult diaper, the absorbency quality of the adult diaper, the textile surface feature, the ability to adapt to the sensor and the rate of preference in the Turkish market have been taken into consideration.

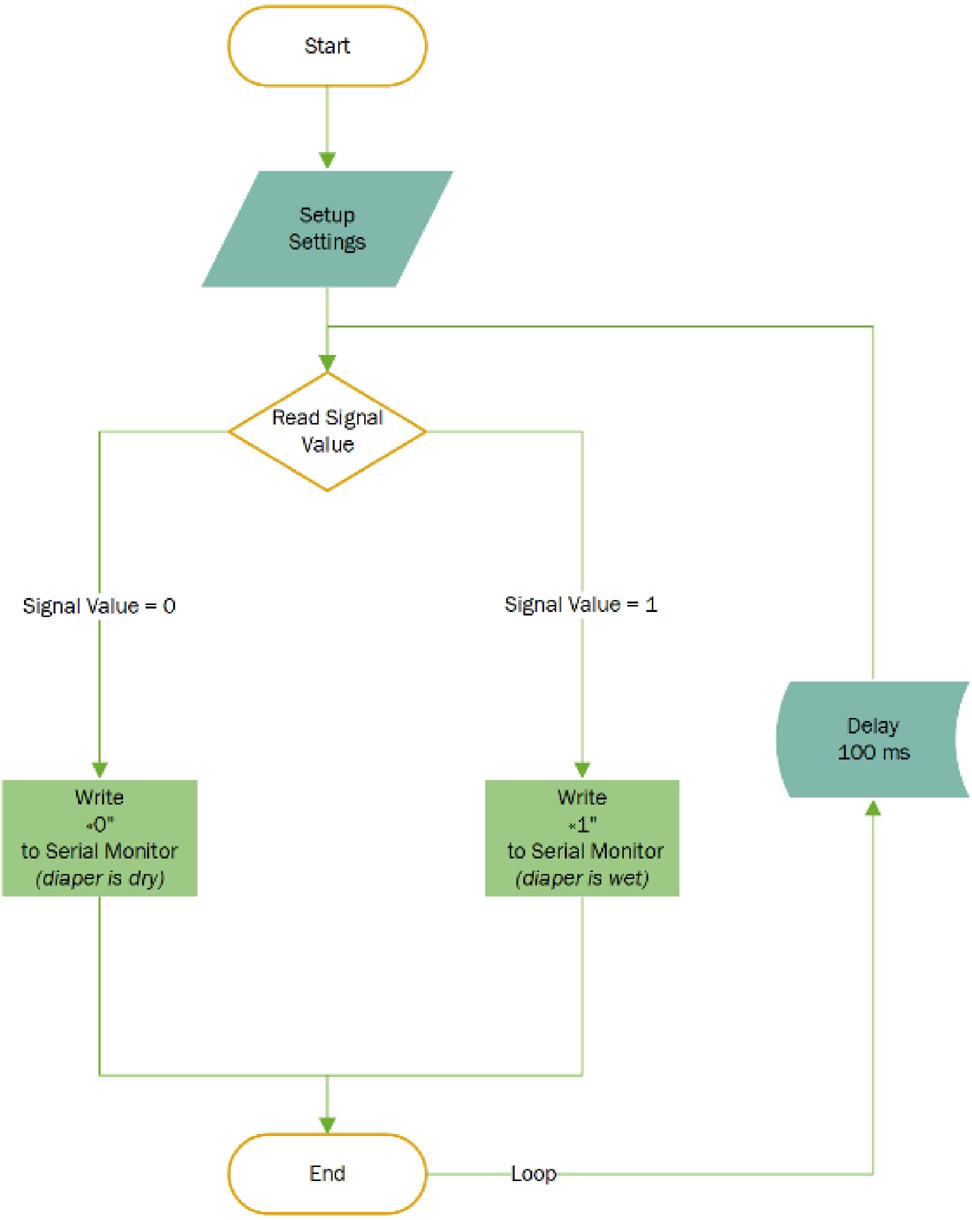


Figure 3.5: Algorithm of the Pre-test

3.4 Ink Printing

Electric paint from Bare Conductive has been used to apply ink printing (Figure3.6) [68]. This electric paint used is a conductive, water-based and water-soluble paint type. It also has a non-toxic content. Considering its use in diapers, it is an important criterion that the paint is not toxic, since it is a substance that directly or indirectly touches the body. It can act as a resistor element, capacitive electrode or conductive path in various circuits.

Figure 3.6: Bare Conductive Electric Paint [68]

When the conductive paint is processed by manual screen printing, the resistance of the path is calculated as approximately 32 Ω/sq. The graph shown in Figure 3.7 shows how the resistance changes with the length when the conductive paint is applied as a line. An equation is also given to roughly estimate the surface resistance.

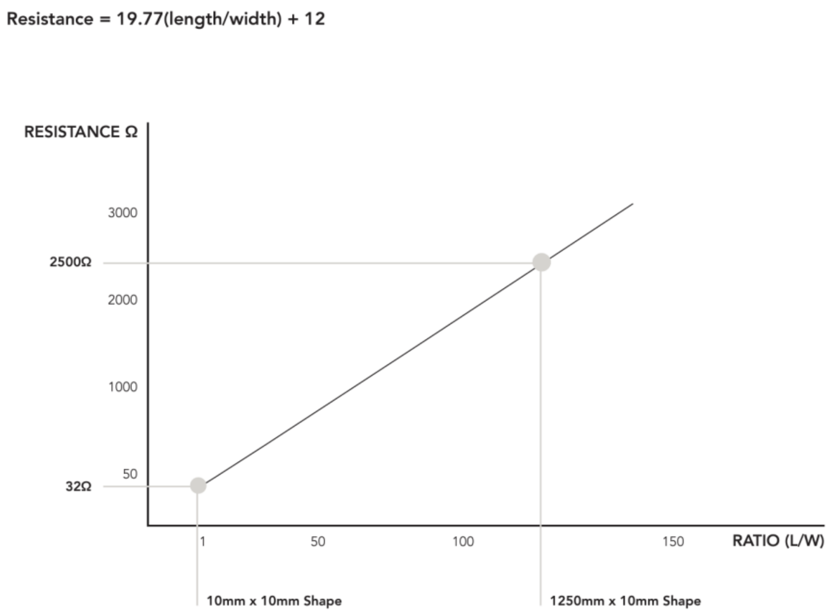


Figure 3.7 : Resistance graph and equation of Bare Conductive Electric Paint [68]

3.5 Conductive Thread

A conductive thread has been used from stainless steel fibre to make the conductive thread sensor (Figure 3.8) [69]. The features that separate this conductive thread from other conductive threads are 12 μm stainless steel fibre, incredibly smooth and neat. The resistance of the conductive thread is 27 ohms per meter.

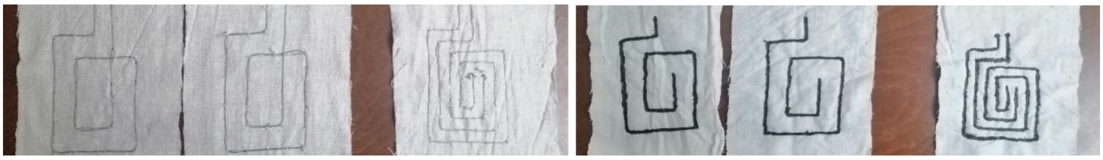
Figure 3.8 : Lilypad Conductive Thread [69]

3.6 Test Implementing

Cotton fabric has been used to process both conductive paint and conductive thread. Cuts have been made to fit the selected adult diaper. Then, as can be seen in Figure 3.9, sensor layout sketches were drawn for both single layer and two layers. Afterwards, the conductive thread has been embroidered or conductive paint has been manually printed on these sketches.

Figure 3.9 : Sketches of the Sensors

We will test two different structures for the sensors. For the sensor we will operate with the short circuit technique, we will process both probes on a single layer in the first structure, and we will process two probes on two different layers in the second structure (Figure 3.10). In this way, we will be able to see the effects of both sensors and layers.



(a) (b)

Figure 3.10 : Pre-test Sensors (a) Conductive Thread (b) Ink Printing

In the use of a single layer, the fabric with the sensor was placed under the absorbent surface (Figure 3.11). In order to prevent the effects of sweat, etc. in personal use, it has been chosen the settlement, considering that it will be used under the absorbent surface. In the use of two layers, the first fabric with the sensor is placed under the inner part of the diaper at the top, and the second fabric with the sensor is placed under the absorbent surface, inside the outer part of the diaper. So that the absorbent surface has been placed between the two layers.

(a) (b)

Figure 3.11 : Placement of the sensors inside the adult diaper (a) 1-Layer (b) 2-Layers

The positive terminal has been connected to one of the two paths in the sensors and the negative terminal was connected to the other (Figure 3.12). When we can take the voltage we give from the positive terminal from the negative terminal, that is, when the current flows between the negative and positive terminals, we will have detected that there is liquid.

We have used the Arduino Uno board as a processor to detect wetness. It will send the value "0" or "1" to the computer screen at 100 ms intervals according to the incoming voltage value. We made all the connections as shown in Figure 3.13 and started the tests.

Figure 3.12 : Connections of the Sensors

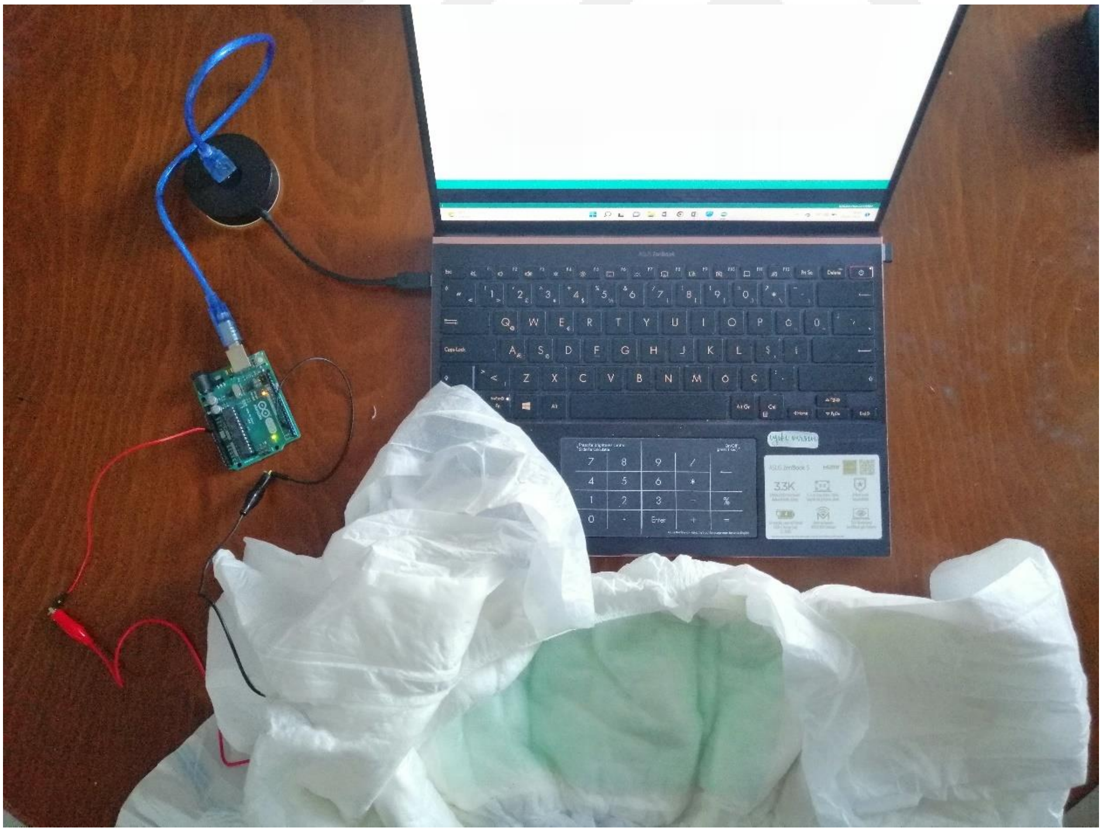


Figure 3.13 : Pre-test Setup

We performed liquid measurements in 50 ml, 100 ml and 250 ml volumes with a measuring glass (Figure 3.14).

Figure 3.14 : Liquid Volumes

We performed the tests by pouring the liquid we took in the measuring cup from a height of 15 cm towards the absorbent surface of the diaper at a speed of approximately 20 ml/sec (Figure 3.15).

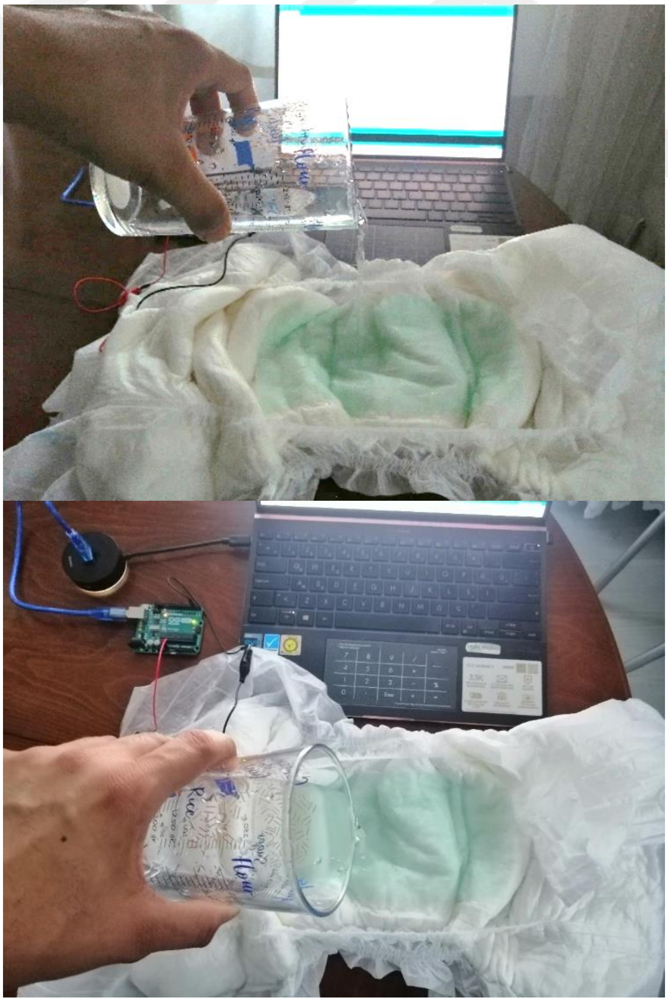


Figure 3.15 : Performing of Pre-tests

Fabrics made using 2 different sensor materials have been placed inside 36 adult diapers using 2 different layer techniques. Their connections have been made with the electronic circuit respectively. Tests have been carried out by pouring 3 different liquids in 3 different volumes onto the absorbent surface.

3.7 Test Results

At the end of 36 different test scenarios tried in total, the most prominent result was that both the conductive thread and the conductive paint could not detect wetness in the tests performed with water. Although this result is an expected result since water does not have sufficient conductivity at low voltage, we proved this with the tests, and proved that the conductive thread or conductive paint/ink sensor systems created with the short-circuit technique cannot detect urine if the urine has low conductivity due to any biological problem. Table 3.2 shows the liquid detection times of the sensors in each test in the pre-tests. Since the sensors could not detect the water in the tests performed with water, these data are not included in the table.

In the tests performed with both salt solution and urine, the sensors performed the detection. Surely, the response times of the sensors varied according to the sensor material, layer technique, liquid type and liquid volume.

Each test was performed not only by recording response times but also by monitoring for 5 minutes. We thought that when the conductivity or liquid volume was not enough, there could be breaks in the signals. In the results obtained, we observed that the signal was not stable in the use of low volume liquid and remained stable only after 60 seconds.

The conductive thread sensor made with 1-layer technique can detect both salt solution and urine (Figure 3.16). When the liquid amounts are 100 ml and 250 ml, the sensor can detect both liquids. However, as can be seen from the results, the sensor could not give a stable value when the amount of liquid is 50 ml. This shows that in real practice, when the amount of urine is as low as 50 ml due to any biological reason, there will be a problem in the detection of urinary incontinence.

The conductive thread sensor made with the 2-Layers technique can detect both salt solution and urine, just like the conductive thread sensor made with the 1-Layer technique (Figure 3.17). Similarly, when the liquid amounts are 100 ml and 250 ml, the sensor can detect both liquids. However, when the amount of liquid is 50 ml, the sensor could not give a stable value. In addition, we observed a very late detection problem in the 50 ml tests. While response time over 10 seconds is considered unsuccessful, the response time here is measured as about 30 seconds. This result, which is well above the limit value, shows that there will be a problem in the detection of urinary incontinence when the amount of urine is as low as 50 ml due to any biological reason in real practice.

Table 3.2 : Response times of pre-tests

Test No	Sensor Material	Sensor Layer	Test Liquid	Test Volume	Response Time (s)
1	Thread	1-Layer	Salt-Solution	50 ml	6,200
2	Thread	1-Layer	Salt-Solution	100 ml	3,096
3	Thread	1-Layer	Salt-Solution	250 ml	3,523
4	Thread	1-Layer	Urine	50 ml	11,483
5	Thread	1-Layer	Urine	100 ml	4,238
6	Thread	1-Layer	Urine	250 ml	0,694
7	Thread	2-Layers	Salt-Solution	50 ml	37,123
8	Thread	2-Layers	Salt-Solution	100 ml	3,074
9	Thread	2-Layers	Salt-Solution	250 ml	1,691
10	Thread	2-Layers	Urine	50 ml	28,818
11	Thread	2-Layers	Urine	100 ml	6,544
12	Thread	2-Layers	Urine	250 ml	2,097
13	Ink	1-Layer	Salt-Solution	50 ml	2,962
14	Ink	1-Layer	Salt-Solution	100 ml	2,077
15	Ink	1-Layer	Salt-Solution	250 ml	0,766
16	Ink	1-Layer	Urine	50 ml	3,430
17	Ink	1-Layer	Urine	100 ml	3,502
18	Ink	1-Layer	Urine	250 ml	1,654
19	Ink	2-Layers	Salt-Solution	50 ml	2,965
20	Ink	2-Layers	Salt-Solution	100 ml	1,854
21	Ink	2-Layers	Salt-Solution	250 ml	2,217
22	Ink	2-Layers	Urine	50 ml	4,114
23	Ink	2-Layers	Urine	100 ml	3,057
24	Ink	2-Layers	Urine	250 ml	3,706

Conductive ink sensor made with 1-layer technique can detect both salt solution and urine (Figure 3.18). When the liquid amounts are 100 ml and 250 ml, the sensor can detect both liquids. However, when the amount of liquid is 50 ml, the sensor could not give a stable value. However, it has a more stable result compared to the conductive thread sensor.

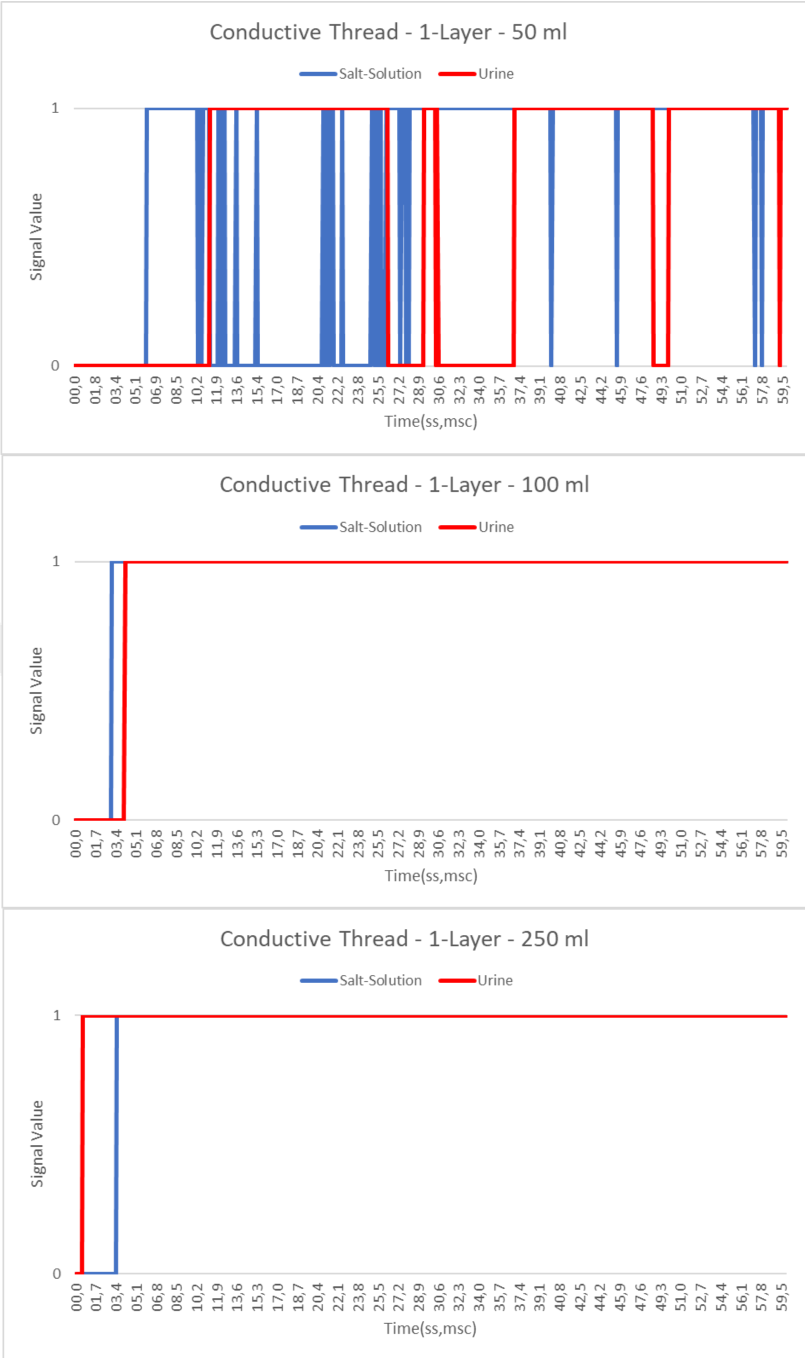


Figure 3.16 : Results of Conductive Thread Sensor made with 1-Layer Technique

The conductive ink sensor made with 2-Layer technique can detect both salt solution and urine, just like the conductive ink sensor made with 1-Layer technique (Figure 3.19). Similarly, when the liquid quantities are 100 ml and 250 ml, the sensor can detect both liquids. Unlike the others, the sensor gives a stable value when the amount of liquid is 50 ml. However, the conductive ink sensors made in the 2-Layers technique, although not as much as the conductive thread sensors, give a late response compared to the conductive ink sensors made in the 1-Layer technique.

