REPUBLIC OF TURKEY
YILDIZ TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

SEMI - AUTONOMOUS WAREHOUSE COUNTING SYSTEM

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MASTER OF SCIENCE THESIS
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A thesis submitted by Gizem Melike CİDAL in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** is approved by the committee on 07.08.2020 in Department of Mechatronic Engineering, Mechatronic Engineering Program.

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Gizem Melike CİDAL

Signature

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Dedicated to my family
and to anyone
who wants to produce something

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Gizem Melike CİDAL

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LIST OF ABBREVIATIONS

AFOV	Anguar Field of View
BGR	Blue Green Red
CCD	Charge Coupled Device
CMOS	Complementary Metal Oxide Semiconductor
CPU	Central Processing Unit
DMA	Direct Memory Access
FOV	Field of View
FPS	Frame per Second
GND	Ground
HFOV	Horizontal Field of View
IMU	Inertial Measurement Unit
IT	Information Technologies
I / O	Input / Output
MLP	Multilayer Perceptron
MPx	Megapixel
NIC	Network Interface Card
PoCL	Power over Camera Link
PoE	Power over Ethernet
PPM	Pixel per Milimeter
RFID	Radio - Frequency Identification
RGB	Red Green Blue
RT	Reach Truck
SKU	Stock Keeping Unit

SSCC	Serial Shipping Container Code
UDP	User Datagram Protocol
WIND	Warehouse Inventory Management Device
WMS	Warehouse Management System
XML	Extensible Markup Language

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ABSTRACT

Semi - Autonomous Warehouse Counting System

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Department of Mechatronic Engineering
Master of Science Thesis

Advisor: Asst. Prof. Huseyin ÜVET

This thesis presents a concept for the semi - automatic Warehouse INventory management Device (WIND) that can be installed on reach truck (RT) vehicles. Inventory counting is a compulsory operational process in supply chain management. Current counting methods often threats employee's health and safety and are not cost efficient. The WIND is designed to take automatic image recording to perform manual counting process. The WIND system consists of a high resolution industrial camera for visual inventory counting. A wheeled encoder and a laser distance measurement sensor are ready on the system in order to maintain semi - automatic functions. A sensor fusion algorithm run in the background and provides localization among the warehouse racks. While a RT is on the move, its current location can be matched data sensors' data using the warehouse management system. The camera unit has an automatic triggering mechanism which switches on only when the RT is in the correct location. The captured photos are saved with their readed product barcode informations to an industrial computer on the WIND instantly and uploaded to the main database which is on the company's server upon completing whole tasks. In the final stage, readed product barcode informations are compared automatically with the system informations, also users can count inventories manually on a computer screen and then, save in to the database. By the proposed system, organizations can correct records, identify flaws in the inventory process and avoid discrepancies. Most importantly, with this new process and developed system, the situation endangering human health during the counting process is removed. And also as a second part of this thesis an otonomous indoor flight drone will be design and develop to use at same stock counting mission.

Keywords: Inventory management systems, stock management, indoor localization, computer vision, sensor fusion

ÖZET

Yarı Otonom Depo Sayım Sistemi

Gizem Melike CİDAL

Mekatronik Mühendisliği Anabilim Dalı
Yüksek Lisans Tezi

Danışman: Dr. Öğr. Üyesi Huseyin ÜVET

Bu tez, elektrikli bir elleçleme aracı olan Reach Truck (RT) isimli cihazın çatallarına kolayca monte edilip çıkarılabilen yarı otomatik depo envanter yönetimi cihazı (WIND) için bir konsept sunmaktadır. Stok sayımı, tedarik zinciri yönetiminde zorunlu bir operasyonel süreçtir. Mevcut sayma yöntemleri genellikle çalışanların sağlığını ve güvenliğini tehdit eder ve/veya yüksek maliyetlidir. WIND, stok sayım sürecini gerçekleştirmek için otomatik görüntü kaydı alabilecek şekilde tasarlanmıştır. WIND sistemi, görsel envanter sayımı için yüksek çözünürlüklü bir endüstriyel kameraya sahiptir. Ayrıca cihazın depoda ilgili koridordaki konumunun anlık olarak ölçümü için tekerlekli bir enkoder ve lazer mesafe ölçüm sensörü içerir. Bir sensör füzyon algoritması arka planda çalışır ve cihazın depo rafları arasındaki lokalizasyon hesaplamasını yapar. WIND, RT hareket halindeyken cihazın anlık konumu ile depo yönetim sisteminden çekilen (sistemdeki mevcut kayıt) raf konumunu karşılaştırabilen ve yalnızca RT doğru konumdayken tetiklenen otomatik bir tetikleme mekanizmasına sahiptir. Çekilen fotoğraflar okunan ürün barkod bilgileriyle birlikte WIND üzerindeki endüstriyel bir bilgisayara anlık olarak kaydedilir ve ve ilgili koridor için tüm görevler tamamlandıktan sonra sunucudaki ana veritabanına yüklenir. Son aşamada, okunan ürün barkod bilgileri sistem bilgileriyle otomatik olarak karşılaştırılır ve kullanıcı bilgilendirilir, ayrıca kullanıcılar bir bilgisayar ekranında manuel olarak stokları sayabilir ve daha sonra veritabanına kaydedebilir. Geliştirilen WIND sistemi ile birlikte organizasyonlar stok kayıtlarını düzeltebilir, envanter sürecindeki hataları tespit edebilir ve tutarsızlıkların yarattığı riskleri önleyebilir. En önemlisi ise geliştirilen bu yeni süreç ve sistem ile sayım sürecinde insan sağlığını tehlikeye atan durumlar ortadan kalkmaktadır.