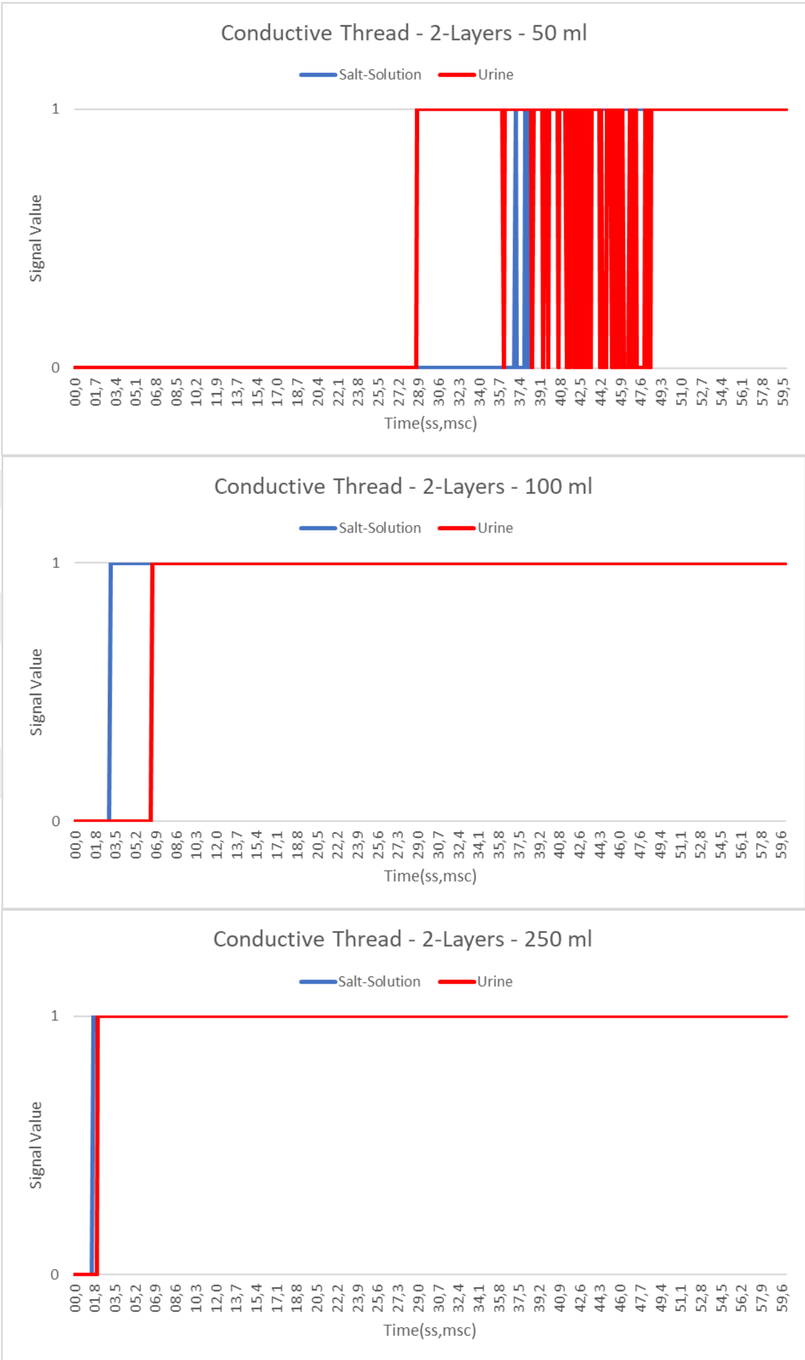


Figure 3.17: Results of Conductive Thread Sensor made with 2-Layers Technique

At this point, we will compare each parameter that affects response times. As a result of these comparisons, we will see the negative or positive effect of each parameter variable and its advantage or disadvantage compared to the other variable(s).

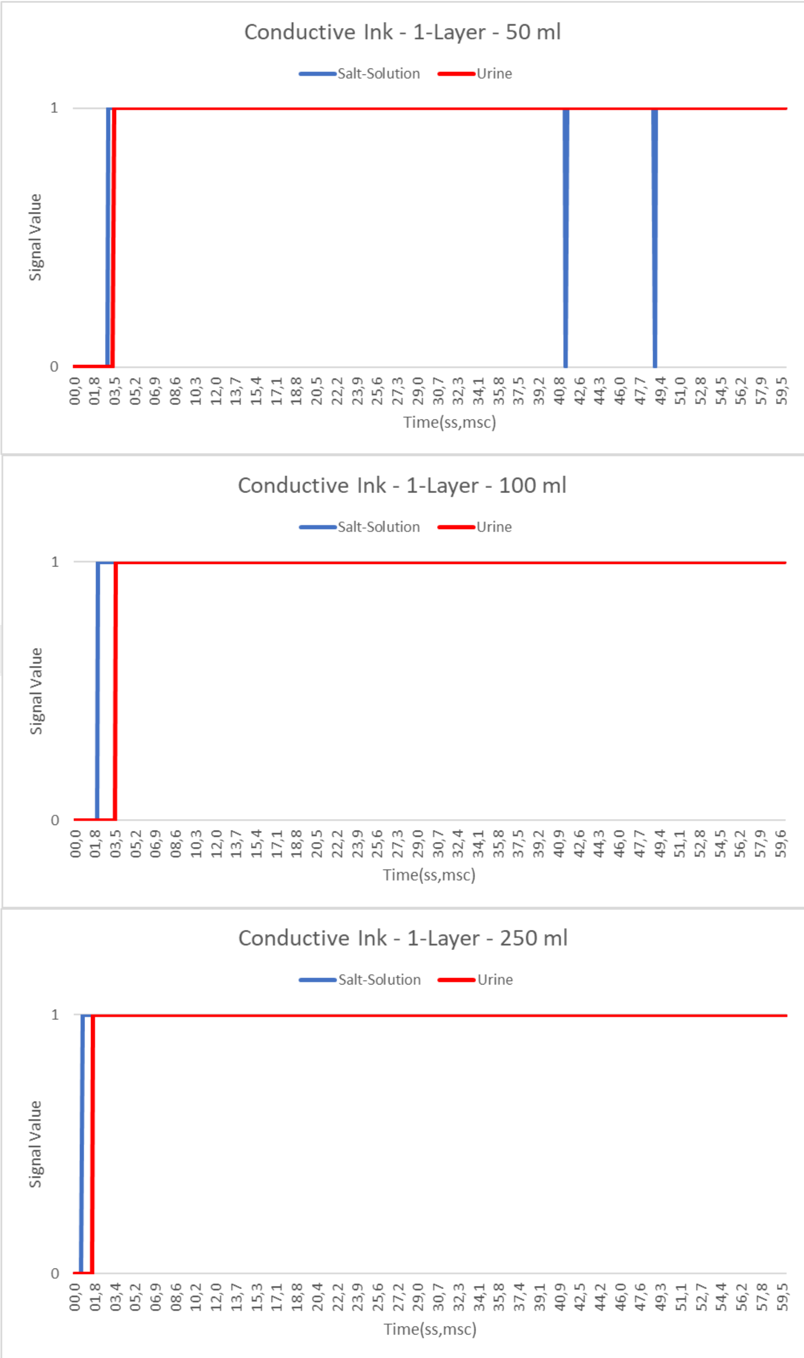


Figure 3.18: Results of Conductive Ink Sensor made with 1-Layer Technique

Firstly, when we compare the sensor material, we see that the conductive thread reacts later than the conductive ink (Figure 3.20). Moreover, the response times of the conductive thread are in a wide range, while the response times of the conductive ink are in a narrower range. This is because the conductive thread sensor is a mixture of stainless steel and fibre. Stainless steel which is the conductive part of the conductive thread can be inside or outside of the mixture. In order for the transmission to be ensured, the liquid must first be absorbed by the conductive thread so that the liquid can reach the stainless steel. We think that the difference in response times between conductive thread and conductive ink sensors is due to this.

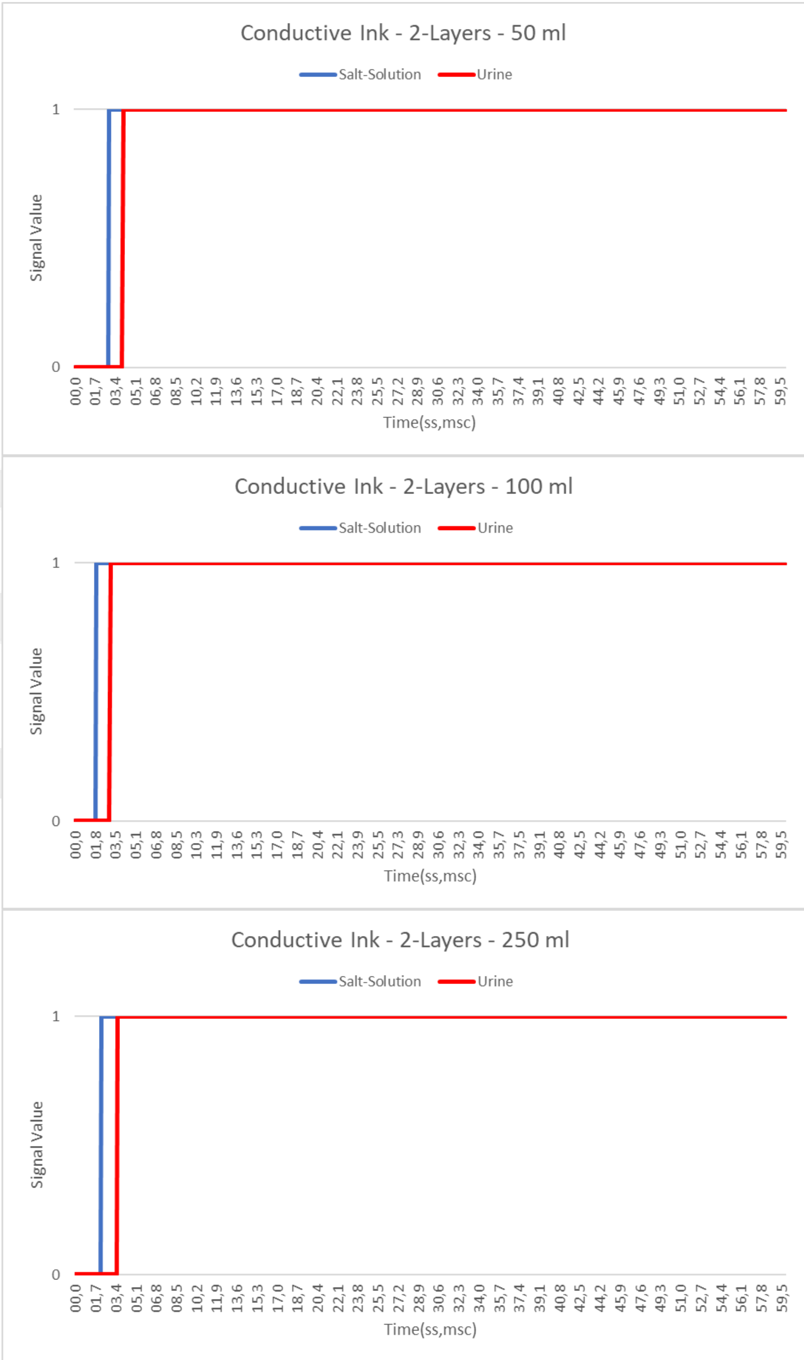


Figure 3.19: Results of Conductive Ink Sensor made with 2-Layers Technique

Secondly, when we compare the sensor layer technique, we see that 2-Layers responds later than 1-Layer (Figure 3.21). In addition, the response times of 2-Layers are in a wide range while the response times of 1-Layer are in a narrower range. This is because in the 2-Layers technique, the pathways that provide the transmission are located in two different layers and there is an absorbent surface between the layers. In order to ensure transmission, the liquid passing through the first layer must also pass through the absorbent surface in between in order to reach the second layer. As the liquid moves along this path, it is naturally absorbed by the absorbent surface. For this reason, the reaching of the liquid to the second layer is somewhat delayed. Since the absorbent surface also becomes a transmission path, there must be enough liquid to saturate the absorbent surface. Otherwise, it can take time for the liquid to spread on the absorbent surface and there can be delays in the response time, or because the absorbent surface cannot receive enough liquid, transmission breaks may occur. In the 1-Layer technique, since the two pathways that provide the transmission are located on one layer, reaching of the liquid to the layer is sufficient for the transmission.

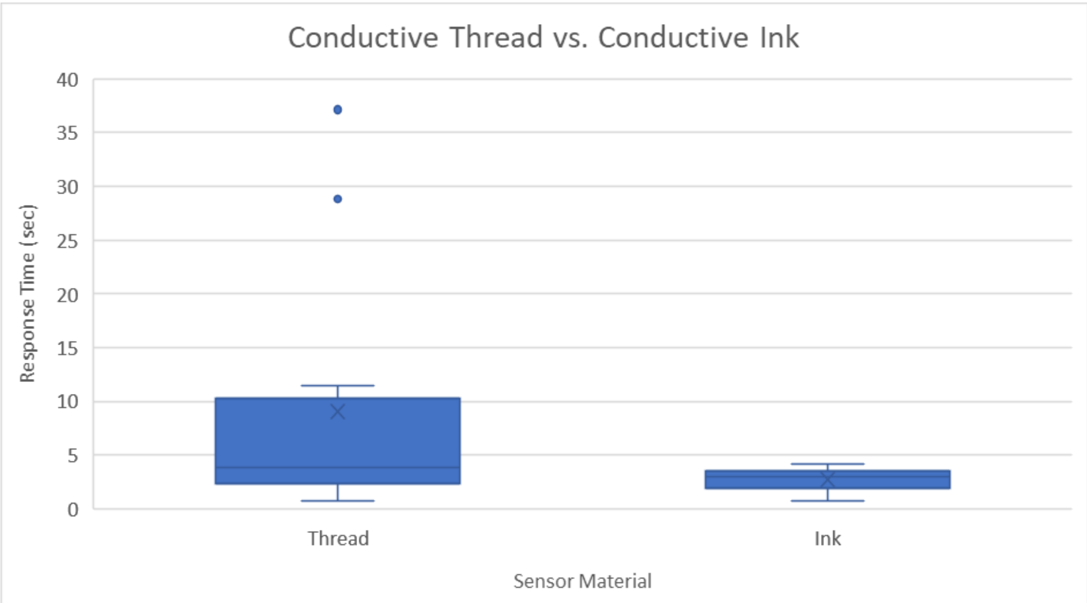


Figure 3.20: Comparison of the Sensor Material Effect

Thirdly, when we compare the types of liquid used in the tests, we see that the sensors respond later when urine is used in the tests than when using the salt solution in the tests (Figure 3.22). Also, the response times when urine is used in the tests are in a wide range, while the response times when salt solution is used in the tests are in a narrower range. The reason for this is that the salt solution used in the tests has the same constant conductivity value, while the urine does not have a constant conductivity value. As stated previously, it is a fact that even the urine of the same person can vary during the day and have different pH and conductivity values. Therefore, since the urines used in the tests do not have the same conductivity value, the response times are different.

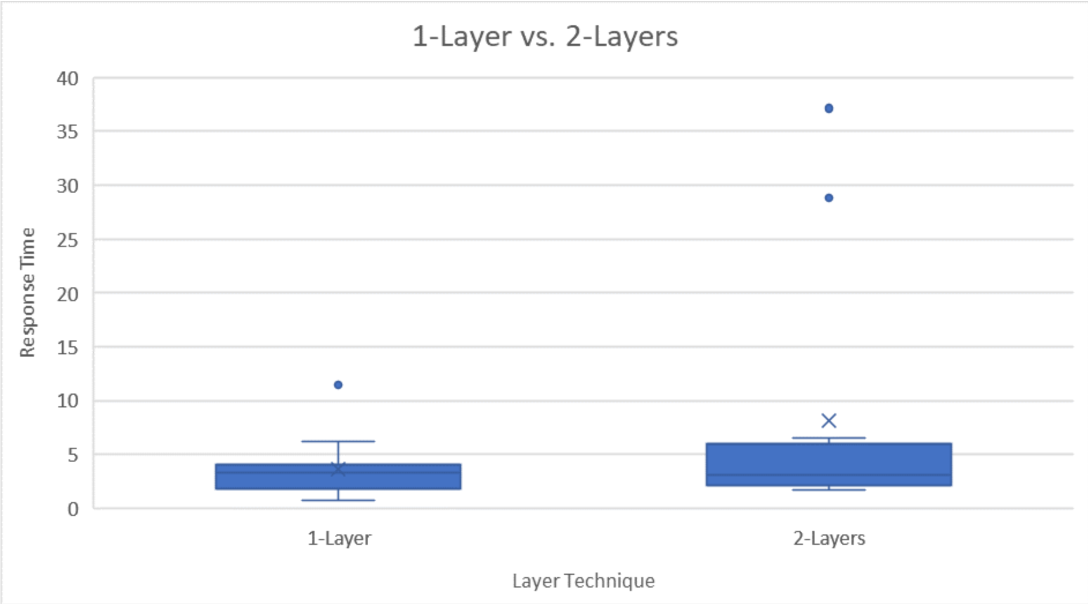


Figure 3.21: Comparison of the Sensor Layer Effect

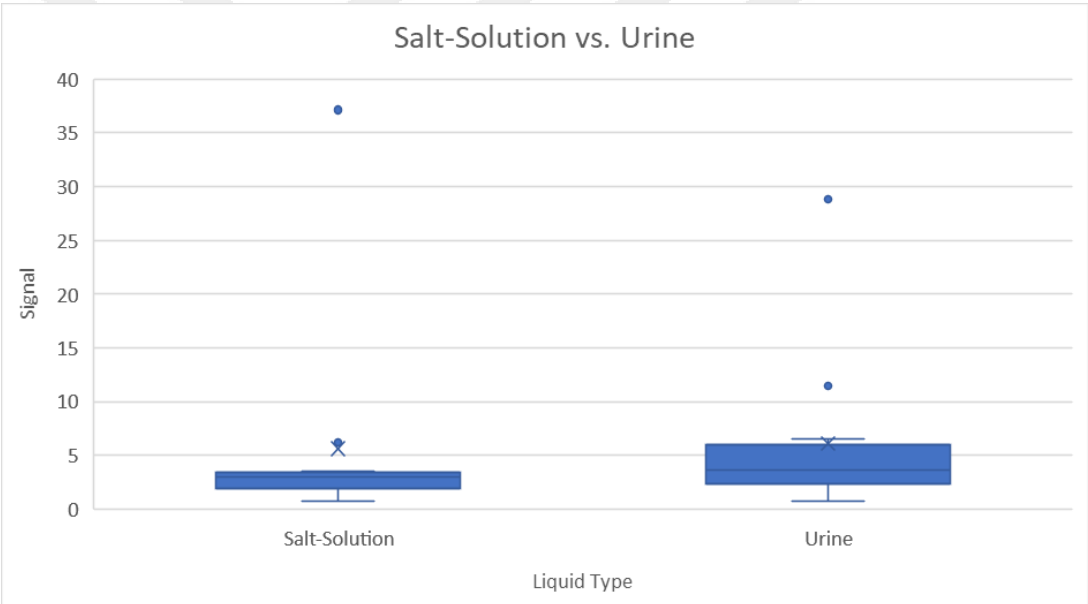


Figure 3.22: Comparison of the Liquid Type Effect

Fourthly, when we compare the liquid volumes used in the tests, we see that the sensors respond later as the liquid volume decreases (Figure 3.23). Also, as the volume of liquid decreases, response times are in a wide range. This is due to the fact that the liquid is also a pathway that provides transmission. There must be sufficient liquid between the sensor paths so that the transmission can be provided uninterrupted and stable. In addition, there must be enough liquid to reach the sensor while passing through the absorbent surface. Otherwise, the liquid will be absorbed by the absorbent surface and sufficient liquid will not reach the sensor paths. As seen in the tests, as the amount of liquid decreases, both the response times increase and the signal transmission is interrupted. On the other hand, as the amount of liquid increases, both the response times decrease and stable signal transmission can be achieved.

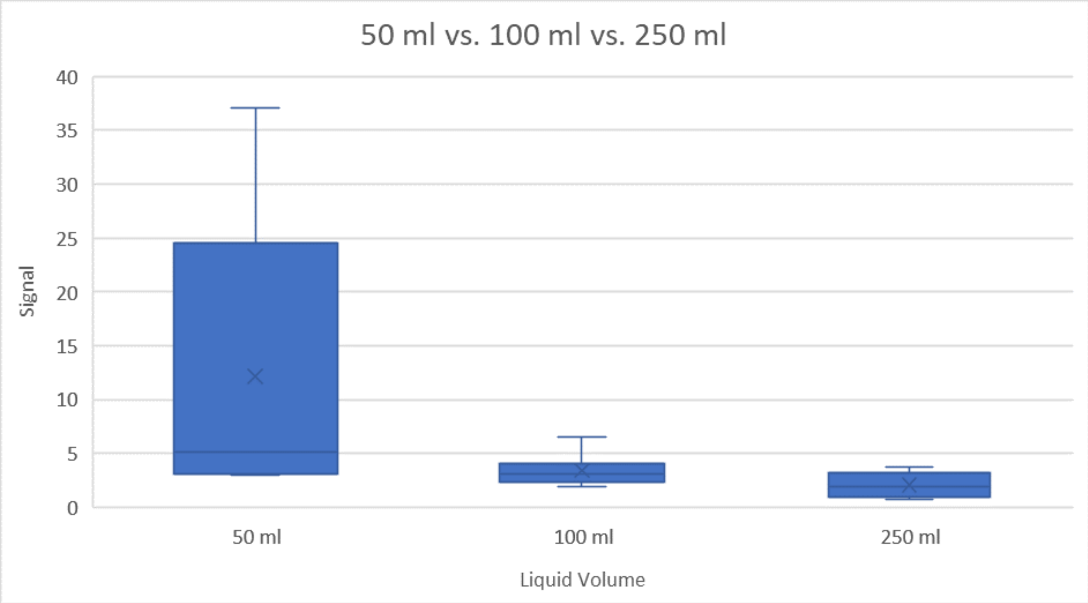


Figure 3.23: Comparison of the Liquid Volume Effect

When we have compared the factors affecting the response time results, we see how much each parameter affects and we have tested the advantages and disadvantages of the studies in the literature (Figure 3.24). With these comparisons, we have obtained tips for the "smart electronic adult diaper" project that we will carry out.

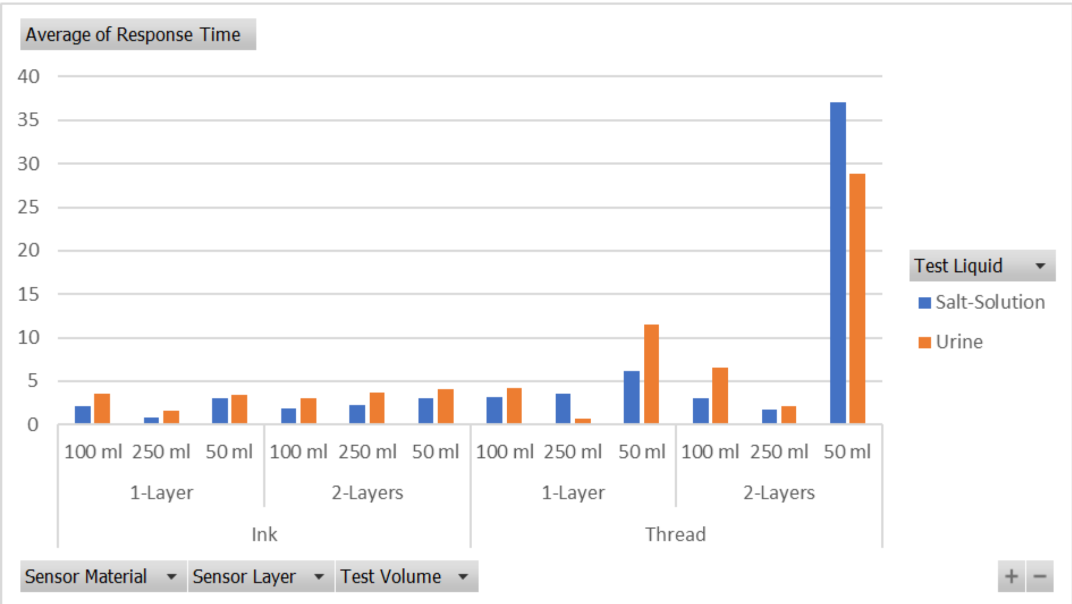


Figure 3.24: Response Times of Pre-tests

4. DEFINITION PHASE OF SMART ELECTRONIC ADULT DIAPER

4.1 User and Caregiver Experiences

4.1.1 User experience

First of all, this adult diaper design aims to provide to check the adults who need to care. It is also important to be useful while providing this (Figure 4.1). The adults should feel living without an adult diaper when they use the adult diaper. For this, it is important that the electronic circuits, connection paths, and sensors on it have a comfortable structure as well as a comfortable structure, that is, a structure that will not disturb the user. Otherwise, the user will be uncomfortable and want to remove the adult diaper.

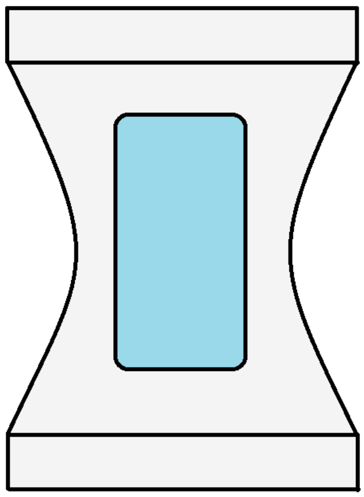


Figure 4.1 : An example of the view of the adult diaper

We have carried out various studies on the design of the adult diaper so that the user can use it comfortably and not be disturbed while using it. The electronic circuitry is placed on a belt, located at the front of the adult diaper. In this way, the structure resembling a belt buckle is made not to disturb the user (Figure 4.2). We found that it would be uncomfortable if the electronic circuit was on the back or on the side, especially considering that adults in need of care mostly sleep on their backs. This structure provides both a comfortable usage for the user and an advantage in terms of the durability of the system. Conductive pathways and sensors in the adult diaper are passed under a thick layer of cotton. In this way, the user's skin contact and the user's sense of the sensor structure and conductive paths are prevented.

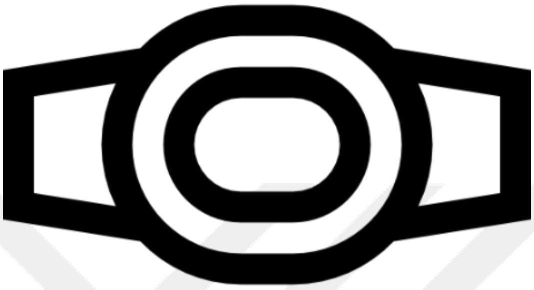


Figure 4.2 : An example of the external view of the electronic circuit structure

4.1.2 Caregiver experience

Family members or caregivers who are responsible for caring for adults who need help want to be able to easily control adults and to care for them easily when needed. In the event that these procedures are difficult, both the caregivers or family members complain about this situation, and the adults in need of care are psychologically affected by this situation.

In order for caregivers or family members to easily check on adults in need of care, information is sent to caregivers and/or family members through our electronic system. So, caregivers or family members are notified instantly when users need it. In this way, the caregiver or family member intervene immediately, and health problems of users that may occur in case of late intervention are prevented. Moreover, the adult diaper is used as a diaper, not as an underwear. Thanks to its opening structure, it is possible to replace the adult diaper without removing the users from their beds (Figure 4.3). We found that designs used as underwear cause difficulties for both the caregiver/family member and the user.

4.2 Choice of Sensor

There are many sensors used to detect wetness in the industry. It is very important to choose the sensor according to the specs of the area to be used. As a result of our evaluation according to the specs of the adult diaper to be used, we decided to use the DHT11 temperature and humidity sensor for wetness detection in adult diapers (Figure 4.4).

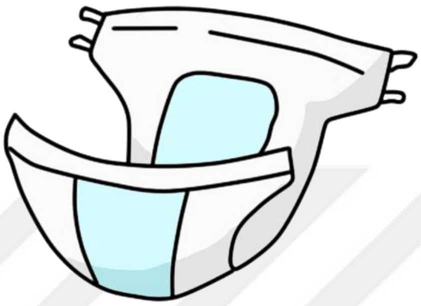


Figure 4.3 : An example of the external 3D view of the adult diaper

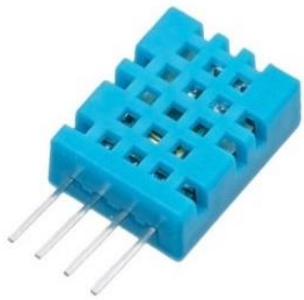


Figure 4.4 : DHT-11 Sensor [70]

The DHT11 sensor can measure both temperature and humidity. In addition, the data it measures has stability and calibration. Temperature measurement takes place with NTC logic. The humidity measurement has a resistive type component. It has a fast response feature (Figure 4.5) [71].

As it can be seen, the DHT11 sensor can measure not only humidity but also temperature. The temperature will be necessary for us in two ways. The first is to monitor body temperature - as much as possible - and the second and most importantly, to detect the situations of defecation in addition to enuresis. Because in the case of defecation, the pee does not necessarily occur, it can only be excrement. Considering the situations where the excrement is not wet, we will use the temperature value for the detection of defecation.

Parameters	Conditions	Minimum	Typical	Maximum
Humidity				
Resolution		1%RH	1%RH	1%RH
			8 Bit	
Repeatability			±1%RH	
Accuracy	25℃		±4%RH	
	0-50℃			±5%RH
Interchangeability	Fully Interchangeable			
Measurement Range	0℃	30%RH		90%RH
	25℃	20%RH		90%RH
	50℃	20%RH		80%RH
Response Time (Seconds)	1/e(63%)25℃, 1m/s Air	6 S	10 S	15 S
Hysteresis			±1%RH	
Long-Term Stability	Typical		±1%RH/year	
Temperature				
Resolution		1℃	1℃	1℃
		8 Bit	8 Bit	8 Bit
Repeatability			±1℃	
Accuracy		±1℃		±2℃
Measurement Range		0℃		50℃
Response Time (Seconds)	1/e(63%)	6 S		30 S

Figure 4.5 : Technical Specifications of DHT11 Sensor [71]

4.3 Choice of Microprocessor

In wearable product designs, there are various devices or applications in many areas today. Various processors or circuit blocks with processors are used in these devices or applications. In wearable products, it is desired that electronic mainboards take up as little space as possible. On the other hand, in addition to taking up little space, the processor or circuit block with the processor should also have many features.

We will use the Arduino Nano circuit block designed for wearable products in the electronic adult diaper (Figure 4.6). There is an ATmega328 processor inside the Arduino Nano circuit board. Together with its peripherals, it is a small but complete circuit board for the project. Its processor speed is 16 MHz and its memory is 32 KB. Arduino Nano is one of the smallest among Arduino circuit boards [72].

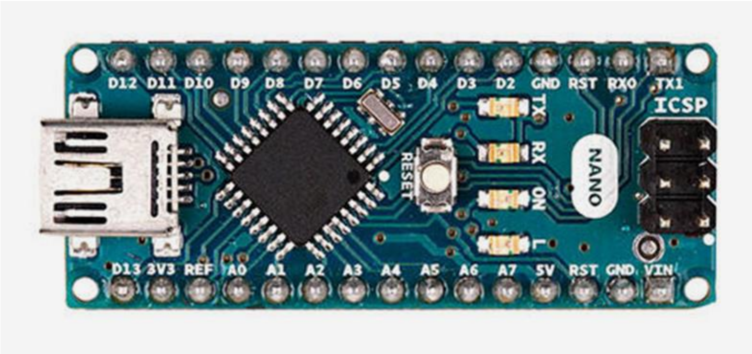


Figure 4.6 : Top-view of Arduino Nano [72]

4.4 Choice of Communication

Comfortable and active use of the user and their family members or their caregivers is as important to us as the design for electronic adult diapers. The status of the user using electronic adult diaper should be traceable. We will use wireless communication methods to monitor the status of the user and adult diapers instantly. For this purpose, Bluetooth and Wi-Fi communication methods will be used.

4.4.1 Bluetooth

Our purpose of using the Bluetooth method is for the use of electronic adult diapers when both the user and the person responsible for the user are in the same place, room or home. Although this method provides short distance communication, the bluetooth method provides an important advantage since it cannot be understood from the outside by the person responsible for taking care of the user when enuresis or defecation occured. We will use the H05 Bluetooth module to use the Bluetooth method in the SEAD (Figure 4.7).

Figure 4.7 : HC-05 Bluetooth Module [73]

HC-05 Bluetooth module communicates with SSP. It is designed for serial connection and is easy to use. It has a 2.4 GHz radio antenna. It supports Bluetooth 2.0. It provides a fast and reliable connection with CMOS technology (Figure 4.8) [74].

- Typical -80dBm sensitivity
- Up to +4dBm RF transmit power
- Low Power 1.8V Operation ,1.8 to 3.6V I/O
- PIO control
- UART interface with programmable baud rate
- With integrated antenna
- With edge connector

Figure 4.8 : Technical Specifications of HC-05 Bluetooth Module [74]

4.4.2 Wi-Fi

Our purpose of using the Wi-Fi method is to ensure that the user's status can be monitored at any time, regardless of location and time, from wherever there is the internet. This method is particularly advantageous when the caregiver or family members are not always close to the user. It provides an advantage for caregivers to intervene easily in environments with more than one person in need of care. In addition, family members who want to monitor the user's status, even remotely, will be able to follow the system data at any time.

We decided to use the ESP8266 module for Wi-Fi communication (Figure 4.9). ESP8266 is a small, low-cost and user-friendly Wi-Fi module. It provides a simple TCP/IP connection Arduino etc via Serial Port. It is easily programmable with a microcontroller. It is widely used in IoT projects, especially cloud-based and embedded projects [75].

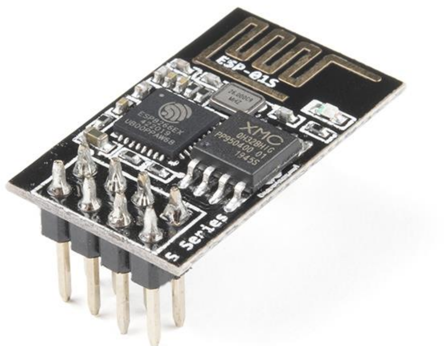


Figure 4.9 : ESP8266 Wi-Fi Module [76]

The ESP8266 Wi-Fi module can easily connect to the internet and exchange data. The module can be easily programmed via the Arduino IDE. We may share the data obtained within the system with third-party applications over the internet. In addition, the system can be controlled by taking direction over the internet.

ESP8266 Wi-Fi module can provide all Wi-Fi network features (Figure 4.10). With its internal memory, most projects can be realized without the need for external memory. It also provides an advantage for system performance. It realizes SPI communication and can be easily connected to Arduino etc. With its internal antenna, secure and fast communication can be made over the network without the need for an external antenna (Figure 4.11).

- 802.11 b / g / n
- Wi-Fi Direct (P2P), soft-AP
- Built-in TCP / IP protocol stack
- Built-in TR switch, balun, LNA, power amplifier and matching network
- Built-in PLL, voltage regulator and power management components
- 802.11b mode + 19.5dBm output power
- Built-in temperature sensor
- Support antenna diversity
- off leakage current is less than 10uA
- Built-in low-power 32-bit CPU: can double as an application processor
- SDIO 2.0, SPI, UART
- STBC, 1x1 MIMO, 2x1 MIMO
- A-MPDU, A-MSDU aggregation and the 0.4 Within wake
- 2ms, connect and transfer data packets
- standby power consumption of less than 1.0mW (DTIM3)

Figure 4.10 : Technical Specifications of ESP8266 Wi-Fi Module [77]

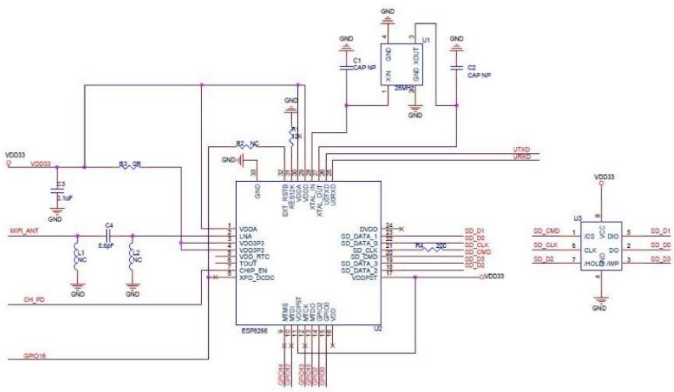


Figure 4.11 : Schematic View of ESP8266 Wi-Fi Module [77]

5. DESIGN PHASE OF SMART ELECTRONIC ADULT DIAPER

5.1 Hardware Design

5.1.1 Textile part of SEAD

The design of the electronic adult diaper is a system design in itself. As with every system design, it also has subsystems. The system consists of textile, sensor, processor, transmitter (Bluetooth or Wi-Fi module), battery and cable groups.

First of all, we use a standard adult diaper as a textile material. The aspects we pay attention to here are that the adult diaper has an absorbent and leakproof structure. We form the base of our project with a standard adult diaper. We will use an adult diaper that is reliable in terms of absorbency and impermeability, high quality in terms of comfort and is one of the best-selling adult diapers in the Turkish market. The adult diaper is one of the tape-attachment types (Figure 5.1) [78].

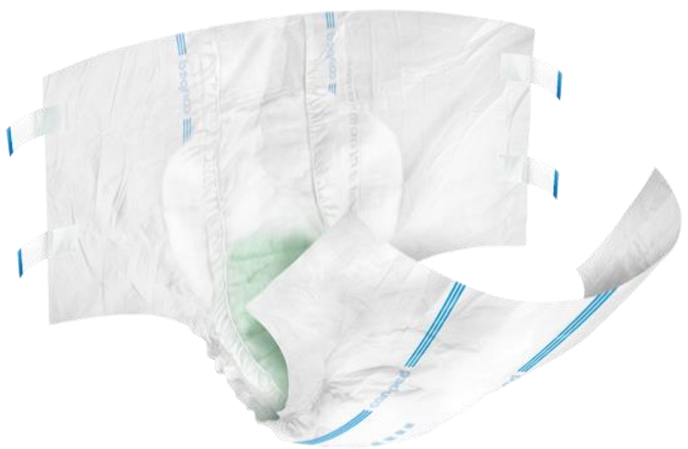


Figure 5.1 : Textile Part of SEAD [78]

5.1.2 Position of sensor

Secondly, DHT-11 temperature and humidity sensor is placed in the middle of the adult diaper, under the cottony surface (Figure 5.2). The reason for placing it in the middle part here is to ensure that it is unisex and to detect both urine and stool. The reason for placing it under the cottony bottom surface is to prevent the sensor from contacting both the user's skin and the urine or stool. Preventing the sensor from contacting the user's skin provides us with two advantages. The sweat that may occur as a result of the user's sweating can be perceived by the sensor as if urine has occurred. Moreover, the contact of the user's skin with the sensor may cause discomfort to the user. As a result of this discomfort, the user will want to remove this adult diaper. Especially unconscious people can remove the diaper without the caregivers or family members being aware. Here, we gain two advantages by preventing these two problems from happening.

Figure 5.2 : Placement of the Sensor

5.1.3 Connection of DHT-11 sensor

Thirdly, the transmission wires from the sensor to the Arduino Nano are placed. There are 3 different cables here. Two of them provide the operating voltage of the sensor and the other provides information transmission. VCC voltage (3.3 V) is connected to Pin 1 of DHT-11 and GND is connected to Pin 4 of DHT-11 to provide operating voltage. The Pin 2 of DHT-11 is used for information and provides input to the Arduino. The Pin 3 is the non-connected pin (Figure 5.3). Figure 5.4 shows the connection diagram of the DHT11 sensor to the Arduino Nano.

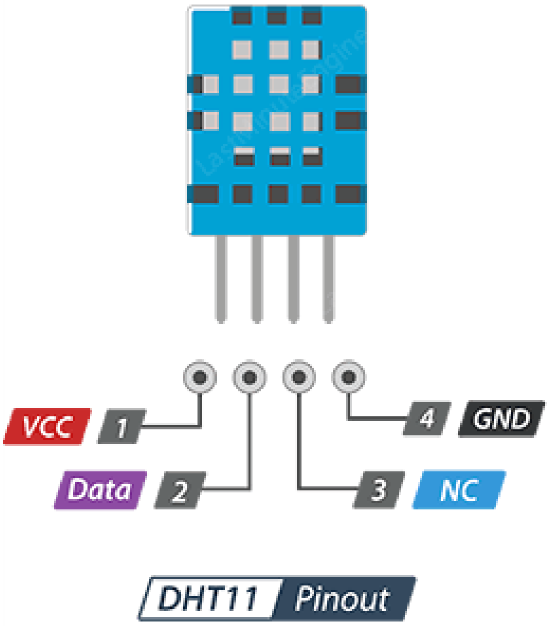


Figure 5.3 : Pinout diagram of DHT-11 [79]

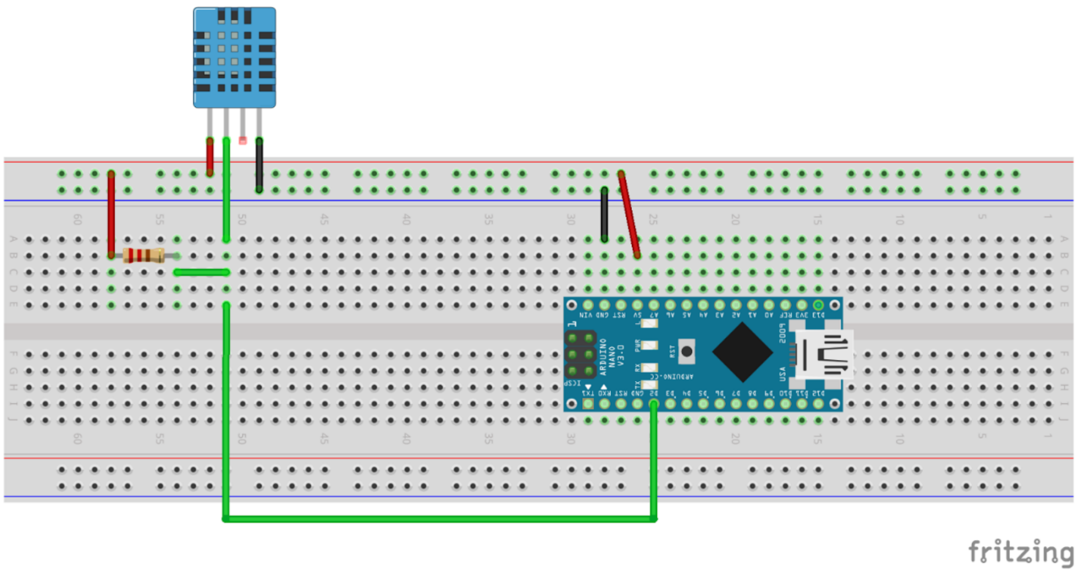


Figure 5.4 : Connection of DHT-11 [80]

It is also an important criterion to ensure reliability in the connections of the cables. In order to avoid the short circuit problem, the connection paths must proceed independently of each other. For this reason, connection cables are selected from silicon-coated insulated cables. This insulation also provides resistance against acidic urine and heat. Additional insulation has also been applied to the sensor at the connection points (Figure 5.5).

Figure 5.5 : Sensor and wires

5.1.4 Connection of bluetooth

Bluetooth is a communication protocol developed for short-distance communications, using the 2.4 - 2.48 GHz ISM band. Bluetooth modules (if there is no obstacle) provide a communication range of about 20 meters.

There are 4 pins on the Bluetooth module, namely VCC, GND, Rx and Tx (Figure 5.6). VCC and GND pins are used to feed the module. In order for the commands sent by the Arduino to be received by the Bluetooth module, the Tx pin of the Arduino must be connected to the Rx pin of the Bluetooth module. Likewise, in order to transfer the messages from Bluetooth to Arduino, Arduino's Rx pin must be connected to the Tx pin of the Bluetooth module. Figure 5.7 shows the connection diagram of the DHT11 sensor to the Arduino Nano.

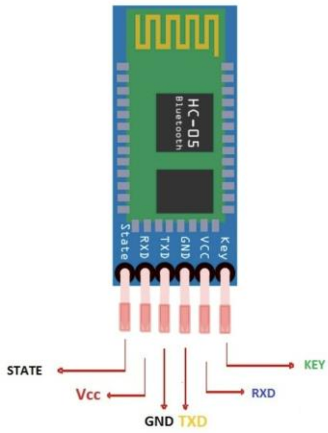


Figure 5.6 : Pinout of HC-05 Bluetooth Module [81]

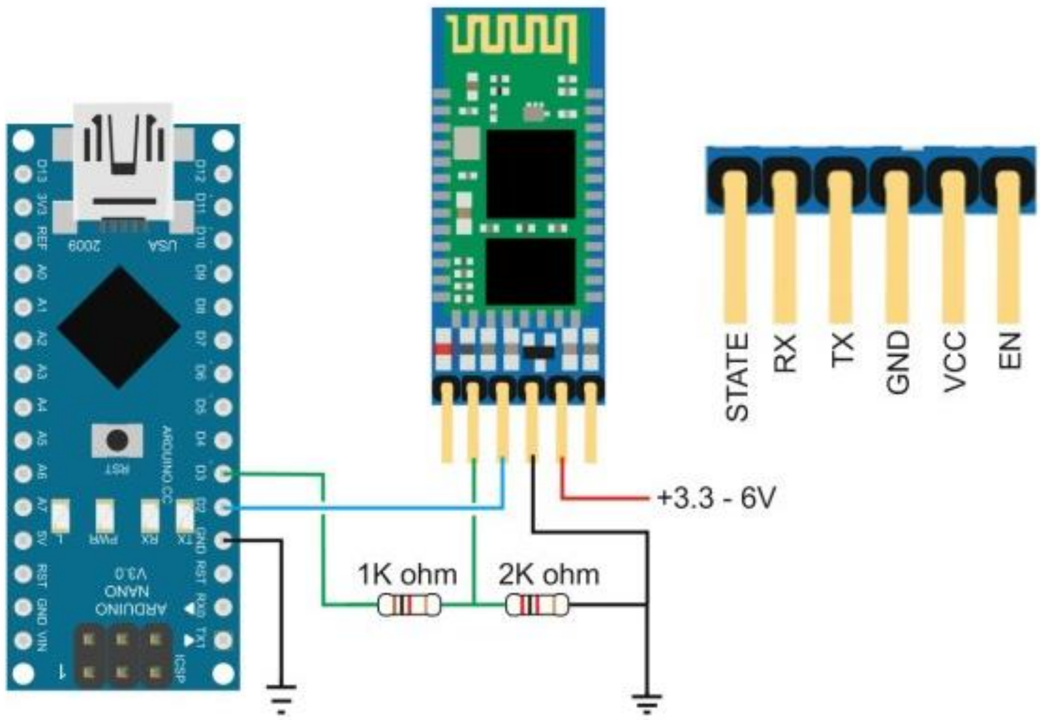


Figure 5.7 : Connection of HC-05 Bluetooth Module [82]

In order for Bluetooth modules to be connected to devices with Bluetooth features such as computers or phones, these devices must first be paired with the Bluetooth module. In smartphones, this process can be done like a normal phone pairing. After the pairing process is completed, we need intermediate programs that will enable the communication of smart devices via Bluetooth. Here we used the application called "Serial Bluetooth Terminal".

Since Arduino UNO has only one communication port, the Bluetooth module is connected to pins 10 and 11 of Arduino. The 'Software Serial' library is used to use these pins as serial ports. Bluetooth modules could also be connected to the Arduino's hardware serial port. But at that time, data could not be sent to the computer via the 'Serial Monitor' and these pins had to be removed every time programming was done.

5.1.5 Connection of wi-fi

It is necessary to connect the ESP8266 Wi-Fi Module according to the pinout diagram. ESP8266 module has 8 pins. In this project, we will use 5 out of 8 pins (Figure 5.8).

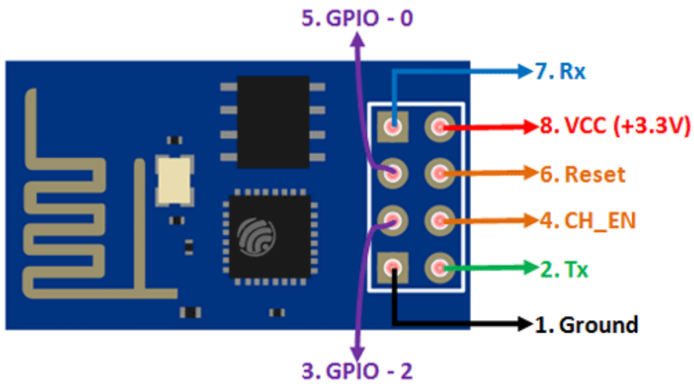


Figure 5.8 : Pinout Diagram of ESP8266 [83]

GND and VCC pins are used to feed the ESP8266 module. VCC voltage is 3.3 V. Tx and Rx pins are used to communicate with Arduino. We feed the CH_EN pin with 3.3 V to activate the chip. Because it needs to be "HIGH" to be active (Table 5.1).

Table 5.1 : ESP8266 Pinout Configuration [83]

Pin Number	Pin Name	Alternate Name	Normally used for	Alternate purpose
1	Ground	-	Connected to the ground of the circuit	-
2	TX	GPIO – 1	Connected to Rx pin of programmer/uC to upload program	Can act as a General purpose Input/output pin when not used as TX
3	GPIO-2	-	General purpose Input/output pin	-
4	CH_EN	-	Chip Enable – Active high	-
5	GPIO - 0	Flash	General purpose Input/output pin	Takes module into serial programming when held low during start up
6	Reset	-	Resets the module	-
7	RX	GPIO - 3	General purpose Input/output pin	Can act as a General purpose Input/output pin when not used as RX
8	Vcc	-	Connect to +3.3V only	-

Figure 5.9 shows the connection diagram of the ESP8266 module to the Arduino Nano.