Anahtar Kelimeler: Envanter yönetim sistemleri, stok yönetimi, iç mekan lokalizasyonu, bilgisayar görüsü, sensör füzyonu

1
INTRODUCTION

1.1 Literature Review

1.1.1 Examination of Existing Stock Counting Processes

The main reason behind the emergence of the project idea has been the manual methods currently applied in most warehouses for the management of the counting process. Although the counting process is critical importance in terms of operational quality and inventory accuracy of products today, it poses serious risks in terms of occupational health and safety, contains operational inefficiencies and cannot be monitored systematically. For the selected pilot operation, the annual stock counting process which is currently applied has been performed and the workflow of the process has been established as below:

1. All other operational processes (such as goods acceptance, product placement, collection, shipment, final control) are stopped while counting.
2. The counting lists of the locations to be counted are printed manually by the counting operators.
3. The counting of each location in the warehouse is performed by using RT. (It performs 2 people, one person using RT and one person in the basket used for counting.)
4. The counting lists containing the counted location information are entered into the warehouse management system manually by the counting operators.
5. The locations that do not match with the WMS are determined and the list of locations that do not match is printed.
6. Mismatched locations are rechecked by warehouse personnel.
7. Systematic arrangements are made according to the location lists that do not match.

8. After warehouse facility finished the inventory management process, the customer checks the inventory for last control and the counting process ends.

1.1.2 Literature Search, Market Research and Patent Research

At this stage of the thesis, literature review, market research and patent - related researches were made for the counting methods used in inventory management. Firstly, research titles were determined for detailed literature and product scanning. These titles can be summarized as follows:

- Occupational health and safety practices
- Barcode reading with camera
- High resolution cameras and lenses
- Inventory management in warehouses
- Barcode reading with image processing
- Localization sensor usage in warehouses
- İndoor localization methods

In researches for barcode reading methods, it has been seen that every line of the barcode can read by applying the edge detection method to the taken image from the camera with image processing algorithms [1]. Regarding the conversion of the data on the detected barcode into binary format and finding the character equivalents, examined taking into account the solvent algorithm method given in the article written by Chai, D. and Hock, F [2]. Since processing of a high resolution image due to the excessive number of pixels requires an intense processing load, the article on the barcode recognition algorithms to reduce the processing load written by Burian, A., Vehviläinen, M. and Kangas, J. examined. Accourding to article [3] after converting from colored(RGB) image to gray scale image, if the region where only the barcode is detected and processed, not the whole image, the processing load will be less and real - time image processing can be done.

Studies on methods to solve 1D and 2D barcodes are abundant in the literature. Decoding one - dimensional barcodes which are created for reading with laser readers with a camera is relatively difficult to decode square codes which are developed in accordance with the digital cameras especially under harsh conditions such as light change and glare, label quality impairment. However, the use of one - dimensional

barcodes on the products continues to be superior. The decoding of QR codes, which are suitable for the digital cameras due to allow the pixels to be decode quickly, can be done in a more healthy and high accuracy compared to 1D barcodes [4–6]. Within the scope of this thesis, the device to be developed will grab the pallet images automatically while in motion and 1D barcodes will be decoded over the photographs taken. The literature review was made in line with this target. As a result of the researches; it is considered there will possible data losses in the images due to the motion blur and light deficiencies in the warehouse environment. It is predicted that reading the barcode by post process will be challenging. In studies in the literature, it has been observed that artificial intelligence and machine learning methods are frequently applied in barcode readings under difficult conditions. Image processing will consist of two main parts. First of all, the barcode area must be determined from the whole image and it must be decoded to match the existing data in the system which is correct from one - dimensional barcodes in the barcode areas found.