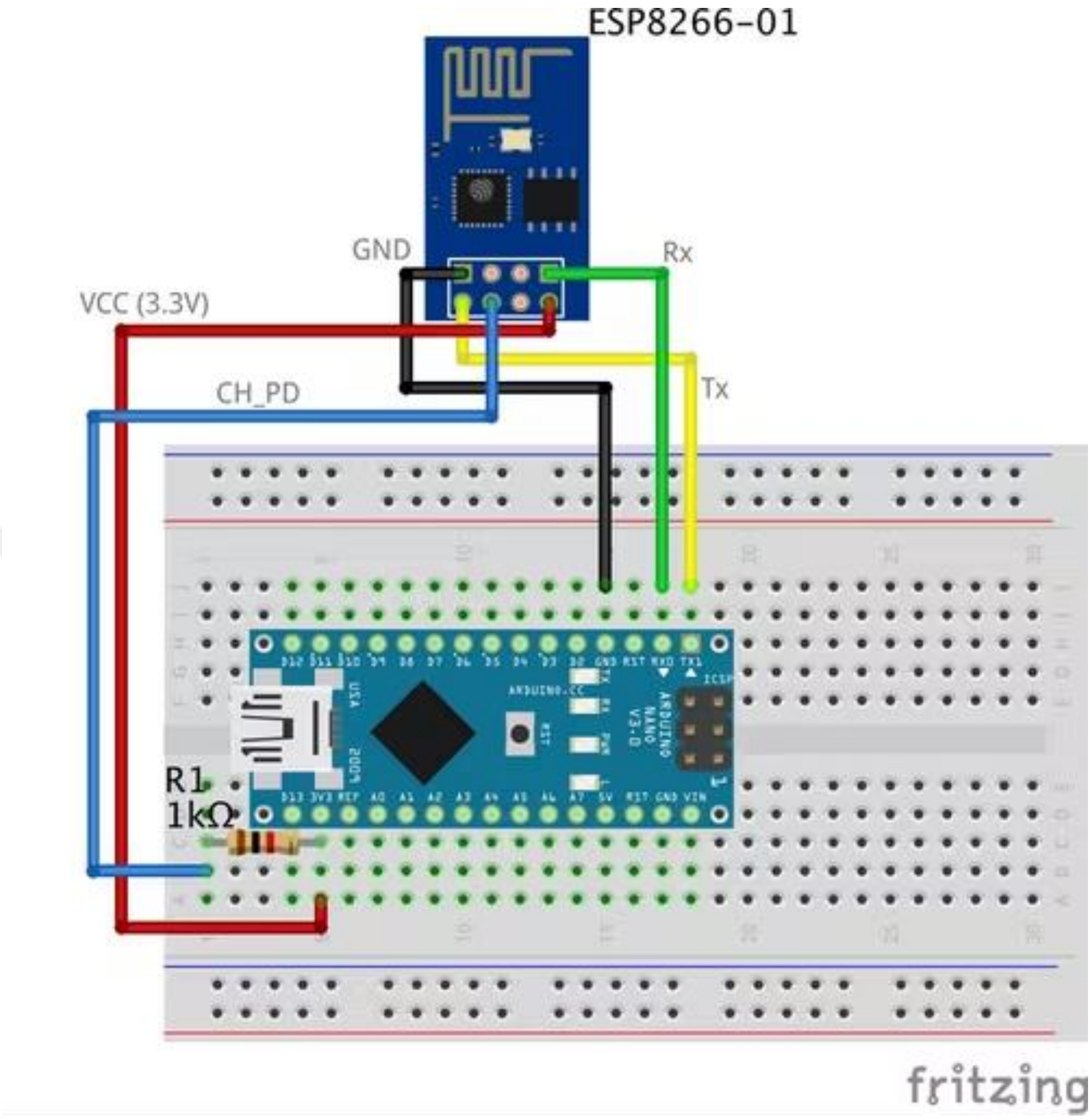


Figure 5.9 : Connection of ESP8266 Wi-Fi Module [84]

5.2 Software Design

Since we will use the Arduino board as a processor, we wrote the software with Arduino IDE (Figure 5.10). With the Arduino IDE, we can program any Arduino, as well as circuit boards from different companies. We can use Arduino IDE software in all operating systems.

5.2.1 Receiving data from DHT-11

Each sensor has a working diagram and this diagram needs to be transferred to the software. There are libraries for each sensor in the literature. In order to receive data from DHT11, first of all, the library of DHT11 must be added to the software. We add the library to the Arduino IDE software (Figure 5.11).

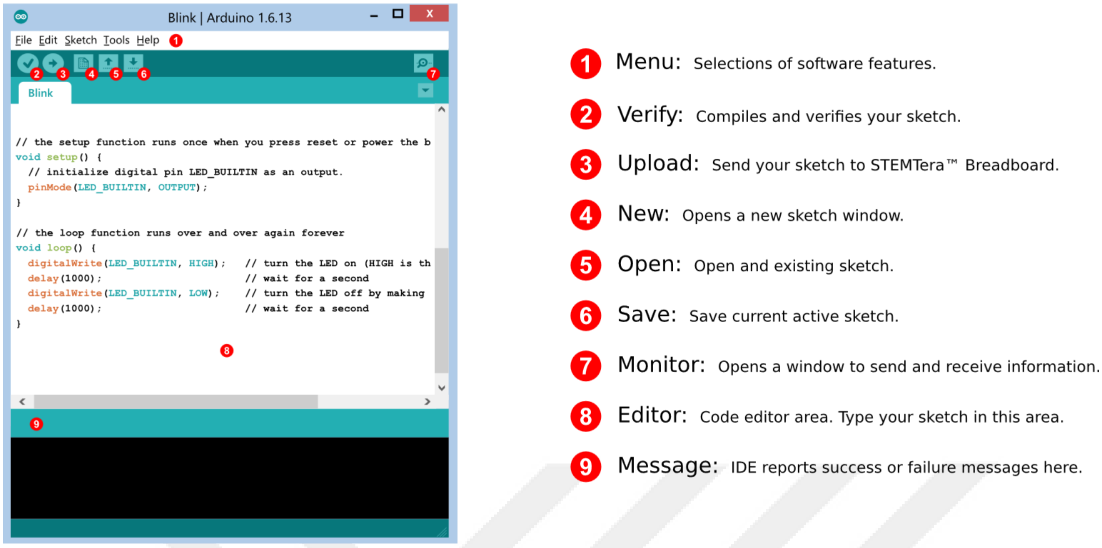


Figure 5.10 : Arduino IDE view and menu information [85]

The software required to receive data from the DHT11 sensor is simply shown in the figure below. Using the DHT11 library, this software converts the data received from the sensor to the temperature value in Celcius and the humidity value in the %RH unit so that we can understand it (Figure 5.12).

```
#ifndef DHT11_H_
#define DHT11_H_
#include <Arduino.h>
#define DHT11_RETRY_DELAY 1000  // 1000ms

class DHT11 {
    int pin;
    unsigned long last_read_time;
protected:
    byte readByte();
    unsigned long waitFor(uint8_t target, unsigned long time_out_us);
    void waitFor(uint8_t target);
public:
    DHT11(int pin_number);
    ~DHT11();
    int read( float& humidity, float& temperature);
};

#endif /* DHT11_H_ */
```

Figure 5.11 : DHT11 Library Codes

By constantly monitoring the humidity and temperature values obtained with the DHT11 sensor, when these values exceed the limit values, we can give various notifications or warnings depending on which value is exceeded. Even if any value does not exceed the limit values, information about the system will be given to the users or the caregiver instantly. This data will be able to be viewed and continuously monitored on a smartphone or computer screen (Figure 5.13).

```
#include <DHT11.h>
#include <SoftwareSerial.h>

int pin = 2;
DHT11 dht11(pin);


void setup() {
  // put your setup code here, to run once:
Serial.begin(9600);
Serial.println("Activated");

}

void loop() {
  // put your main code here, to run repeatedly:
float humidity;
float temperature;
int reading = dht11.read(humidity,temperature);

if (isnan(humidity) || isnan(temperature)){
  Serial.println("Sensorden veri okunamadi.");
  return;
}

Serial.print("Nem: ");
Serial.print(humidity);
Serial.println(" %\t");
Serial.print("Sicaklik: ");
Serial.print(temperature);
Serial.print(" *C");
Serial.println("\n");

delay(1000);

}
```

Figure 5.12 : DHT11 Sample Code

For example; when the person in need of care has urinated in the diaper, caregivers or family members will be alerted and information will be displayed on the screen of the computer. When urinary incontinence happens, a warning appears on the screen as "SEAD IS WET. PLEASE CHANGE" (Figure 5.14).

As another example; when the body temperature of the person in need of care rises, a warning can be sent to the caregivers or family members and information can be displayed on the screen of the computer. When the body temperature unexpectedly rises above normal body temperature, a warning appears on the screen "BODY TEMPERATURE IS HIGH. PLEASE CHECK" (Figure 5.15). On the other hand, instead of this situation, which is given as an example of the use of temperature data, we will use the temperature data value in SEAD's software to detect fecal incontinence. Wetness and humidity cannot be detected because there is no liquid in the absence of urine. In some cases, stool may occur without urine. In this case, we will be able to detect fecal incontinence from the temperature rise.

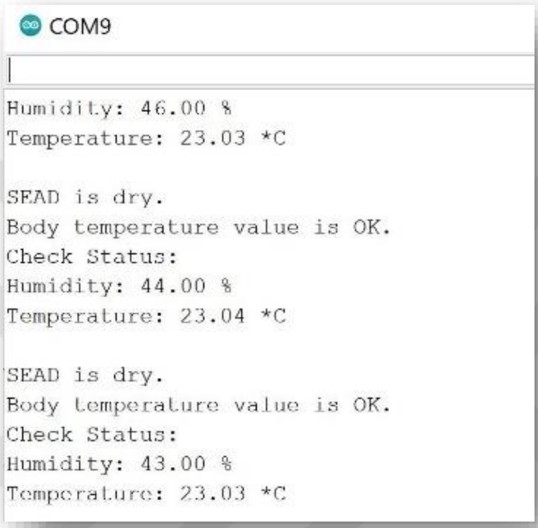


Figure 5.13 : Showed Information on the Screen

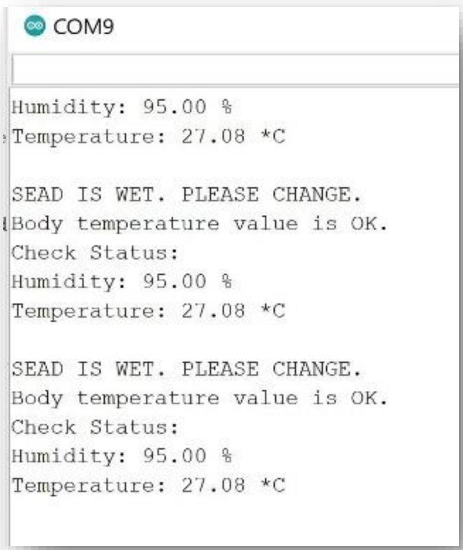


Figure 5.14 : Showed Information on the Screen (Urinary Incontinence)

Figure 5.15 : Showed Information on the Screen (High Body Temperature)

5.2.2 Sending information with bluetooth

"SoftwareSerial" library is used to communicate with Bluetooth. The *"SoftwareSerial"* library has been developed for boards with only one pair of Tx Rx pins, such as the Arduino Nano. With the help of this library, other pins of Arduino can be used as Tx and Rx. In order to use the *"SoftwareSerial"* library, we must first add this library to our project. This library is automatically created when the Arduino IDE is installed.

After adding the library to our code with the *"#include <SoftwareSerial.h>"* command, we can define the two pins we will choose as Rx and Tx. For this, *"SoftwareSerial bluetoothModule(10, 11)"* command is used. Here, a different variable name can be given instead of *"bluetoothModule"*. This variable is the object we will use to call serial communication functions. The numbers 10 and 11 written to the object setup show the pin numbers. For example, here pin 10 is defined as Rx and pin 11 is defined as Tx. Since the Rx and Tx pins are defined, we can operate on these ports. First of all, communication should be started with the command *"bluetoothModule.begin(9600)"*. Since it is sufficient to use this command once, it is sufficient to write it in the *setup* function. We use the "bluetoothModule.println" command for the data we will send to the mobile phone (Figure 5.16).

We can send all the data to the computer and ensure that the caregivers or family members have all the data and can track it. We will keep the data we send to the smartphone as limited as possible. Because sending the data to the smartphone as simply and clearly as possible will be more beneficial both in terms of user/caregiver experience and to prevent warnings from being overlooked. Sending too much data can make tracking difficult and cause warnings to be missed. Therefore, only information about the status of SEAD will be sent. Figure 5.17 shows the notifications sent to the smartphone when the SEAD is clean, urinary incontinence has occurred, and urinary/fecal incontinence has occurred, respectively.

```
...

#include <SoftwareSerial.h>
  // The library is added required for Bluetooth Communication.

SoftwareSerial bluetoothModule(10,11);
    // Bluetooth RX and TX pins are assigned to Pin 10 and 11 of Arduino.


...


void setup() {
  // put your setup code here, to run once:
Serial.begin(9600);
Serial.println("Activated");
    // Serial Communication has been adjusted so that data can be seen on the Serial Monitor.

bluetoothModule.begin(9600);
bluetoothModule.println("ACTIVATED");
    // Bluetooth Communication has been adjusted so that data can be seen on the Mobile Phone.



...
```

Figure 5.16 : Codes for Bluetooth Module

5.2.3 Sending information with wi-fi

"SoftwareSerial" library is also used to communicate with Wi-Fi. Because the *"SoftwareSerial"* library has been developed for boards with only one pair of *Tx Rx* pins, such as the Arduino Nano. We need the Tx and Rx pins for Wi-Fi communication. With the help of this library, other pins of Arduino can be used as Tx and Rx. "SoftwareSerial" library must be added to the software similar to the Bluetooth version.

After adding the library to our code with the *"#include <SoftwareSerial.h>"* command, we can define the two pins we will choose as Rx and Tx similar to the Bluetooth version. For this, *"SoftwareSerial esp(rxPin, txPin)"* command is used.

Communication should be started with the command *"esp.begin(115200)"*. Since it is sufficient to use this command once, it is sufficient to write it in the setup function. We use the *"esp.println"* command for the data we will send to the mobile phone or the computer.

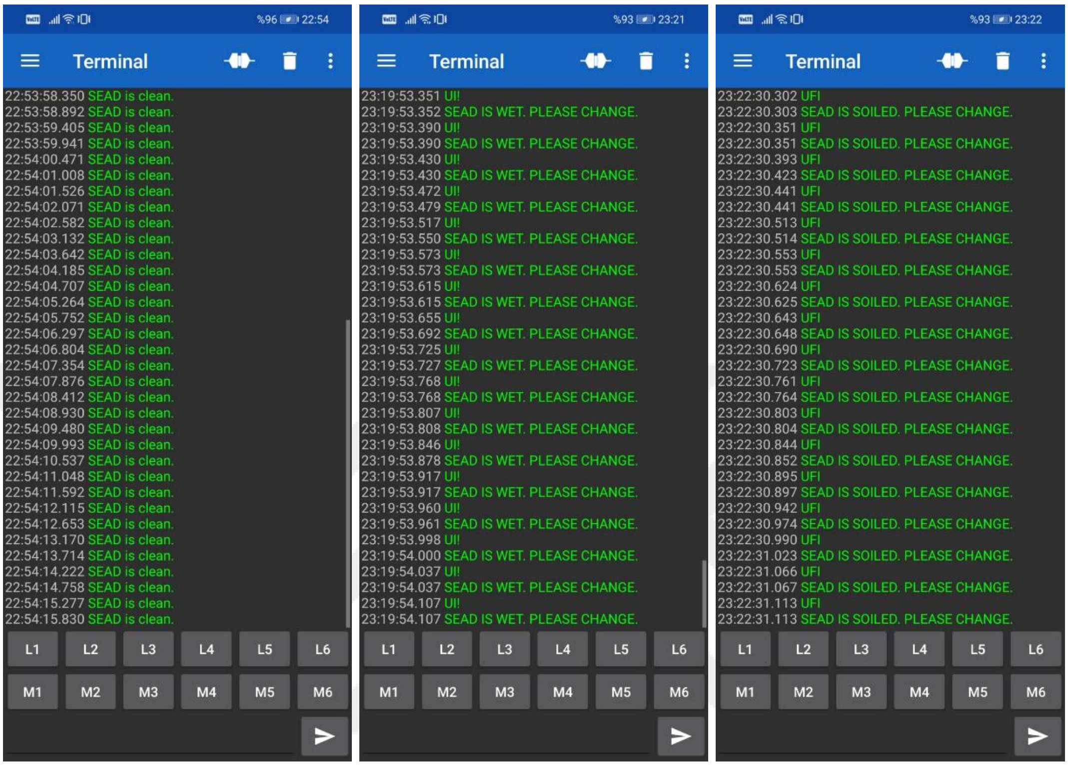


Figure 5.17 : Showed Information on the Mobile Phone Screen

Unlike the Bluetooth module, some special commands are used in the Wi-Fi module. We use these commands, called AT commands, in every step of communication over Wi-Fi. There are various commands assigned according to the desired purpose (Table 5.2, Table 5.3).

AT Commands of ESP8266 have four types:

- Test: to get the parameters of command and their range.
- Query: to return the present value of the parameters of a command.
- Set: to set the values of the parameters in the commands and also run the commands.
- Execute: to run the commands without parameters.

Table 5.2 : AT Commands Classification

Command Type	AT Command Format	Function
Test	AT+TEST=?	Returns value range of parameters
Query	AT+TEST?	Returns current value
Set	AT+TEST=parameter1, parameter2, …	Set configuration
Execute	AT+TEST	Executes an action

The ESP8266 AT Commands Set is divided into three categories. They are:

- Basic AT Commands
- WiFi AT Commands
- TCP/IP AT Commands

There are a total of 88 AT Commands for ESP8266 WiFi Module.

Table 5.3 : Some of ESP8266 AT Commands

Commands	Description	Type
AT+RST	restart the module	Basic
AT+CWMODE	wifi mode	Wi-Fi
AT+CWJAP	join the AP	Wi-Fi
AT+CWLAP	list the AP	Wi-Fi
AT+CWQAP	quit the AP	Wi-Fi
AT+ CWSAP	set the parameters of AP	Wi-Fi
AT+ CIPSTATUS	get the connection status	TCP/IP
AT+CIPSTART	set up TCP or UDP connection	TCP/IP
AT+CIPSEND	send data	TCP/IP
AT+CIPCLOSE	close TCP or UDP connection	TCP/IP
AT+CIFSR	Get IP address	TCP/IP
AT+ CIPMUX	set mutiple connection	TCP/IP
AT+ CIPSERVER	set as server	TCP/IP

The AT commands required for Wi-Fi communication will be added to the software in order. First of all, we send the information that we will start the AT commands to the ESP8266. At the same time, we are sending information to the Serial Monitor to see if these commands have been processed or not.

esp.println("AT");

Serial.println("AT was sent");

We wait until the module is ready. Here, a while loop is used to continuously send the *"esp.println("AT")"* command until the ESP8266 is found. When ESP8266 is found, it exits the while loop and goes to the next step.

```
while(!esp.find("OK")){
    esp.println("AT");
    Serial.println("ESP8266 Not Found.");
}
Serial.println("OK command received.");
```

In the next step, we set the ESP8266 module as a client. Similarly, a while loop is used to wait until the setting is done.

```
esp.println("AT+CWMODE=1");
while(!esp.find("OK")){
    esp.println("AT+CWMODE=1");
    Serial.println("Setting Up....");
}
Serial.println("ESP8266 set as client");
```

In the next step, we send the necessary command to connect to the network. Likewise, it waits until it connects to the network.

```
Serial.println("Connecting to the Network...");
esp.println("AT+CWJAP=\""+agAdi+"\",\""+agSifresi+"\"");
while(!esp.find("OK"));
Serial.println("Connected to the network.");
```

AT commands up to this point were setup commands. The next AT commands will be in the loop and will send the data to the phone or computer when it receives data.

We need to use a third-party application to send it to the phone or computer. Here we will share the data through the "ThingSpeak" application. For this, the necessary connection commands are sent and waited until it is connected. If it does not connect the error message is sent to the Serial Monitor.

```
esp.println("AT+CIPSTART=\"TCP\",\""+ip+"\",80");
if(esp.find("Error ")){
        Serial.println("AT+CIPSTART Error");
 }
```

Required commands are written to send the data received from the sensor to the ThingSpeak application. The data is collected from the sensor as a data packet. When the data packet is complete, it is sent to the application. To create a new data packet, the connection is disconnected and the loop starts again.

```
String veri =
"GET https://api.thingspeak.com/update?api_key=J9LK6YOUH88F3QGC";
veri += "&amp;field1=";
veri += String(temperature);
veri += "&amp;field2=";
veri += String(humidity);
veri += "\r\n\r\n";
esp.print("AT+CIPSEND
 esp.println(veri.length()+2);
delay(2000);
if(esp.find("&gt;")){
        esp.print(veri);
        Serial.println(veri);
        Serial.println("Data sent.");
        delay(1000);
}
 Serial.println("Connection Closed.");
esp.println("AT+CIPCLOSE");
delay(1000);
```

When we look at the account created for the system in the ThingSpeak application, we can instantly follow the data received from the sensor (Figure 5.18).

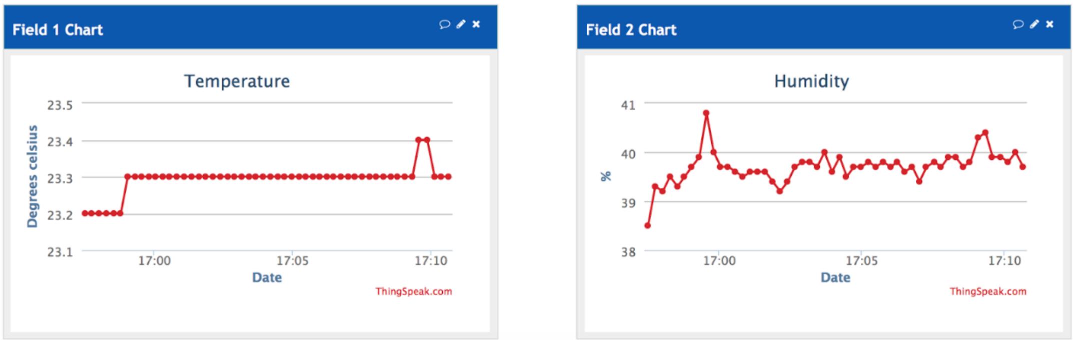


Figure 5.18 : Showed Information on the Computer Screen [86]

5.3 Algorithm Design

To create the working diagram of SEAD, we also need to design an algorithm. Algorithm design is as critical as hardware and software to have a reliable and stable system.

At this stage, we are designing what data and/or warnings SEAD will send to users and family members/caregivers in which conditions. Different warnings and different data will be sent depending on the presence of urinary incontinence and fecal incontinence. Likewise, the scope of the data to be sent while the diaper is clean will also be different. In addition, the scope of the data will differ depending on whether the data is sent to the computer or smartphone. We can share all of the data over the computer so that data can be collected on the computer and all records can be monitored. However, data and warnings to be sent to smartphones should be as simple and understandable as possible. Otherwise, warnings to be sent by SEAD may be overlooked due to overinforming and it may be late for a diaper change.

We have simply summarized the algorithm diagram we have designed as shown in Figure 5.19.

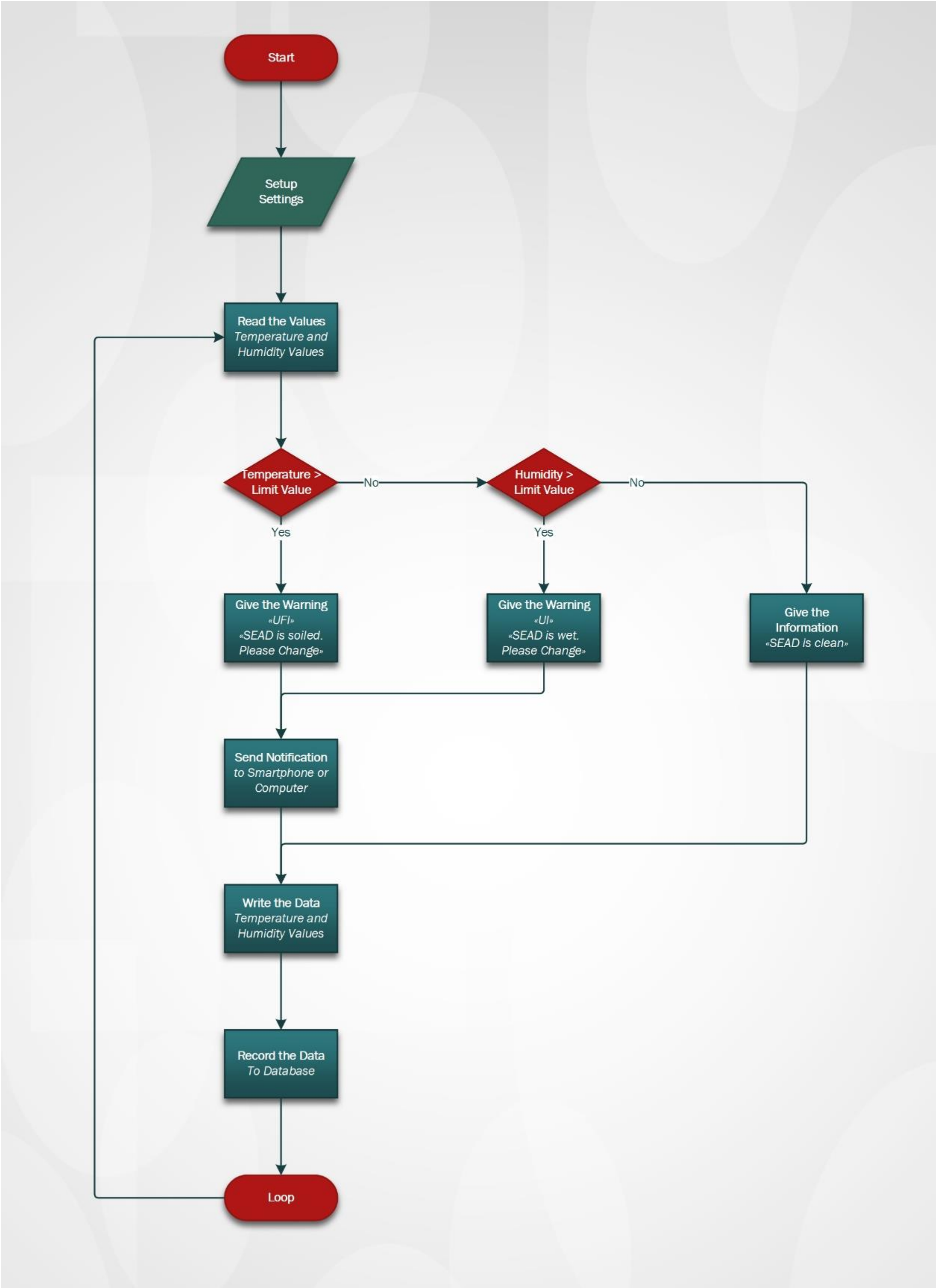


Figure 5.19 : Algorithm Design of SEAD

6. TESTS

We need to run tests to ensure the reliability and performance of the Smart Electronic Adult Diaper we designed. We do not need to set up an external test set-up for this because we will test the system as a whole. We will be using the same design structure, hardware and software to test the system. We will use Bluetooth for communication.

To test the system, we will run the same tests we did in the pre-tests section. So we will test the system with three different liquids (water, saline solution, urine) in three different volumes (50 ml, 100 ml, 250 ml). We will observe their response times and stability during testing. Afterwards, we will discuss the advantages and disadvantages of the system by comparing the performance of our design with the performance of other sensors mentioned in the pre-tests.

6.1 Test Results of SEAD

6.1.1 Signal value

Firstly we want to analyse the SEAD's response to all liquids. It is critical for SEAD to provide stable and reliable data for the detection of urinary/fecal incontinence. It will also enable us to discover the properties of the system, which reacts to each liquid.

The signal output values obtained as a result of the tests can be followed both on the computer screen and the phone screen via Bluetooth. The obtained signal output values have continued to be measured for five minutes, and the course of the values has been examined in terms of stability and reliability. During this period, since the signal output values give a stable and reliable value after the first 10 seconds, the progress of the signal output value during the first minute is shown in the figures.

The first step of SEAD's tests was carried out starting with the water tests (Figure 6.1). 50 ml, 100 ml and 250 ml volumes of water were used in the tests. The following figures show the signal output values obtained from both the computer screen and the smartphone screen.

Figure 6.1 : SEAD Signal Value in Tests with Water

As can be seen from the figures, wetting can be detected in less than 7,09 seconds in tests performed with water. As mentioned earlier, in the case of urinary/fecal incontinence, the reaction time is desired to be as short as possible and 10 seconds is considered the maximum acceptable time. The fact that SEAD reacts even against water in less than 10 seconds demonstrates that SEAD can respond quickly. Moreover, the detection is stable and reliable, regardless of volume. The fact that the obtained signal output value does not experience any instability shows the reliability of the

SEAD design. More importantly, SEAD can detect water, while previously tested sensors cannot detect water. As it is known, the reason why we used water in the tests has been to test whether the urine with low conductivity could be detected, since the pH and conductivity of the urine can change in case of some health problems. These results show us that even if the urine has low conductivity, SEAD can detect urinary incontinence.

In the next step, salt solution tests were applied to SEAD (Figure 6.2). Salt solutions in volumes of 50 ml, 100 ml and 250 ml were used in the tests. The received signal output values are shown in the figures below from both the computer screen and the smartphone screen.

As can be seen from the figures, wetting can be detected in less than 6,5 seconds in tests performed with the salt solution. The fact that SEAD also reacts to salt solution in less than 10 seconds shows that SEAD can also react quickly to liquids with high conductivity. Moreover, the detection is stable and reliable regardless of the volume. The fact that the obtained signal output value does not experience any instability shows the reliability of the SEAD design against artificial urine. As it is known, the reason why we used salt solution in the tests was to test whether urine could be detected by creating artificial urine. These results show us that SEAD can detect urinary incontinence.

In the previous part of the thesis study, we performed pre-tests to compare the sensor and system studies in the literature. When we compare the results of the tests we performed with the salt solution in these pre-tests with the SEAD results, Figure 6.3 is obtained.

As can be seen from the figures, SEAD seems to be more advantageous than other sensor types in terms of reliability and stability. Although they show similar and close performance in salt solutions used in 100 ml and 250 ml volumes, the performance difference of the sensors in salt solutions used in 50 ml volumes is obvious. As it is known, the reason why we used the volume of 50 ml for liquids in the tests has been to test whether low volumes of urine could be detected, since the amount of urine may decrease because of some health problems. These results show us whether urinary incontinence can be detected when there is low urine volume. In the tests performed using 50 ml of salt solution, we see that the sensors either respond late or are unstable or both in other tests other than (a) and (e). This shows that SEAD is more stable and reliable compared to other sensors. It is very important for the health of users suffering from urinary/fecal continence that the sensor and system provide fast warning and stable and reliable data.

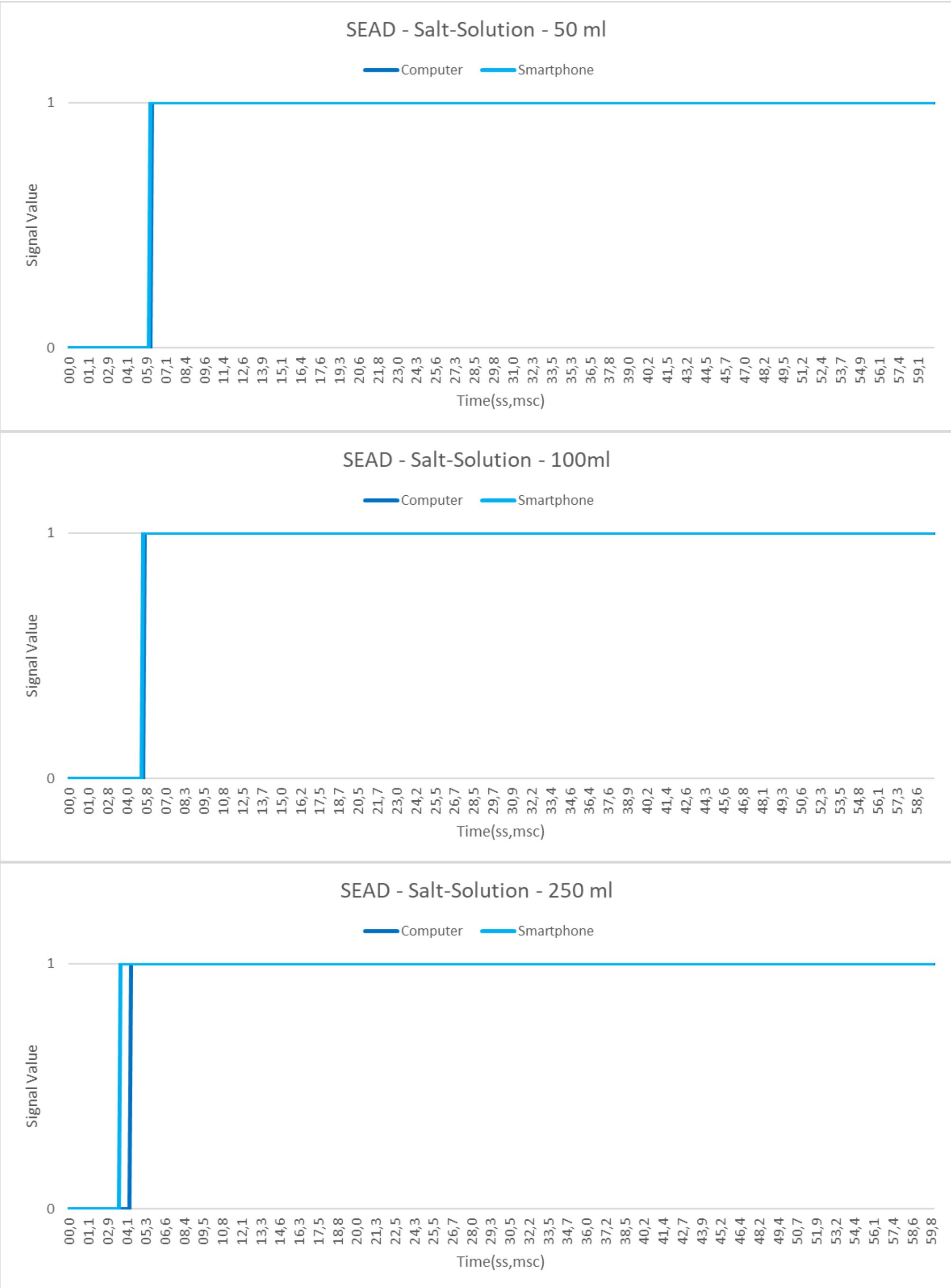


Figure 6.2 : SEAD Signal Value in Tests with Salt Solution

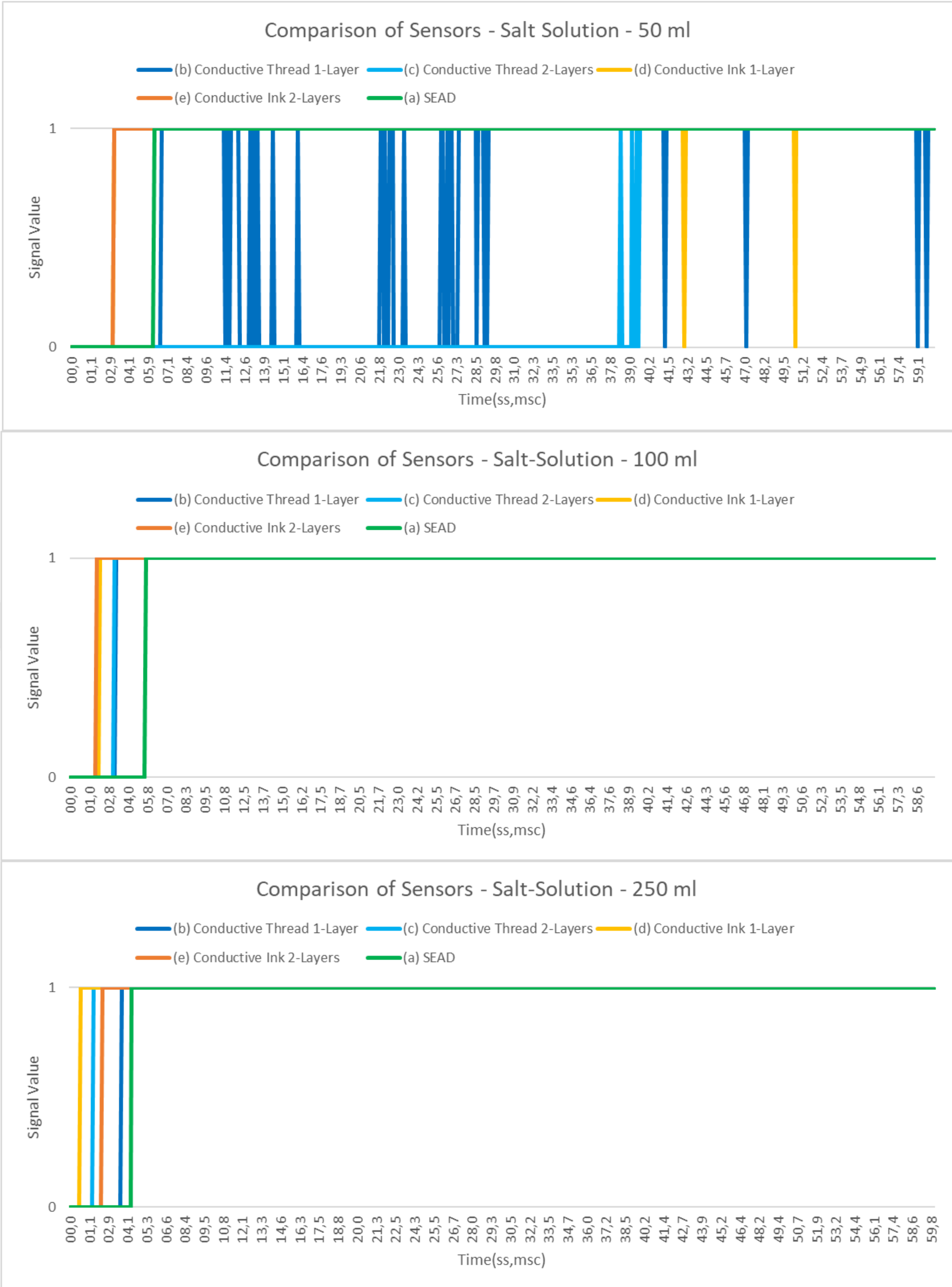


Figure 6.3 : Comparison of Signal Values in Tests with Salt Solution (a) SEAD (b) Conductive Thread 1-Layer (c) Conductive Thread 2-Layers (d) Conductive Ink 1-Layer (e) Conductive Ink 2-Layers

In the last step of the tests, real urine tests were applied to the SEAD. Urine volumes of 50 ml, 100 ml and 250 ml were used in the tests. The received signal output values are shown in Figure 6.4 from both the computer and the smartphone screen.

Figure 6.4 : SEAD Signal Value in Tests with Urine

As can be seen from the figures, wetting can be detected in less than 4,67 seconds in tests performed with real urine. The fact that SEAD also reacts to urine in less than 10 seconds shows that SEAD can also react quickly to real urine. In addition, the detection is stable and reliable regardless of the volume. The fact that the obtained signal output value does not experience any instability shows the reliability of the SEAD design against real urine. As it is known, the reason why we used real urine in the tests was to see if real urine would have a different effect on the sensor and the system in case of urinary incontinence and to test whether real urine could be detected. These results show us that SEAD can detect urinary incontinence in actual use.

Considering all the results in the tests, it is clear that SEAD has successfully passed the tests in all liquid types and all liquid volumes used.

Considering the real urine, comparing the test results of other sensors in the pre-tests and the test results of SEAD is very important in terms of enabling us to see the advantages or disadvantages of SEAD (Figure 6.5). When we compare the results of the tests we perform with urine with the SEAD results, the following figures are obtained.

As can be seen from the figures, SEAD seems more advantageous in real urine tests than other types of sensors in terms of reliability and stability. Against the urine used in 100 ml and 250 ml volumes, SEAD, (c), (d) and (e) have shown similar and close performance. Against the urine of 50 ml, SEAD, (d) and (e) have shown similar and close performance. In other tests, we see that the reactions of the sensors are both late and undecided. Considering these results, it shows that SEAD is stable and reliable in actual use compared to other sensors. It is very important that the sensor and the system provide fast warning, stable and reliable data in actual use for users suffering from urinary/fecal continence.

Considering all the results in all comparisons, it is seen that SEAD has more reliable and more stable results in all types of fluids used and all the liquid volumes used than other sensors.

As it is known, we also compared the response times of the sensors in the literature in the pre-tests. In this section, we will compare the response times of SEAD according to fluid types and fluid volumes.

Firstly, when we compare the response times according to the types of fluids used in the tests, we see that the SEAD responds more quickly to urine, even though there is not a critical difference between the response times (Figure 6.6). This shows that SEAD can react faster in actual use.

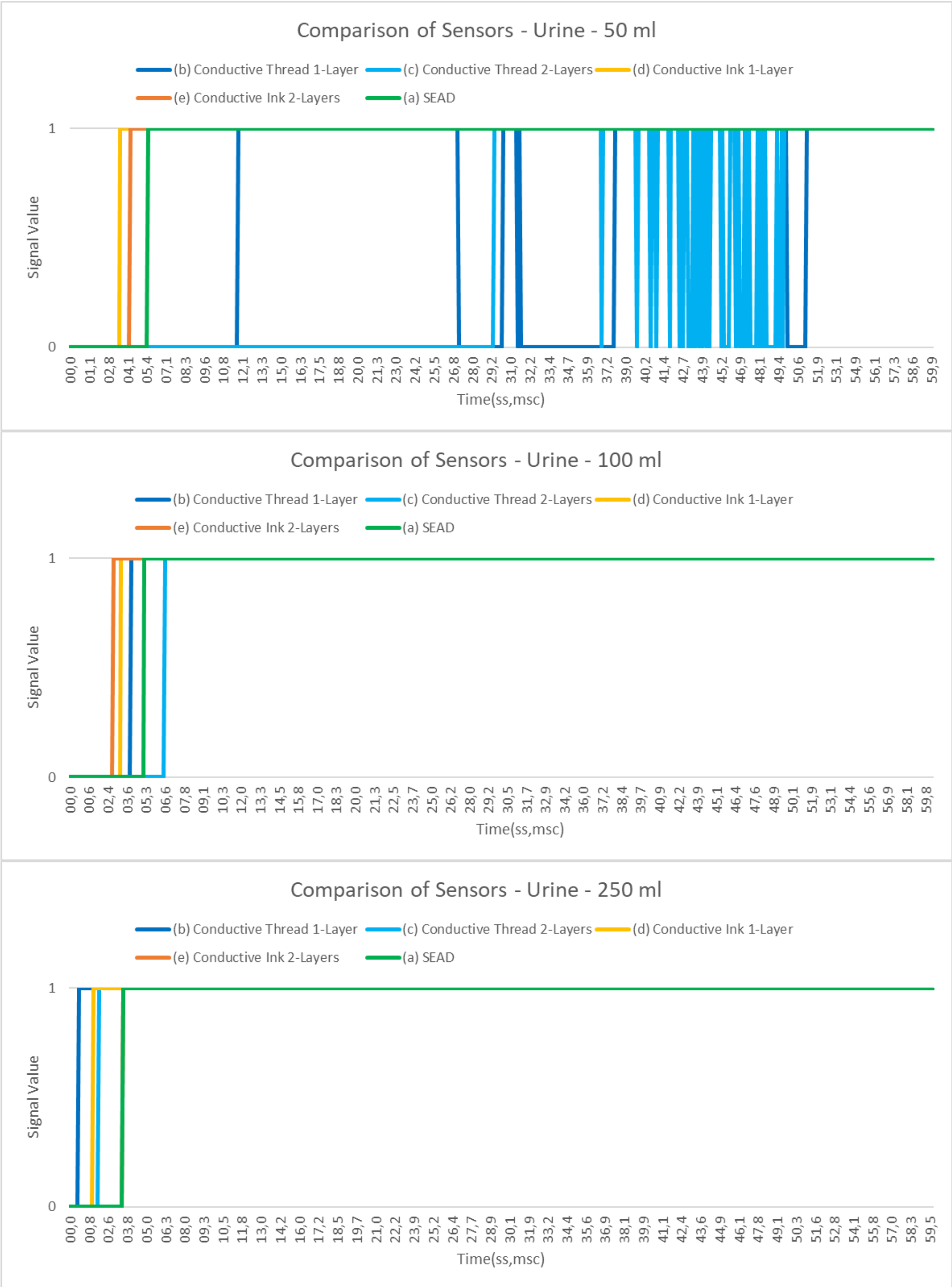


Figure 6.5 : Comparison of Signal Values in Tests with Urine (a) SEAD (b) Conductive Thread 1-Layer (c) Conductive Thread 2-Layers (d) Conductive Ink 1-Layer (e) Conductive Ink 2-Layers

Secondly, when we compare the response times according to the volumes of fluid used in the tests, we see that the SEAD responds faster as the volume of fluid increases, even though there is no critical difference between the response times (Figure 6.7). The higher the amount of liquid while passing through the absorbent surface, the faster humidity reaches the sensor, and the less it is, the later moisture reaches the sensor. In addition, although 50 ml is quite low as liquid volume, the SEAD can respond quickly in under 10 seconds. As is known, we have determined that the sensors in the literature responded over 10 seconds in the pre-tests. SEAD seems to be more advantageous in this respect as well.

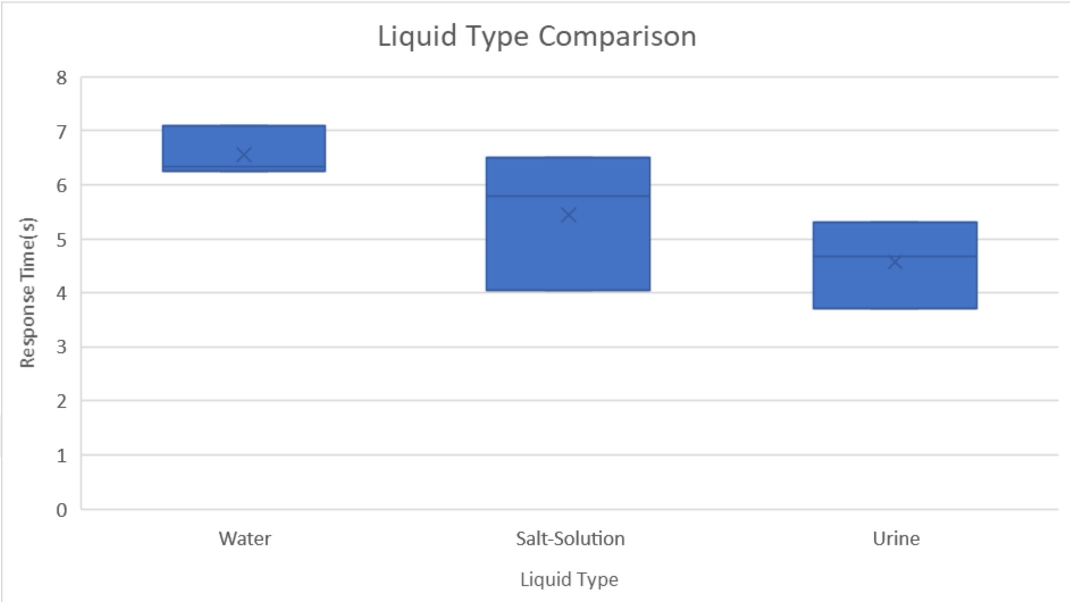


Figure 6.6 : Comparison of SEAD's Response Times by Fluid Type

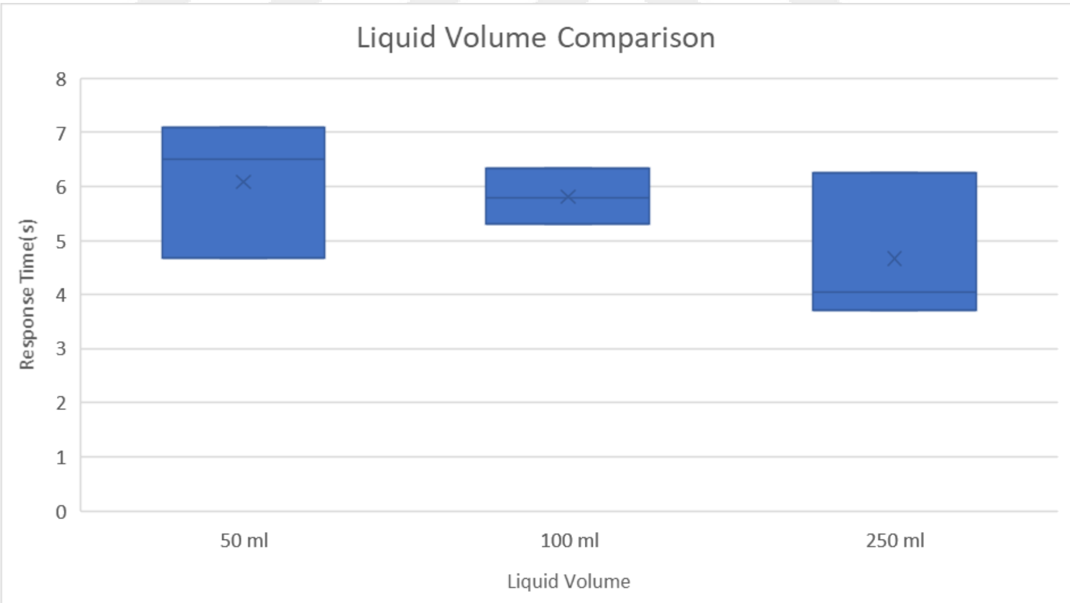


Figure 6.7 : Comparison of SEAD's Response Times by Fluid Volume

When we compare the response times in the tests done so far, we see that SEAD performs close to the sensors in the literature (Figure 6.8, Table 6.1). However, we also see here that it is not correct to comment only by looking at the response times. When we went into the details of the tests and made detailed comparisons, we confirmed that SEAD was more reliable and stable. The most obvious detail in the comparison shown in the figure below is that while other sensors in the literature cannot detect water, SEAD can detect it and do this in less than 10 seconds. Although the content and characteristics of the urine may change due to any health problem, SEAD will be able to detect urinary incontinence. Moreover, if stool occurs in liquid form due to any health problem, SEAD will be able to detect fecal incontinence.