Zamberletti et al. studied for detect to 1D barcodes under taken challenging conditions. They proposed on the properties of the Hough Transform in their study [7]. They trained supervised machine learning model which is named as MLP (Multilayer Perceptron) to identify the rotation angle of every barcode in taken images by analyzing their Hough Transform spaces and a subsequent phase detects the bounding boxes surrounding those barcodes. Their algorithm be able to detect the barcode area on the images in 270 ms even under challenging conditions such as partially damaged barcodes. As a conclusion their algorithm has added to ZXing barcode reading library which is a robust library for barcode reading [8]. On the other hand Lin et al. in their study, presents an automatic barcode detection and recognition algorithm for multiple and rotation invariant barcode decoding. They segmented the barcodes by applying background small clutter reduction, candidate barcode segmentation, barcode verification and barcode rotation and regularization for coarse - to - fine operation. Their approach consists Gaussian smoothing filtering, connected component analysis, orientation homogeneity, moment analysis and iterative thresholding processing methods. Their algorithm achieved 90.7 percent of accurate reading rate at 331 ms on the overall [9]. Tekin and Coughlan propose a Bayesian framework for decoding 1D barcodes that models the shape and appearance of barcodes, allowing for geometric distortions and image noise, and exploiting the redundant information contained in the parity digit [10]. Their study doesn't need to detect barcode area first, this is the main advantage of their study. Another study which is published by Gallo and Manduchi uses likelihood function to decode barcodes. With their algorithm the need for binarization before barcode decoding has been eliminated due to the using deformable barcode digit models in a maximum likelihood settings

[11]. When the study results are analyzed, it is thought that this study will allow the reading of barcode photographs with low resolution and data losses.

For the interior localization of the system, drone control methods which are related to drone interior positioning where many studies are still conducted in the literature, have been examined. Mapping and locating methods with wireless sensors or cameras used studies are seen. In the mapping methods, the internal environment where the application will be made is mapped and the location information is calculated on the IMU (Inertial Measurement Unit). It was observed that this method was successful in short - term applications, but due to the continuous increase of the integral value of the acceleration value obtained from the output of the IMU unit, the position value will be continuously increased and the system went into instability. In another method, using wireless sensors, the location information can be determined by using the triangulation method when the transmitter on the drone enters the sensor range. It has been concluded that the disadvantage of this method is to use a large number of sensors for the warehouse (high cost) and where the metal density is high such as warehouse, wi - fi communication cannot be done in a healthy way. In the patent research conducted for stock counting with the drone, the drone, which is controlled by a RF barcode reader integrated with the drone, is directed towards the pallets and the data read by the barcode reader is transferred to the computer in the patent numbered 2016/0247116 by Craig Olivo and Micheal Buzaki [12]. It was observed that the patent was inadequate about the drone controlling with an external RC controller in the warehouse environment due to the interruption of the signal caused by the metal density and decided to design system fully autonomously to avoid fuzziness.

To determine the goals and objectives of the thesis project clearly, to design the best practice to achieve the goals and objectives, to validate the practice, all the inventory counting methods have examined. According to field research, the other methods used in counting and the results of the evaluations regarding these methods in this thesis project are listed below:

- In the counting with counting cage method, an employee is tied to a cage which is attached to the RT's forks. The employee counts the rack locations while RT is moving, and filling the papers in his hand according to the information read from the shelf.
- In the counting with manlift method, a hydraulic scissor system known as human lift instead of basket is used. There are serious occupational health and safety threats arising from the working at height of 10 - 15 meters both in these

two methods. And these methods are open to human mistake and there is no evidence of a retrospective systematic record.

- In the counting with by using RFID tags method which has become more widespread; for the systematic record keeping RFID tags must attached to each of the products [13]. In this method, the tags attached on each product cause an increase in the inventory management process costs. This cost can be eliminated by adding the price to the product's sale price in organizations that have their own production line and storage. But in the organizations that only carry out the storage business RFID tags cause extra costs because each tag is attached to only one product and tags cannot recycle. In addition, serious investments are needed to make the recording data of these tags correctly because warehouses are metal - intensive environments due to metal stocking shelves.

- Also there are frequently encountered warehouse inventory counting software but this software cannot solve the problems caused by the counting process in the field. Although the inventory counting process at the warehouses is critical importance in terms of operational quality and stock accuracy of products; it has serious risks in terms of occupational health and safety, includes operational inefficiencies and cannot be monitored systematically.

1.2 Objective of Thesis

Although the counting process is critical important in terms of operational quality and inventory accuracy of products today, it poses serious risks in terms of occupational health and safety, contains operational inefficiencies and cannot be monitored systematically. The main reason behind the emergence of the thesis' project idea has been the manual and risky methods currently applied in most warehouses for the stock counting process. With the new method to be developed, it is aimed to prevent work accidents and increase productivity as a result of harmonious programming of software and integrated devices. The current counting method will be redesigned and presented to the logistic sector due to the following reasons with the success criteria shown in Table 1.1:

- The working conditions at height is contained risks in terms of occupational and worker health

- New technologies are needed to provide automation dynamically in warehouse and product layout arrangements

- Current stock counting methods are caused loss of work power, time, resources and energy
- The current process is open to human error
- The current process couldn't be followed systematically.

Table 1.1 Targeted success criteria

Measure of Success	**Target Value**
Number of work accidents in the counting process	0
Expected efficiency increase	%59
Expected decreasing of average entry time to system per location	%35
Inventory location accuracy	%99

1.3 Hypothesis

With the sensor design to measure for localization of the camera, a high resolution camera can be triggered automatically while on the move, and the counting process in the warehouses can be automated by reading the barcode information from the taken image with image processing.

2
SYSTEM DESIGN

The main purpose of the thesis project is to automate the manual counting procedure by photographing the pallets on the shelves in the warehouse, making location mappings(by processing the barcodes on the pallet) with the stock in the warehouse management system. For this purpose, it was considered to design and manufacture a vehicle(robot following the line) to record the images of the locations by traveling autonomously in the corridor. However, the market superiority to be achieved through the use of mobile vehicles already in each warehouse was considered; Instead of adding the autonomous vehicle to the system cost, it was decided to use the reach truck(RT) used in each warehouse. In this process, the advantages and disadvantages of RT have been evaluated and solutions have been developed to eliminate the disadvantages.

Advantages of using RT for the movement of the opto - mechanical system;

- The fact that the company will not pay extra fees for the moving parts since it is a movable equipment that is already used in every warehouse
- As it is intended to put and take products on high shelves, it can reach high(10 - 15 m) distances with a certain vibration sensitivity
- RT can move smoothly without deviating from the set location
- The wheels of RT do not skid
- Adjustable and fixed infrastructure can be fixed to a certain speed(for some versions)

Disadvantages;

- The biggest disadvantage is that the RTs are generally rented in warehouses and due to this the system of the RT is inaccessible according to rental contract

- The proximity to the rack cannot be measured(with standard RT conditions)
- Vertical rising of the RT cannot be measured(with standard RT conditions)
- Due to no data regarding speed and/or location from RT wheels horizontal movement cannot be measured(with standard RT conditions)

Advantages have been considered and it has been decided that the system will work integrated with RT since effective solutions are provided for disadvantages.