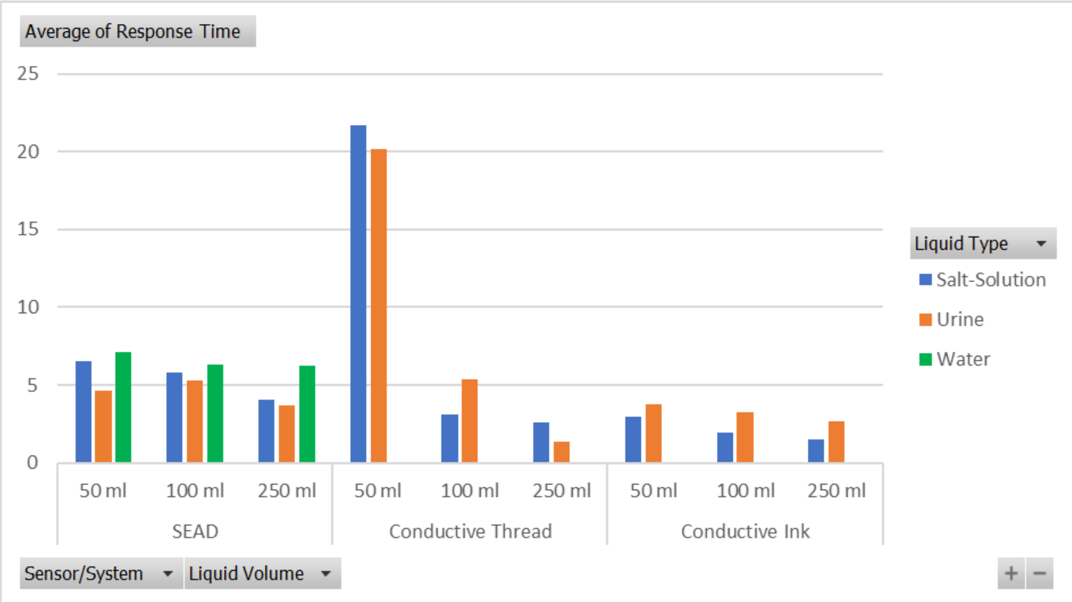


Figure 6.8 : Comparison of Average of Response Times

6.1.2 Humidity and temperature values

One of the advantages of SEAD over other smart diapers is that we can receive both temperature and humidity data. Humidity and temperature data can be accessed from both the computer screen and the smartphone screen. In this way, both humidity and temperature data can be followed, and also fecal incontinence can be detected in addition to urine incontinence.

When the humidity or temperature values exceed a specified threshold value, SEAD gives an alarm. If the humidity value rises above the threshold value, urinary incontinence is detected. If the temperature value rises above the threshold value without the humidity value rising above the threshold value, then fecal incontinence is detected.

In the tests performed, in addition to the signal output value, we also collected humidity and temperature data. Since we used liquids in the tests, we have expected an increase in humidity values. However, we did not expect the temperature data to change much as the tests took place in ambient conditions.

Table 6.1 : Response Times of Sensors

Test No	Sensor/System	Liquid Type	Liquid Volume	Response Time (sec,msec)
1	Conductive Thread 1-Layer	Water	50 ml	-
2			100 ml	-
3			250 ml	-
4		Salt Solution	50 ml	6,200
5			100 ml	3,096
6			250 ml	3,523
7		Urine	50 ml	11,483
8			100 ml	4,238
9			250 ml	0,694
10	Conductive Thread 2-Layers	Water	50 ml	-
11			100 ml	-
12			250 ml	-
13		Salt Solution	50 ml	37,123
14			100 ml	3,074
15			250 ml	1,691
16		Urine	50 ml	28,818
17			100 ml	6,544
18			250 ml	2,097
19	Conductive Ink 1-Layer	Water	50 ml	-
20			100 ml	-
21			250 ml	-
22		Salt Solution	50 ml	2,962
23			100 ml	2,077
24			250 ml	0,766
25		Urine	50 ml	3,430
26			100 ml	3,502
27			250 ml	1,654
28	Conductive Ink 2-Layers	Water	50 ml	-
29			100 ml	-
30			250 ml	-
31		Salt Solution	50 ml	2,965
32			100 ml	1,854
33			250 ml	2,217
34		Urine	50 ml	4,114
35			100 ml	3,057
36			250 ml	3,706
37	SEAD	Water	50 ml	7,090
38			100 ml	6,330
39			250 ml	6,241
40		Salt Solution	50 ml	6,501
41			100 ml	5,779
42			250 ml	4,042
43		Urine	50 ml	4,665
44			100 ml	5,314
45			250 ml	3,719

The measurement data obtained in the tests performed with water and salt solution are shown in Figure 6.9 and Figure 6.10. As can be seen, shortly after the liquid began to pour into the SEAD, the humidity value increased rapidly. A warning is given when the humidity value exceeds the threshold value. On the other hand, the temperature data did not change much but gradually decreased. The reason for this is that the temperature of the liquids used was lower than the ambient temperature.

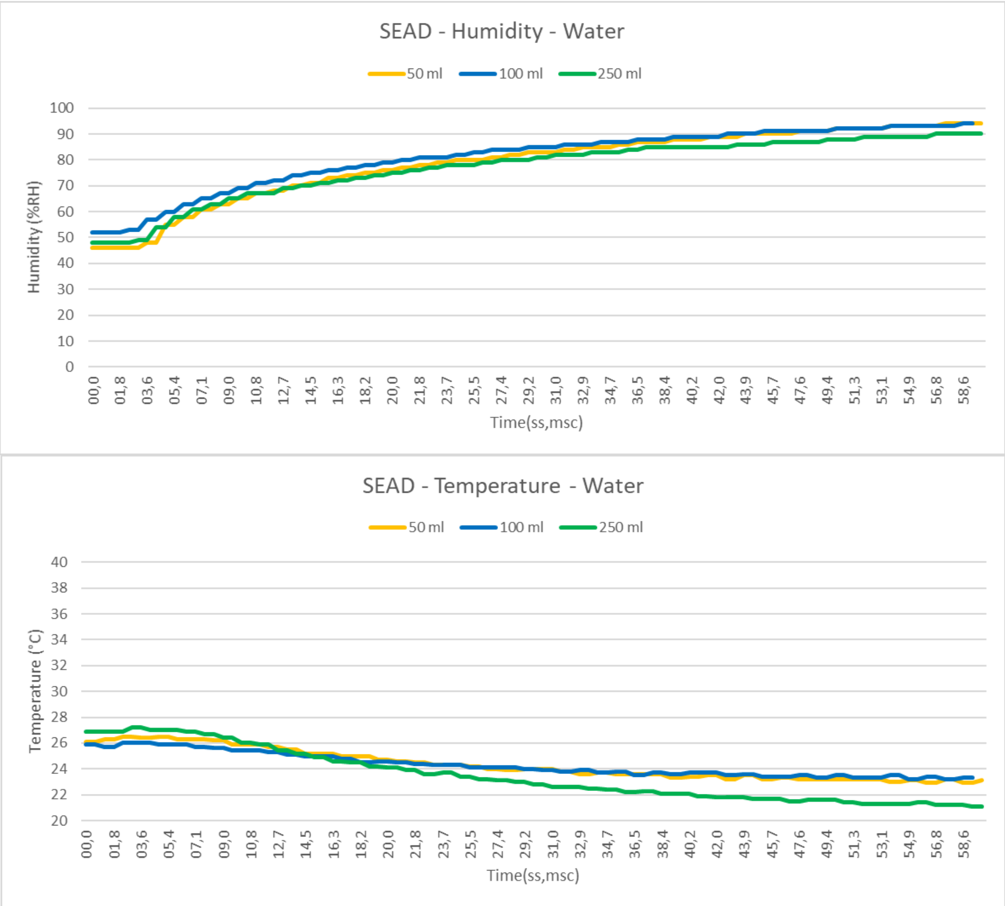


Figure 6.9 : SEAD Humidity and Temperature Values in Tests with Water

Measurement data obtained in tests performed with urine are shown in Figure 6.11. Likewise, shortly after the urine began to pour into the SEAD, the moisture value increased rapidly. A warning is given when the humidity value exceeds the threshold value. On the other hand, the temperature data did not change much but increased gradually. In fact, the urine temperature is higher than the temperature values shown in the graphs. Since the urine is not poured into the SEAD as soon as it leaves the body, and the urine is kept at ambient temperature for a short time in containers of specified volumes, the temperature increase seems to be at a low level. However, the observation of this temperature increase shows that we can follow the urine temperature in actual use.

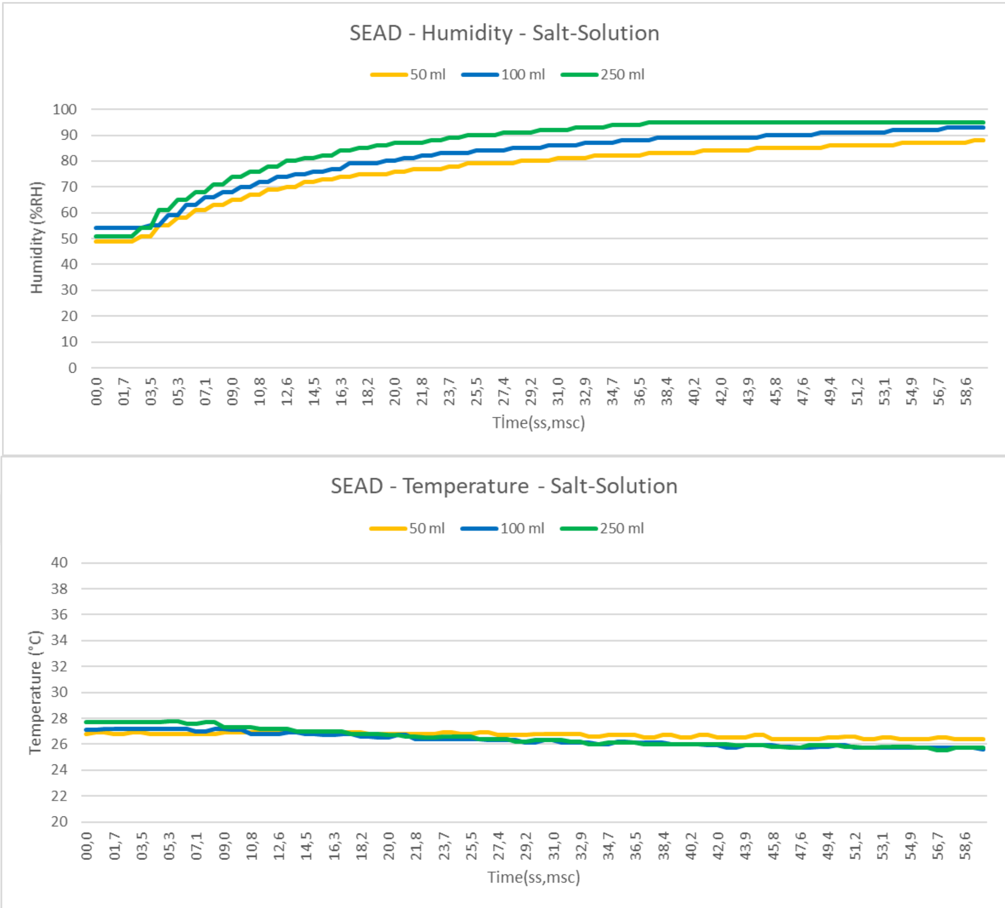


Figure 6.10 : SEAD Humidity and Temperature Values in Tests with Salt Solution

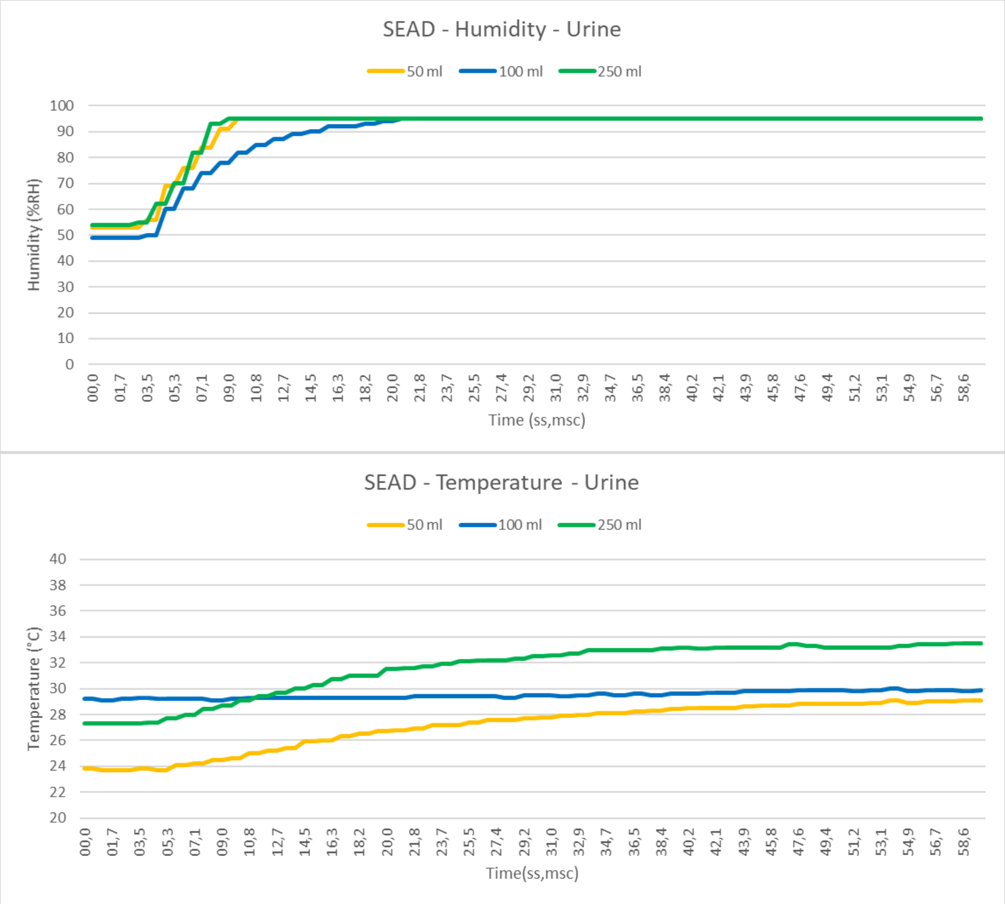


Figure 6.11 : SEAD Humidity and Temperature Values in Tests with Urine

7. DECIDING ON LIMIT VALUES

With SEAD, we can obtain both temperature and humidity data, and we can perform some operations according to these values. Well, what should our limit values be?

In order to determine the limit values, we first need to know the normal condition values reflected on our sensor. Since the sensor is located at the bottom of the diaper and behind the cotton structure, the reflected temperature value will be lower than the body temperature. Thanks to the cotton structure in between, the moisture created by the sweat in the body stays away, so the moisture values reflected on the sensor will be lower than the body. On the other hand, since the sensor is inside the adult diaper and also inside the clothes, the humidity and temperature values reflected on the sensor will be higher than the outdoor ambient conditions. Moreover, considering that bedridden patients are constantly lying down and the sensors are stuck between the bed and the body, it can be predicted that the temperature values reflected on the sensor will increase. For all these reasons, it is critical to determine limit values so that the sensor does not send wrong warnings.

In order to compare the values reflected on the body and the sensor, we first measured the body values. We placed our sensor attached to the body. We also ensured that the sensor was stuck between the bed and the body to ensure the worst condition. After the measurements we took for half an hour, we got Figure 7.1. As can be seen from the figure, humidity and temperature values can be variable due to biological factors. In particular, the variability of humidity values depending on perspiration is clearly visible.

Now we need to look at how these changes in the body are reflected in the sensor. We collected the data by running SEAD as designed. The only difference is that we made sure the SEAD's sensor was clamped between the bed and the body to ensure the same condition for comparison. As a result of measurements taken for half an hour, we obtained Figure 7.2. As can be seen from the figure, the temperature and humidity values reflected on the SEAD's sensor are progressing stably. It is not affected by sudden changes in the body. On the other hand, it is seen that it shows higher values than the ambient condition. Ambient values are 25 ± 2 °C for temperature and 55 ± 5 %RH for humidity.

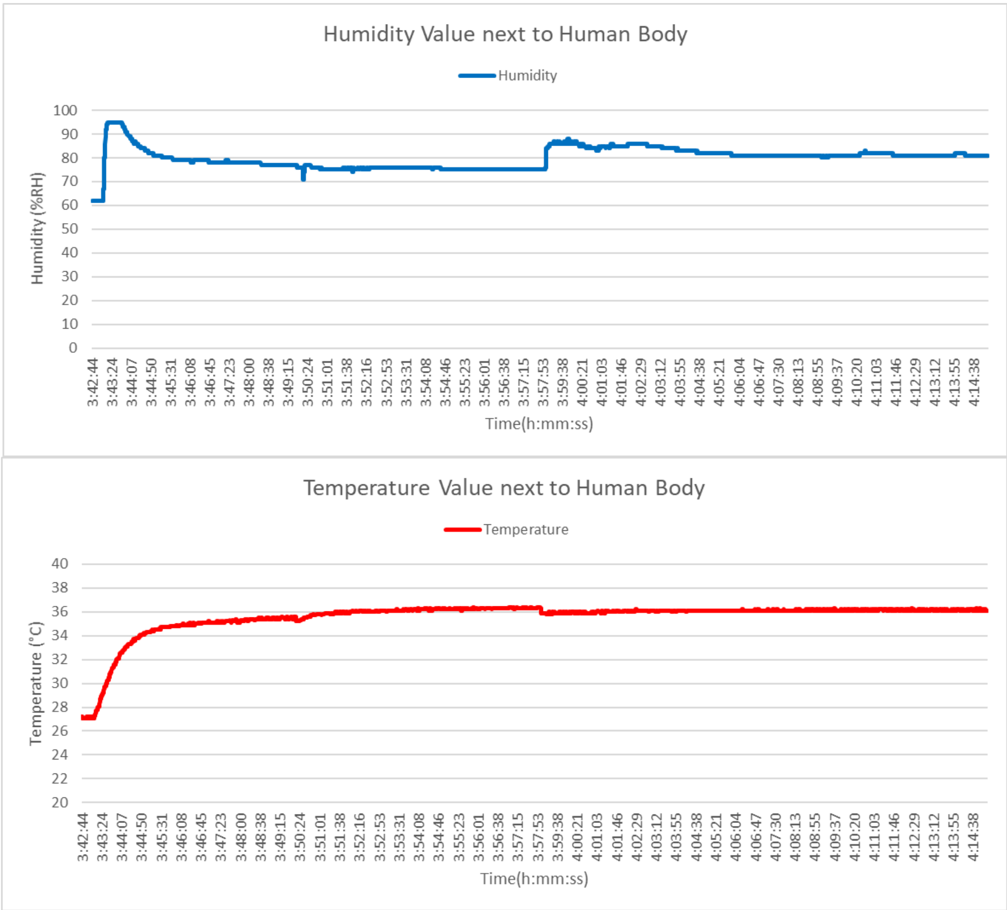


Figure 7.1 : Ambient Values next to the Human Body

When we collect and compare the humidity values on a graph, we have proved that the changes in the humidity in the body are not reflected to the sensor and therefore, wrong signals will not be given due to the formation of sweat in the body. In addition, as can be seen from the graph, the humidity value of our sensor does not exceed 70% RH even under the worst condition (Figure 7.3). Therefore, we can set our limit value as 75 %RH and above.

When we collected and compared the temperature values on a graph, we saw that the temperature in the body was not reflected on the sensor as the same value. The temperature at the sensor location is approximately 5 °C lower than body temperature. Our sensor never exceeded 31.5 °C even in the worst condition (Figure 7.4). Therefore, we can set our limit value as 32 °C and above.

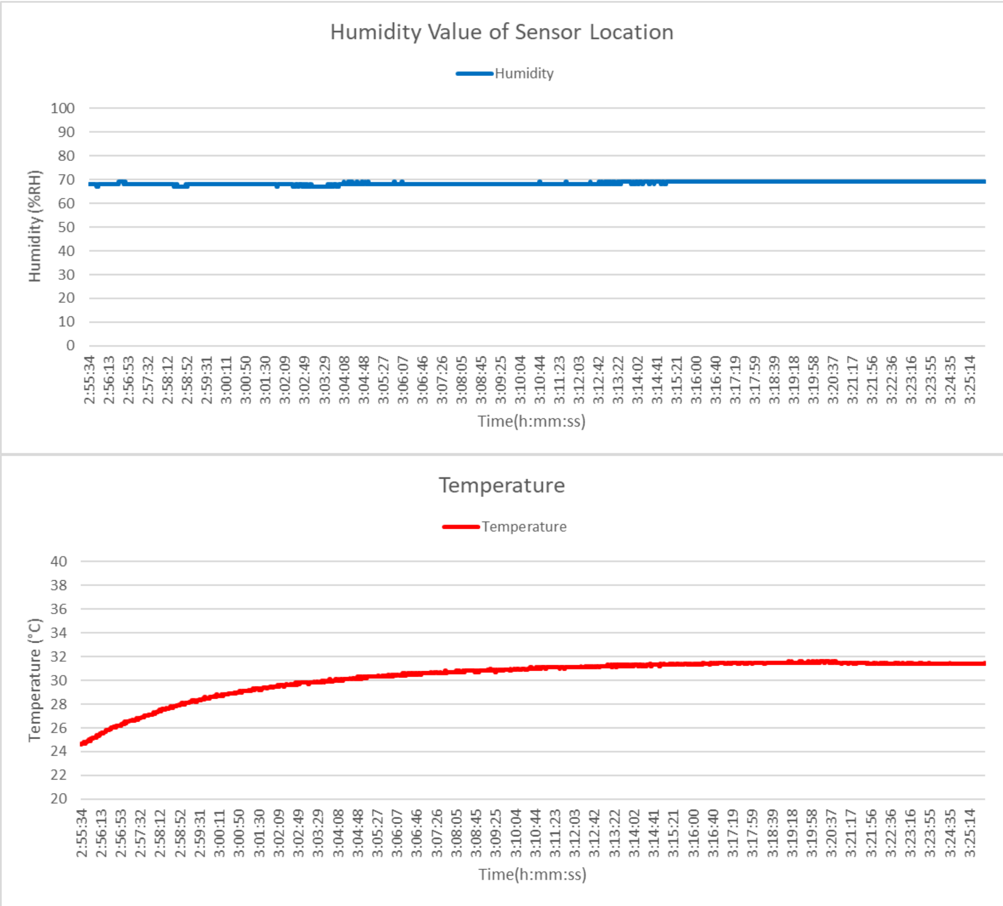


Figure 7.2 : Ambient Values of the Sensor Location

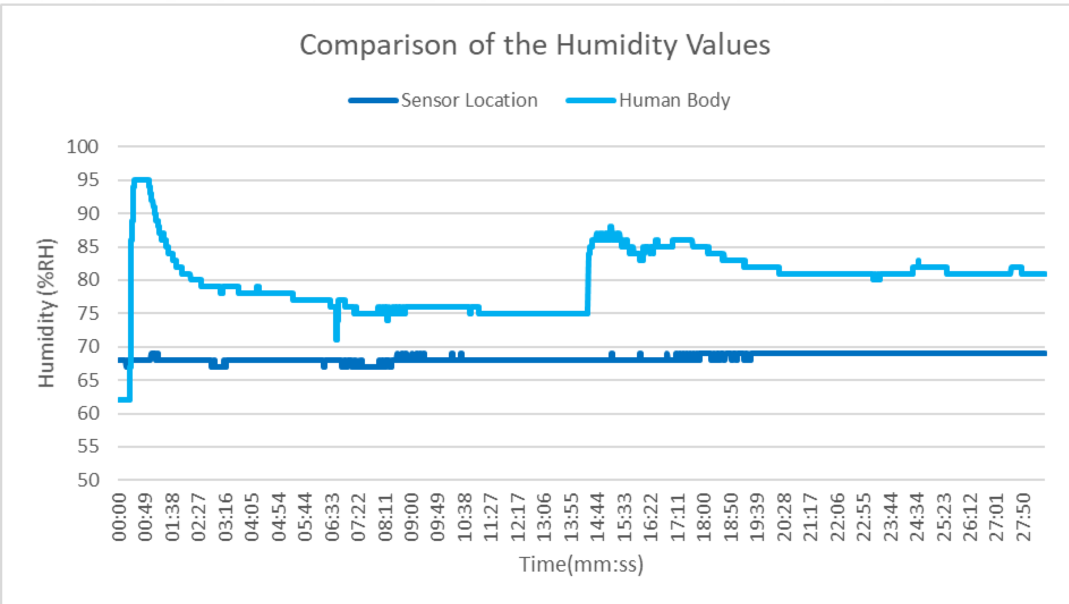


Figure 7.3 : Humidity Values Comparison

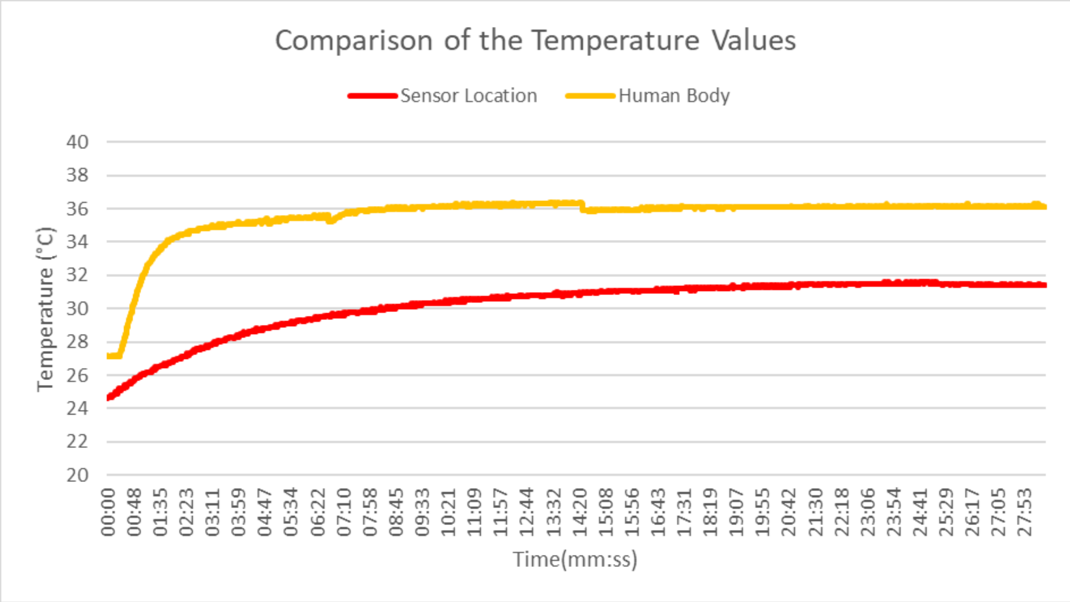


Figure 7.4 : Temperature Values Comparison

8. ACTUAL USE TESTS

SEAD's laboratory and ambient test results clearly showed us how reliable and useful our design is. In order to test our design in actual use, we performed user tests.

We had previously proven that we can detect urine in a very short time when it comes. Therefore, the criterion we measure here will not be response speed. Because it is uncertain when the urine or stool will come. The criterion we will test in actual use will be performance and stability. We will see the performance of SEAD by evaluating the temperature and humidity data we will measure.

8.1 Urinary Incontinence

We have already seen that we can detect urine in the tests we have done under laboratory and ambient conditions. The criteria we will look at in actual use is not the ability to detect urine or the time to detect it. Since it is not known when the urine arrives, performance and stability are more important than response time in actual tests. As a result of the actual use test we have made for urinary incontinence, we have obtained Figure 8.1 with the data measured by SEAD. As can be seen from the figure, while the humidity value was stable, it suddenly increased and reached saturation. The liquid form of the urine allowed the humidity value to progress very quickly. With the increase here, urinary incontinence was detected within seconds.

With the result we have obtained here, we have proven once again that SEAD can detect urinary incontinence quickly and provide reliable and stable data.

8.2 Fecal Incontinence

Unless there are extreme situations, urine always comes as a liquid. However, the form of stool is not always fixed. Sometimes it can come in solid, sometimes liquid, and sometimes mixed forms. SEAD can detect fecal incontinence if stool comes in liquid or mixed forms. As it will be remembered, our sensor could detect any liquid without the need for conductivity. So, how will fecal incontinence be detected if the stool comes in solid form and does not contain any liquid? At this point, SEAD's temperature measurement feature will come into play and will inform us of fecal incontinence through temperature data.

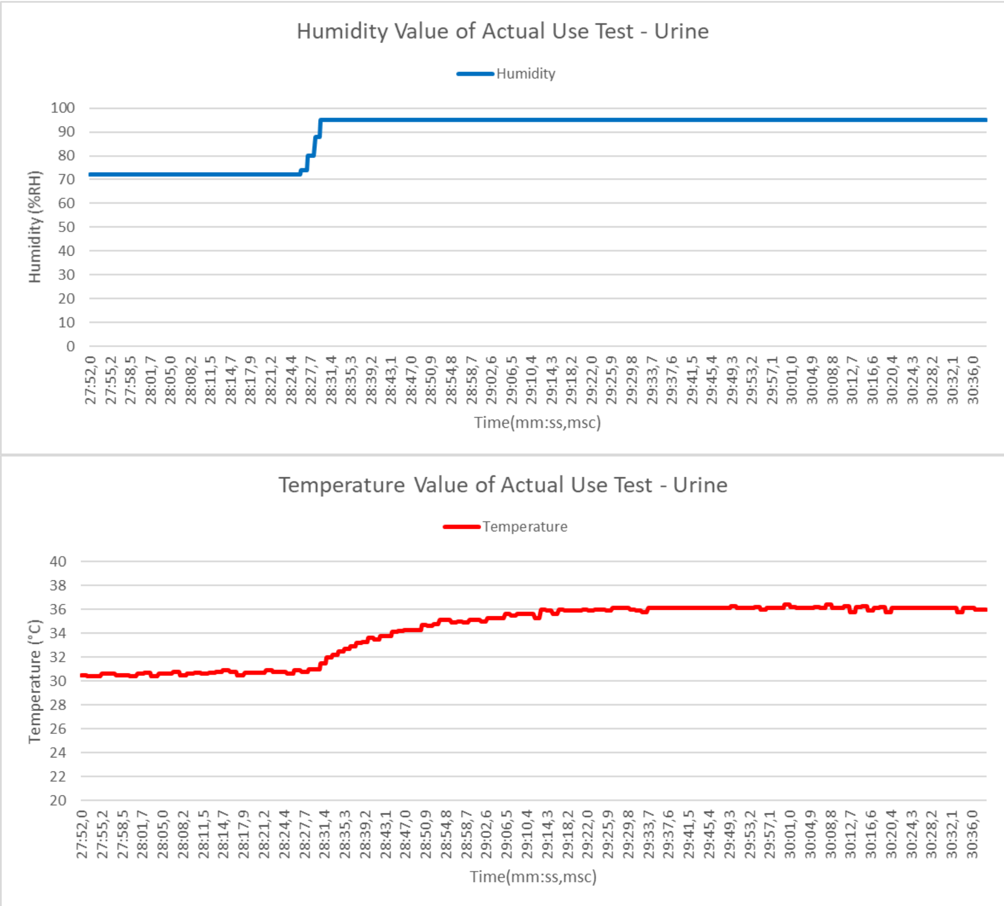


Figure 8.1 : Humidity and Temperature Values of Urine

During our tests, we had the opportunity to perform tests with both hard and soft stools. First of all, when we look at the detection results of hard (solid) stool, we obtain Figure 8.2. As can be seen from the figure, after a while, both temperature and humidity values started to increase and fecal incontinence was detected.

When we proportion the values according to the limit values to understand which of the temperature or humidity passes the limit value first, we obtain Figure 8.3. As can be seen from the figure, first of all, the temperature value exceeded the limit. Since hard stool contains very little liquid, the temperature was transmitted to the sensor before humidity.

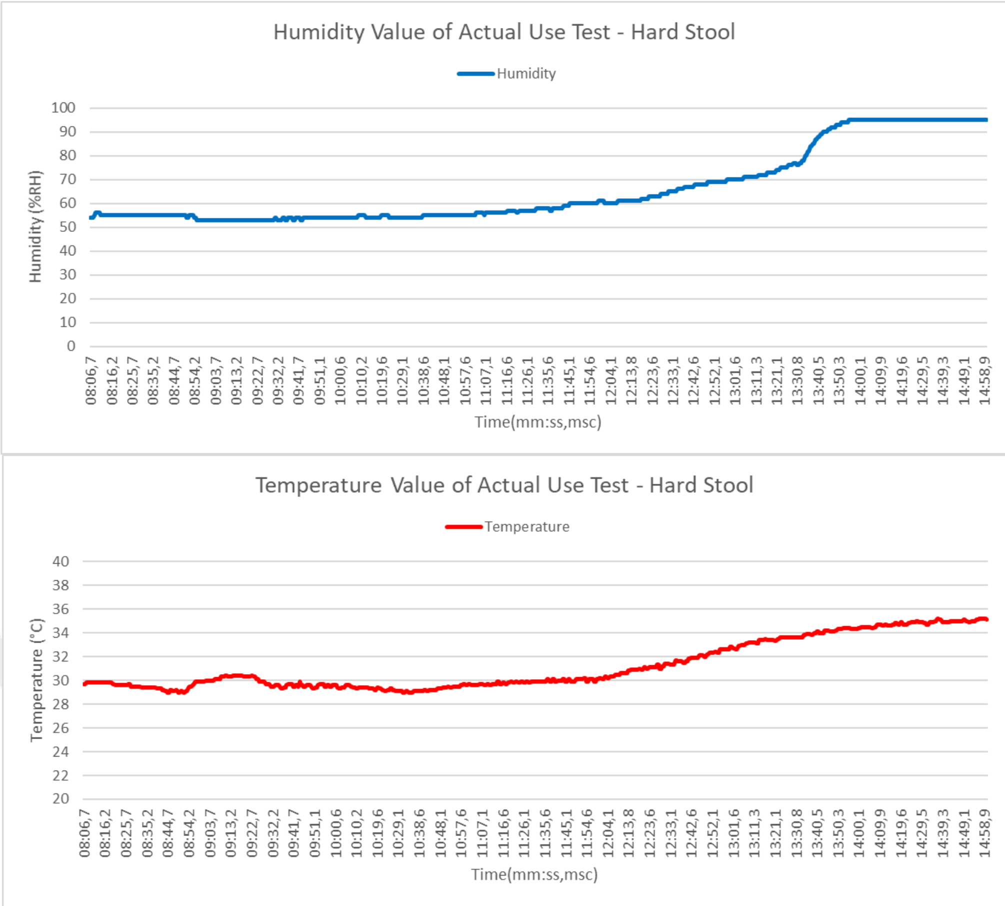


Figure 8.2 : Humidity and Temperature Values of Hard Stool

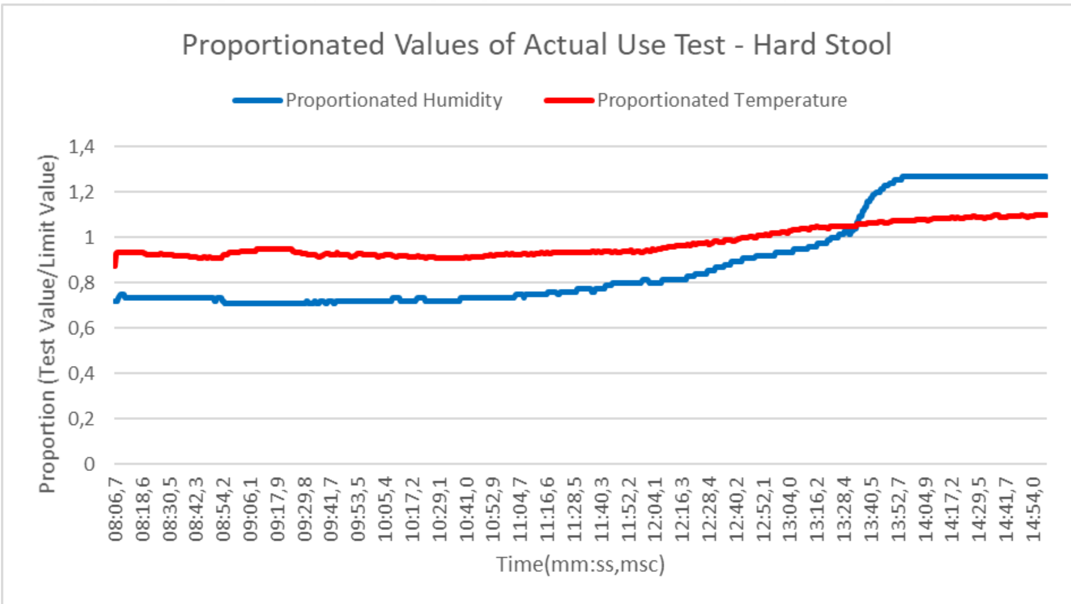


Figure 8.3 : Proportionated Values of Hard Stool

When we compare the signal values, we see that the temperature data first passes the limit value and thus a warning is given (Figure 8.4). With this result, we have proven that we can detect fecal incontinence even when the stool does not contain liquid.

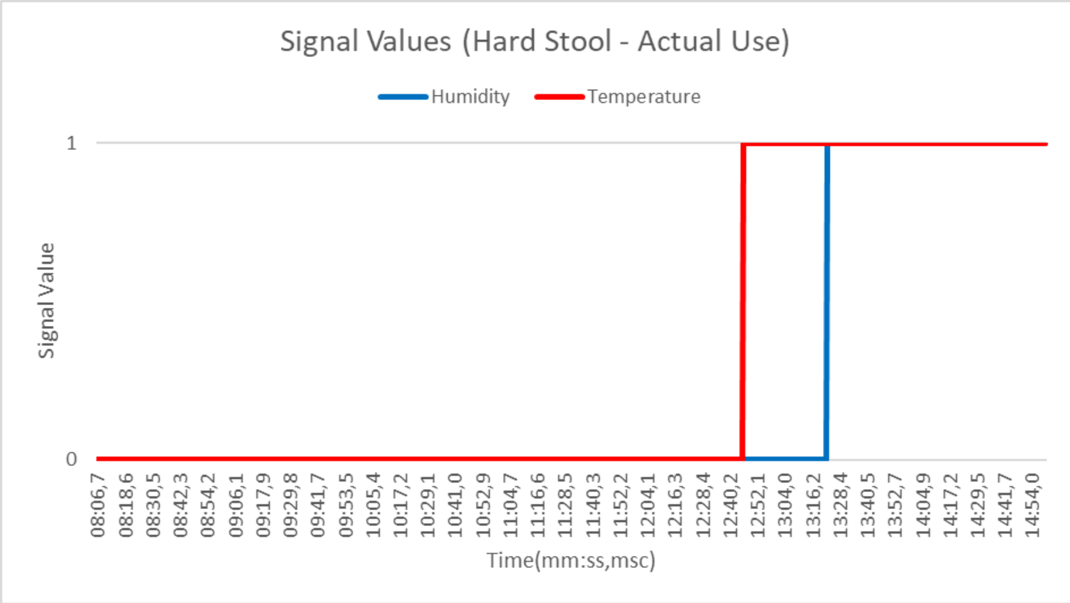


Figure 8.4 : Signal Values of Hard Stool

When we look at the soft stool results, we see that both temperature and humidity values increase after a while time (Figure 8.5).

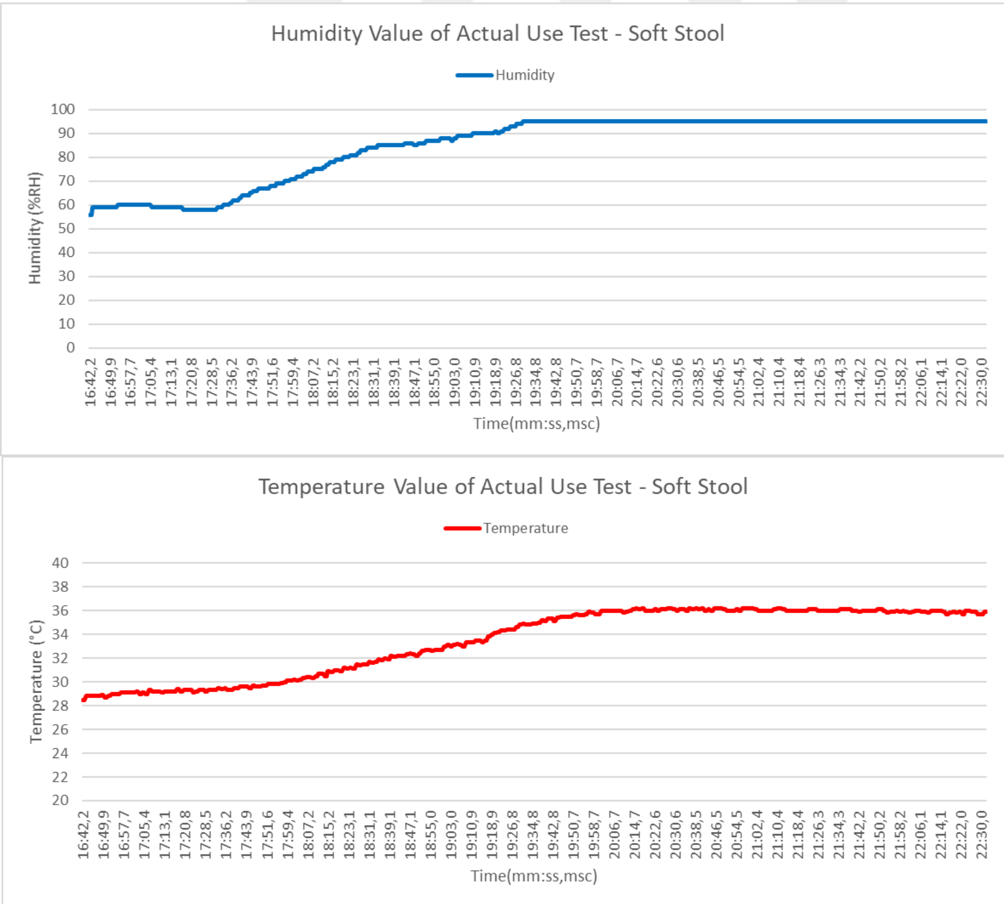


Figure 8.5 : Humidity and Temperature Values of Soft Stool

When we compare the temperature and humidity values with the limit values, it is seen that the humidity value exceeds the limit value first (Figure 8.6). This is because the humidity created by the liquid in the soft stool reaches the sensor earlier.

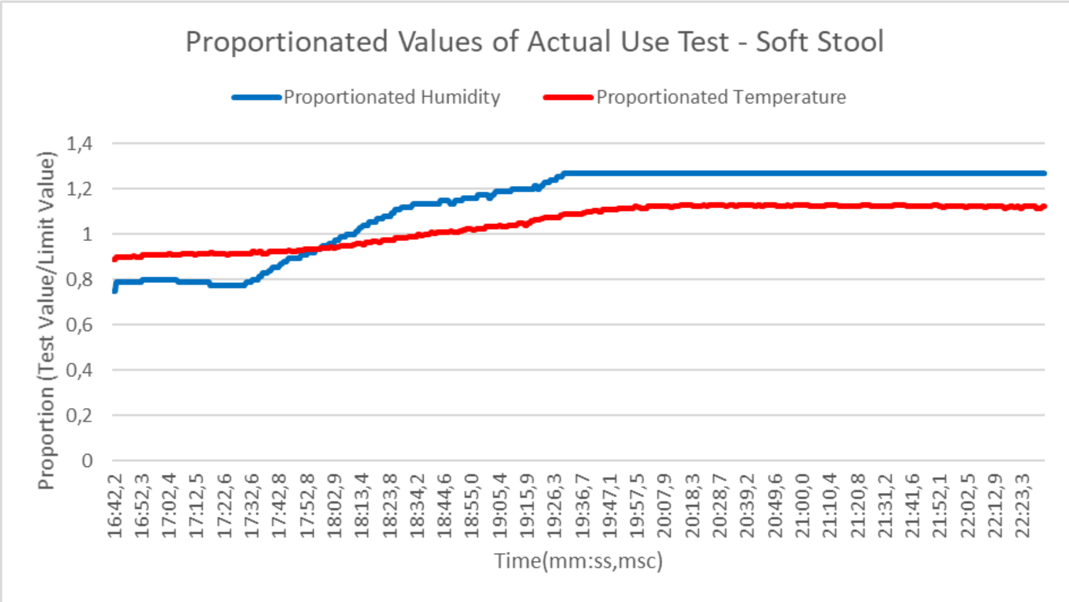


Figure 8.6 : Proportionated Values of Soft Stool

When we make a comparison according to the signal values, we see that the humidity value is more effective to detect fecal incontinence in the case of soft stools (Figure 8.7).

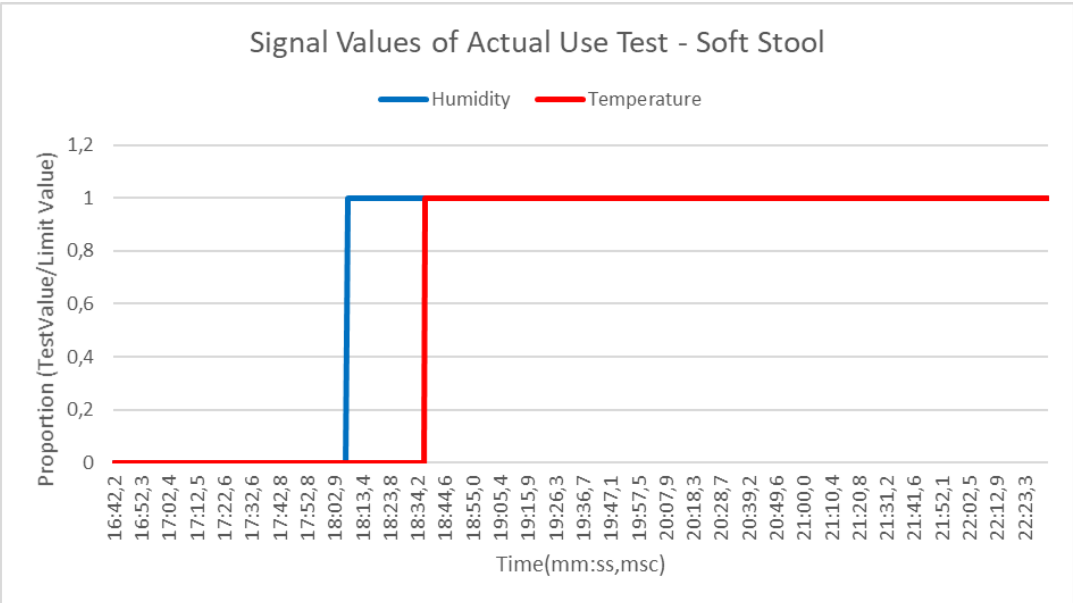


Figure 8.7 : Signal Values of Soft Stool

The results of all the tests we have done show that SEAD has successfully passed all the tests. Having successfully detected both urinary and fecal incontinence, SEAD has also given stable and reliable results. It has proven that it can be used by all people who need adult diapers.

9. CONCLUSIONS AND RECOMMENDATIONS

Every difficulty, trouble, and problem experienced in history can be easily overcome with engineering and science studies today. Every study that was once carried out as a scientific study in laboratories now takes place in one or more areas of our lives and helps us or people in need of help around us. With the development of science and technology, numerous studies have been made and continue to be made in order to make people's lives easier. Scientific studies continue to develop as people's needs and priorities change over the years. Scientific developments are constantly creating new fields for themselves and technologies that offer innovative solutions for these new fields are created.

With the enrichment of the studies made to make people's lives easier, studies are also carried out to collect data about people or their environment. According to the types of data collected, solutions have been developed that will make people's lives easier or help solve their problems with the data analysis. These solutions can be simple solutions such as weather forecasting, or they can be vitally critical solutions that enable the monitoring of the vital data of the patient in surgery. Various sensors have been developed to obtain data. The data obtained from the developed sensors have been also collected and analyzed by various electronic systems developed. As a result of the analysis, visual or audial information is given to the users. With the spread of the Internet, the data obtained from the sensors began to be read and collected remotely. Portable devices have emerged as sensors and electronic systems that collect data from sensors are getting smaller and smaller with the development of technology. With the spread of portable devices, personal data, environmental data or data belonging to a patient that needs to be followed remotely can be obtained even on the move. With the emergence of IoT and the further development of technology, systems consisting of sensors and electronic circuits have become wearable and the concept of wearable technology has emerged. With the spread of wearable technology and making a place for itself in a new area of life every day, works, tasks, processes and studies that were previously difficult can now be done easily. For example, instant tracking of an athlete's training can be done by both the athlete and his/her trainer, the vital data of the patient individual can be followed instantly by both the patient and his/her doctor, etc.

Scientific studies and developments in engineering began to find a place in the diaper industry, primarily in baby diapers. Diapers have emerged for babies to fulfil their toilet needs by putting them under them until they get toilet training. Although this need was met for years, with the spread of wearable technology nowadays, the need to learn when diapers are dirty has been felt. The main reason for this is that babies are not aware of when diapers are dirty and thus their parents are not aware of it. Although the diapers have an absorbent structure, urine and feces are still there and there is a risk of harm to the babies. The acidic structure in the urine and the bacteria in the urine and feces can damage the skin of babies. Then, infections called diaper rash can occur. For these reasons, the diaper should be changed as soon as possible when it gets dirty. The shortest possible time is an instant change, and instant change can be achieved by integrating sensors and electronic circuits into the diaper. Studies in this area have revealed the concept of "smart diapers". Studies on the systems that follow the diapers of babies have given an idea to the emergence of similar studies for children. Although children are toilet trained and aware of the need to toilet compared to babies, urinary incontinence is a common problem in children. It has been observed that children bedwetting, especially at night due to biological or psychological effects. Similarly, the need to be informed about urinary incontinence immediately has emerged in order to prevent diaper rash and similar problems in children as in babies. Immediate notification of urinary incontinence has usually been provided by auditory alerts. The reason for this is that if a warning can be given as soon as the urine comes to the sensor, the child who is woken up by the sound can go to the toilet for the rest of his toilet needs.

Urinary incontinence is unfortunately not a problem seen only in babies and children. People can encounter this problem at almost any age. The cause of this problem can sometimes be biological and sometimes psychological effects. For people who are conscious and not disabled, this problem can be overcome with a simple bladder/continence pad or adult diaper. However, this situation, unfortunately, brings along a difficult process for people such as the disabled, bedridden patients and dementia patients. The urinary/fecal incontinence problems of these patients may also be overcome with an adult diaper, but these people cannot report that the diaper is dirty. Thus, they may experience diaper rash, etc. may experience skin problems. For this reason, the diapers of these patients should be changed as soon as possible. Similarly, in order to provide the shortest possible time, the need for smart diaper studies to be carried out on adult diapers arose.

In this thesis, which we carried out based on the need for smart diaper designs for adults, we designed the "Smart Electronic Adult Diaper", sometimes with reference to electronics, communication, computer, medicine, biology, chemistry and psychology sciences, and sometimes inspired by these sciences.

In the thesis study, we carried out every step of a product design process as much as possible, respectively. First of all, in the continuation of the study, in which we explained the process of how the idea phase evolved, we discussed the studies carried out in the literature in detail. Every component used in smart diaper designs has been examined in detail. We examined the design details of the designed sensors and discussed the advantages and disadvantages of each material and each method used. When we compare the conductive thread, conductive wire, conductive ink and conductive fabric materials used in the designs, we theoretically compared the advantages and disadvantages of these materials against each other. The conductive thread seems to be the appropriate material to be applied to the fabric. Its advantages seem to be that it can be easily processed and kept stable. However, there are also some disadvantages. It is very difficult to connect conductive threads to electronic components. The fact that the connection cannot be achieved by soldering and the legs of the components are connected with stitching shows that there is no reliable connection and some connection problems may occur. Moreover, in designs presented as reusable, it has been determined that the conductor threads are damaged after a few washings and this causes problems in signal transmission. In addition, this situation should be prevented as the conductive threads may overlap and cause wrong short-circuit warnings in case of folding the diaper or underwear. The conductive wires, another material used in sensor designs, seem to be the most suitable material for signal transmission. However, the sensor designs are made with only two parallel wires, which causes the diaper or underwear to not cover the entire area where urine can come. This may cause it to be undetectable even though urinary incontinence happens.

In addition, the hard structure of the conductor wires may cause discomfort to the user. The printed sensors made of conductive ink, another material used in sensor designs, seem to be advantageous in terms of being easily applied to diapers or underwear and signal transmission speed. However, failure to print the conductive ink correctly during application may result in incorrect sensor designs. Failure to control the process during printing may also cause problems such as capillary short-circuit or incomplete path. There is also the need to prevent the folding of the diaper or underwear so that wrong short-circuit signals do not occur. Finally, conductive fabric, another of the materials used in sensor designs, provides an advantage by covering the entire area where urine can come from in the diaper or underwear. However, in this sensor design, which is designed as two parallel conductive fabrics and an absorbing surface between them, it is critical to ensure that the absorber surface is evenly distributed over the entire area in order to avoid wrong short-circuit signals. Moreover, since this structure shows capacitance properties, uneven distribution of the absorbent surface may cause wrong warnings due to the capacitive effect. In addition, in terms of cost, the conductive fabric is an expensive material for diapers.

When we looked at the contents of the electronic units used in diapers or underwear, we saw those very different processors or controllers were used. Since the important thing in the smart diaper is the processing and interpretation of the data coming from the sensor, these units vary according to the designer's initiative. Therefore, when we look at the functions of the electronic units, it processes the information it receives from the sensor according to the sensor design and gives this information to the user as an audial, visual and sensual warning.

It is easy to give the information that the diaper or underwear is dirty audibly to the people nearby as a warning. However, family members or caregivers may not always be nearby. For this reason, there is a need to provide information to distant people. To achieve this, some transmission methods are used. These methods can be to transmit an RF signal to a receiver, sometimes using GSM to send an SMS, and sometimes using Bluetooth or Wi-Fi to send a notification to a smartphone.

Different methods are used to supply the power needs of electronic systems used in diapers or underwear. We have seen that various sizes of cells are used in some studies, while batteries of various sizes are used in some studies. According to the realized design, the choice of cell or battery is a component at the discretion of the designer.

One of the important criteria in smart diaper designs is the content of the diaper or fabric. It should be able to keep urine and stool on its absorbent surface without overflowing. The quality of the absorbent surface is very important, as the absorbent surface plays an important role in designs where the absorbent surface is used as a conductive path. On the other hand, the content and quality of diaper or underwear fabrics are important for the processing of materials such as conductive thread and conductive ink. In our research, it has been seen that although both absorbent surfaces and fabrics are generally made of cotton or cotton blends, this criterion also varies according to the initiative of the designer.

In smart diaper designs, if urine or stool has occurred due to the sensor's information, a warning should be given. The type of this warning varies according to the design. The buzzer has been generally used as an audial warning. LED has been used as a visual warning or warning has been given via computers or smartphone screens. The vibration has been used as a sensual warning.

Before realizing smart diaper designs, it is very important to determine the target users. Because, usage habits, frequency of need to the toilet, requests and complaints may vary according to the target users. For this reason, first of all, it is necessary to research and analyze the target users well. Because babies have skin problems such as diaper rash, the fact that their parents started checking diapers constantly revealed the need to get information when the diaper is dirty. In order to meet this need, smart diaper designs were first studied for babies. The studies for diapers gave an idea to the emergence of smart diapers/underwear for children. Various studies and designs were carried out against the problem of enuresis in children. The fact that urinary/fecal incontinence problems can be seen in people of all ages has revealed the need for smart diaper designs for adults as well.

Since smart diaper studies and designs are costly studies and designs, the possibility of reuse of the realized designs has been presented in some studies. However, the sensors can be damaged both due to the acidic content of the urine and the washers and washing temperatures used during the cleaning of the sensors. After a few uses, the sensors can no longer be used. For this reason, the most optimal solution is studies and designs where the sensor is disposable and the electronic systems are reusable.

Diapers get dirty in three different ways, depending on people's biological routines. With urine, with feces, and with both urine and feces. Therefore, smart diapers must be able to detect all three of these getting dirty conditions. However, when we look at the studies, we see that the studies are only made for urinary incontinence. While these studies can detect the first and third of the diaper getting dirty conditions, they cannot detect the second, fecal incontinence. It is also necessary to be able to detect fecal incontinence.

The studies we examined in the literature and the inferences we obtained from the analyzes we made about the designs have been the clues to our SEAD design. We did pre-tests in order to observe these theoretical analyzes in the test environment.

With the electronic system and software, we designed for the pre-tests, we made sensor designs with the same design layout by using the conductive thread and conductive ink used in the studies and designs in the literature. Then, we tested the sensors using three different volumes of water, salt solution and urine liquids, namely 50 ml, 100 ml and 250 ml. We compared the sensors according to their response time and signal stability.

When we first made a comparison as the sensor material, we found that the conductive thread reacted later than the conductive ink. In addition, we have seen that the response times of sensors made of conductive thread are in a wide range, while the response times of sensors made of conductive ink are in a narrower range. The reason is that the conductive thread is a mixture of stainless steel and fibre. Stainless steel, which is the conductive part of the conductive thread, can be in or out of the mix. For the transmission to be ensured, the liquid must reach the stainless steel and for this, the liquid must first be absorbed by the conductive thread. On the other hand, for the sensor made of conductive ink to transmit the signal, it is sufficient for the liquid to contact the conductive ink. The difference in response times between sensors made of conductive thread and sensors made of conductive ink is due to this difference.

Secondly, when we compare the layer techniques used in sensor designs, we see that 2-Layers respond later than 1-Layer. The reason for this is that in the 2-layer technique, the pathways that provide the transmission are located in two different layers and there is an absorbent surface between the layers. The liquid passing through the first layer to ensure the transmission must also pass through the absorbent surface in between to reach the second layer. As the liquid moves along this path, it is naturally absorbed by the absorbent surface. Therefore, the liquid's reaching the second layer is delayed a little. Since the absorbent surface also becomes a transmission path, there must be enough liquid to saturate the absorbent surface. In the 1-layer technique, since the two paths that provide the transmission are on a single layer, it is sufficient for the liquid to reach the layer. The difference in response times between sensors made with a 1-layer and sensors with a 2-layers is due to this difference.

Thirdly, when we compare the types of liquids used in the pre-tests, we see that the sensors respond more slowly when urine is used in the tests than when salt solution is used in the tests. In addition, the response times are in a wide range when urine is used in the tests, while the response times are in a narrow range when salt solution is used in the tests. This is because the salt solution used in the tests has the same constant conductivity value, while the urine does not have a constant conductivity value. As mentioned before, it is a fact that even the same person's urine can change during the day and have different pH and conductivity values. The difference in the response times of the sensors during the use of the salt solution in the pre-tests and the use of the urine is due to this difference. In addition, when we compare liquid types in pre-tests, one of the most important outputs we see is that the sensors cannot detect the liquid when water is used as a liquid. Because sensors made of conductive thread and conductive ink require a conductive liquid for conduction. But water is not conductive enough for these sensors. This shows that if the urine content loses its conductive properties because of biological reasons, the sensors will not be able to detect urinary incontinence.

Fourthly, when we compare the liquid volumes used in the pre-tests, we see that the sensors respond later as the liquid volume decreases. Also, as the volume of the liquid decreases, the response times of the sensors are in a wide range. The reason for this is that in the studies carried out, the liquid is also included as a pathway that provides transmission. There must be sufficient liquid between the sensor paths to ensure uninterrupted and stable transmission. In addition, there must be enough liquid to reach the sensor while passing through the absorbent surface. Otherwise, the liquid will be absorbed by the absorbent surface and sufficient liquid will not reach the sensor paths. It was observed that as the amount of liquid decreased, both the response times increased and the signal transmission was interrupted. On the other hand, as the amount of liquid increases, it has been observed that both the response times are shortened and stable signal transmission is provided.

After the theoretical analyzes we made after the literature research, we made practically various analyzes in the pre-tests. By comparing the factors in sensor designs, we saw how each parameter affects the performance and reliability of smart diaper studies and designs and tested the advantages and disadvantages of the studies in the literature. These comparisons gave us clues before the "smart electronic adult diaper" design we realized.

After the clues we obtained, we started to realize the SEAD design. While performing the design, we analyzed every parameter affecting the design. Firstly, we discussed the adult diaper structure. The adult diaper design aims to ensure that adults who need care are checked out. One of the intended purposes of design is to be useful. Adults should feel like they are living without an adult diaper when they use it. For this, the electronic circuits, connection paths and sensors on it must have a structure that will not disturb the user. Otherwise, the user will be uncomfortable and want to remove the adult diaper. In addition, from the point of view of family members or caregivers, we decided that the adult diaper structure should be in the form of diapers, not underwear. We found that designs used as underwear cause difficulties for both the caregiver/family member and the wearer. Thanks to the foldable structure of the adult diapers, it will be possible to change the adult diapers of the users without removing them from the bed.

In the selection of sensors for the SEAD design, we decided to use the DHT11 humidity and temperature sensor as a sensor, considering both the research in the literature and the results in pre-tests, as well as the requests and complaints of the users and caregivers. Because we determined that we can detect both urine and stool with the DHT11 sensor. The sensors in the literature were lacking in two important issues. First, when the urine conductivity is reduced for biological reasons, the sensors could not detect it. Second, when there was only stool without urine, the sensors could not detect it in the same way. On the contrary, we determined that we can detect these two situations with the sensor we used in the SEAD design. As can be seen from the results of our tests, SEAD is succeeded.

For SEAD design, we decided to use the Arduino Nano electronic board, considering both the requirements in the design and the usefulness in the selection of the processor. It provides advantages both in terms of comfort with its small footprint and in terms of features as it can provide multiple functions.

Transmitting that information is as important as processing the information received from the sensor in the smart diaper. In the SEAD design, we decided to use both Bluetooth and Wi-Fi to transmit the information received from the sensor. We chose the HC-05 module for Bluetooth and the ESP8266 modules for Wi-Fi.

After choosing the components and methods of SEAD, we started to assemble all the parts of SEAD as hardware. First of all, we placed the sensor in the adult diaper we chose. We placed the sensor in the middle of the adult diaper, under the cotton surface. The reason for placing it in the middle here is to make it unisex and detect both urine and feces. The reason why it is placed under the cotton bottom surface is to prevent it from coming into contact with the user's skin. Preventing the sensor from coming into contact with the user's skin gives us two advantages. We prevent the sweat that may occur as a result of sweating by the user from being detected by the sensor as if urinary incontinence happens. In addition, the cotton structure prevents the sensor from being felt by the user, thus preventing discomfort.

After placing the sensor, we provided the connection between the cables, which have silicone outer coating and elastic structure, and the sensor and the electronic system. The cables were chosen to be resistant to the acidic content of urine and heat. Additional insulation was applied to the ports of the sensor. To avoid the short-circuit problem, the connection paths were placed independently of each other. All precautions have been taken to ensure reliable and stable signal transmission.

On the electronic system side, the connection of the HC-05 module or the ESP8266 module was carried out to Arduino Nano electronic board by the design requirements and according to the signal transmission selection.

After completing all the connections as hardware, we wrote the software to meet the requirements of SEAD. We implemented the software using the Arduino IDE. After the components and libraries required for communication were uploaded to the software, we created the algorithm. We completed our software by writing sub-functions according to the algorithm we created.

We performed tests to see the performance of our SEAD, whose software and hardware we have completed. First of all, we applied the same tests to SEAD as we performed in the pre-tests section. In this way, we had the opportunity to compare our SEAD with the studies in the literature.

Firstly, when we compared according to the liquid types, we proved that the SEAD quickly detects water, salt solution and urine in under 10 seconds. Other sensors in the literature can detect salt solution and urine, however, they could not detect water. On the other hand, SEAD can easily detect water. With this result, it is proven that SEAD can detect urinary incontinence, although the content of the urine may vary due to a biological problem. Moreover, SEAD will also be able to detect fecal incontinence if the stool is in liquid form.

Secondly, we proved that SEAD can detect all liquid amounts in less than 10 seconds when we compare them according to the liquid amounts. Similar to pre-tests, there is an inverse relationship between the amount of fluid and the response time. Nevertheless, SEAD can detect even a very low amount of liquid such as 50 ml in a short time and provides a stable and reliable signal transmission.

Considering all the results in all comparisons and tests, it has been clearly proven that SEAD has more reliable and stable results than other sensors for all types of liquids and all liquid volumes used.

One of the biggest advantages of SEAD over other studies in the literature was the sensor data it collected. SEAD can not only read the signal value but also obtain humidity and temperature data. We designed algorithms to detect urinary and fecal incontinence using humidity and temperature data. With the algorithms we designed, we aimed to detect both urinary and fecal incontinence. As it is known, studies in the literature were carried out to detect urinary incontinence. The SEAD we designed has the ability to detect both urinary incontinence, whether it has conductivity or not, and fecal incontinence, whether with or without urine.

Before using SEAD in actual use tests, we made studies and improvements to determine the limit values. As it is known, we placed our sensor inside the SEAD in such a way that it remained on the middle surface of the diaper and behind the absorbent surface. In this way, we both prevented the user from feeling the sensor and being uncomfortable and prevented the sensor from giving false warnings due to possible sweat on the user's body. Due to the location of the sensor, the temperature and humidity values to be obtained from the sensor under normal conditions are expected to be lower than the body temperature and body humidity values. On the other hand, since the diaper and sensor remain in clothes, it is expected that the temperature and humidity values to be obtained from the sensor under normal conditions will be higher than the ambient temperature and humidity values. We performed decision-making tests both to see these situations and to determine the necessary limit values for SEAD to issue a warning. We performed these tests by holding our sensor in two different locations. Our sensor is placed both in its own planned location inside the SEAD and in the diaper as touching the body. As a result of these tests we carried out, it was seen that there are differences between the humidity and temperature values in the body and the humidity and temperature values of the sensor itself, as expected. This result shows us that the sensor can be isolated from the body under normal conditions. Moreover, when the test results were examined in detail, the humidity values at the SEAD sensor location showed little change, even though the humidity in the body due to perspiration was constantly changing. Thus, we have proven that a wrong warning due to sweat will not be issued. In addition, after a detailed examination of the test results, we determined our limit values required for actual use.

We performed actual use tests with the determined limit values and the final version of our SEAD. In these tests, SEAD was worn on a person and urinary and fecal incontinence conditions were monitored. Because it's unclear when urinary and fecal incontinence will occur, we focused on SEAD's performance and reliability in actual use tests, not response time.

As a result of the actual use tests performed, we examined the results for the detection of both urinary incontinence and fecal incontinence. Firstly, when we examined the test results and data we obtained in the case of urinary incontinence, we proved that SEAD can reliably detect urinary incontinence and present data stably. Secondly, we examined in detail the results and data we obtained for both stool types in actual use tests in case of fecal incontinence. As it is known, in the case of fecal incontinence, the stool is either in liquid form or is hard. We had the opportunity to test both cases in actual use tests. It has been determined that fecal incontinence can be detected when the humidity data exceeds the limit value in the actual use test when the stool is in liquid form, ie it is soft. SEAD's ability to detect fluid regardless of conductivity enabled us to detect fecal incontinence. It has been determined that fecal incontinence can be detected when the temperature data exceeds the limit value in the actual use test when the stool is liquid-free, that is, hard. SEAD's ability to measure not only humidity but also temperature data enabled us to detect fecal incontinence. With these results, we proved that SEAD can detect fecal incontinence reliably and present data stably.

We applied every step of the product design process as much as possible at every stage of the thesis work. During the design, all the factors that provided input to the design were handled and analyzed in detail. During the thesis study, the design was carried out using different perspectives and various improvements were made. Ultimately, we achieved the best possible solution and realized our “Smart Electronic Adult Diaper” design.

We believe that SEAD, which we have created as a result of our thesis work, is a solution that people of all ages can benefit from. With SEAD, we offer solutions to multiple problems that people suffer from. Thanks to SEAD, ordinary adults will be able to instantly monitor their urine or stool movements, monitor urinary/fecal incontinence times, frequency, etc. they can save. They will be able to obtain this information and, if necessary, share it with their doctors. Although they can change their diapers, those who do not feel urinary/fecal incontinence for various biological or psychological reasons will receive instant notification in case of urinary/fecal incontinence thanks to SEAD and will be able to change their adult diapers without any problems. Likewise, urinary/fecal incontinence times, frequency, etc. can be recorded. They will be able to obtain such information and share it with their doctors when necessary. For people who need help and care, a family member or caregiver is instantly notified when urinary/fecal incontinence happens. The family member or caregiver who receives the notification will ensure that the necessary adult diaper changes are made as soon as possible. In this way, medical diseases or infections caused by late adult diaper changes will be prevented. Moreover, there will be no need for constant control by a family member or caregiver and time loss will be avoided. In addition, since the patient will interact with the family member or caregiver for a minimum time during this process, the psychological problems that the patient may experience due to diaper change will be prevented. Similarly, since the duration of urinary/fecal incontinence is recorded, family members or caregivers will be able to see and will be able to record this data, frequency, etc. They will be able to obtain this information and share it with the patient's doctors when necessary.

SEAD is a ready-to-use product in its current form. It can fulfil the needs of an adult suffering from urinary/fecal incontinence. Still, SEAD is open to development. We think that SEAD can be developed in some areas.

Firstly, an application can be created for the data SEAD sends to the smartphone. We are currently sending data via an external application. The data to be sent can be sent through the newly created application. Besides sending information via the application, data can be recorded. Analyses can be performed instantly or periodically with the recorded data, and the analyzes can be presented numerically and visually. Moreover, audible or vibrating alerts can be given via the app. In addition, calibrations related to SEAD's sensor can be made through the application. Limit values can be changed according to the temperature and humidity values of the ambient.

Secondly, SEAD can be used in multiple ways as well as in stand-alone use. All SEADs can be monitored from a single computer or an application, especially when all patients wear SEADs for use in nursing homes. In this case, if urinary/fecal incontinence of a patient happens, his/her SEAD will send a warning and the nurse will take care of that patient immediately and change the diaper. Both the nurses do not have to constantly check the diapers of all patients, and the diaper of the patient whose diaper is dirty is changed before the person gets any infection.

Thirdly, the wireless rechargeable battery can be used as the power source of SEAD. In this way, electronic systems can be easily charged by placing them in a station. Moreover, if an application is created for SEAD, the battery status can be monitored instantly through the application.

Fourthly, SEAD's capabilities can be increased by adding additional sensors to SEAD. For example; a temperature sensor that monitors body temperature or a pulse sensor that controls heartbeat can be added. Or, using an accelerometer, SEAD can also detect falls.

As it is seen, there may be additional features that we can add to SEAD. In the process, we can make versions in which SEAD is further developed and new features are added to SEAD. After this thesis, we will continue to work to make SEAD even more useful and efficient and to have a more reliable and stable structure.

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