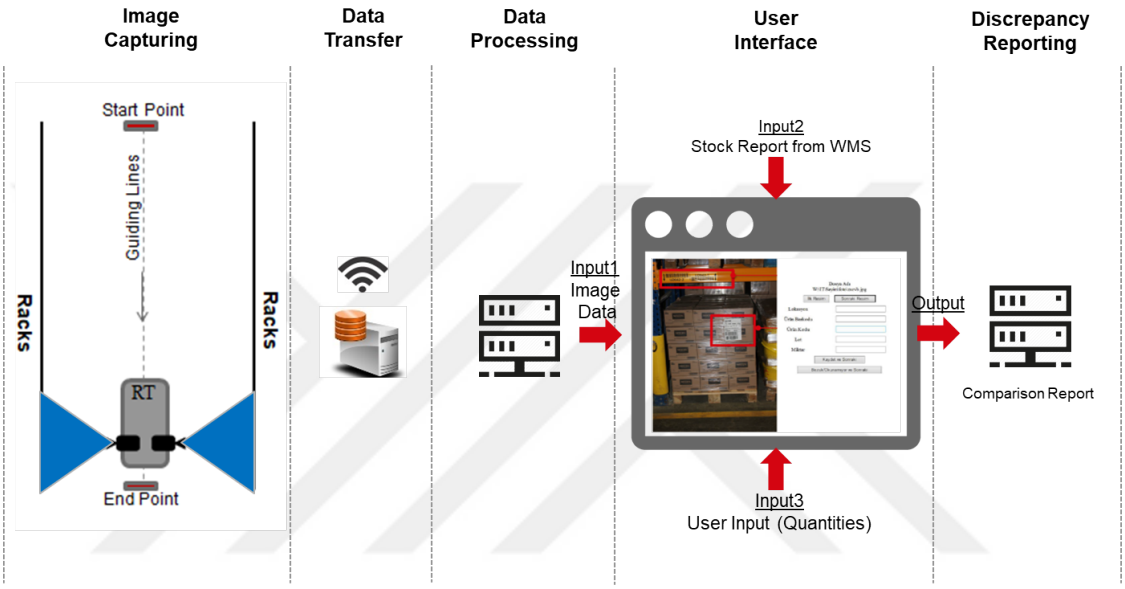

Figure 2.1 Automated image shooting general system design(decision unit) using vertical and horizontal measurement sensors for positioning the RT and triggering the camera.

With the imaging system to be developed; it is desired to take images suitable for image processing between two shelves and from a certain distance. An automated system is designed in the image acquisition section without leaving the operator as much as possible.

As seen in Figure 2.2, it is planned to connect two cameras to the right and left of the system that will be integrated into RT. Thus, the locations both on the right and left of a corridor will be displayed in one cycle, and half the time will be saved. In order to prevent the camera focus and therefore the image quality from deteriorating, guidance lines will be drawn that will allow the RT to be applied to the ground from the middle and straight, and the RT operator will follow these lines at a constant rate. For start and end points, guide lines will be drawn on the ground for the RT driver.

The distance changes on the horizontal and vertical axes of the RT will be measured with sensors(with laser distance measurement sensor and wheel encoder), the camera

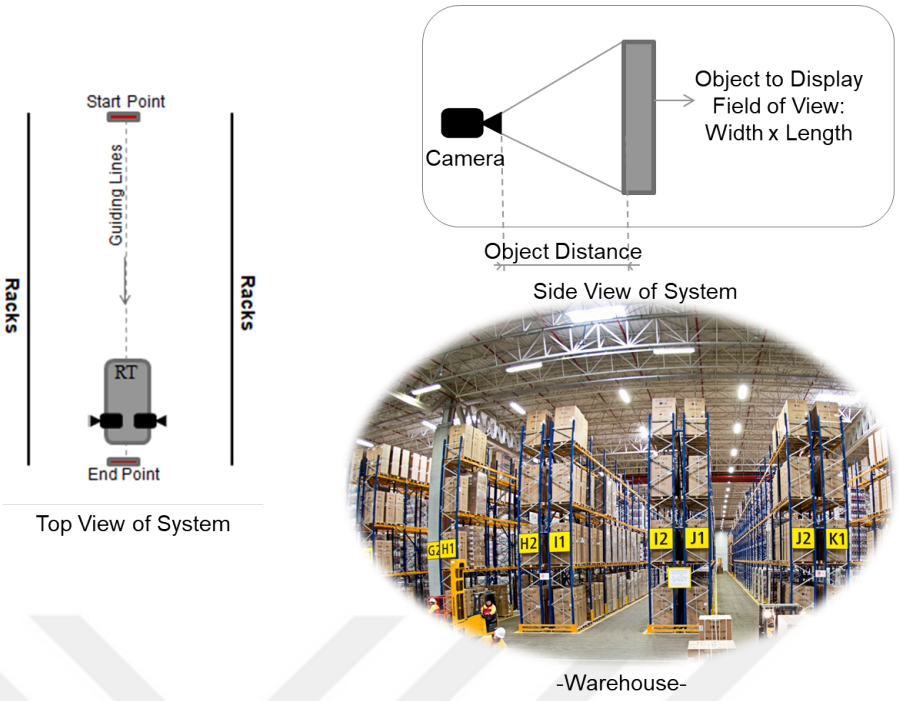

Figure 2.2 Side and top views of the system

will be triggered at the determined distances depending on the pallet position and camera image area and the photo shooting will be automated. Automatic triggering will be achieved by processing the data received from the sensors.

The received images will be sent to the computer via wifi(via the router to which the camera will be connected), after the counting process begins, then these images will be processed in the image processing program by running the server side, and the processed images will be displayed on the computer screen of the person making the count with the web interface software. The interface to be used by the staff who will perform the counting from the screen will be designed very simple, and the staff will be able to enter the counting information into the pallet by zooming on the full rack image.

As a result of the observations made in the warehouse;

- Shelf intervals(height) increase as you go up to the top shelves, and this increase is not standard in every corridor and/or every operation
- It has been observed that the pallet dimensions have changed from shelf to shelf

Since the focus setting of the industrial camera is not automatic, these differences may cause us to get the incorrect image and cannot view the entire pallet. This situation can be solved by developing computer vision algorithms by using motor - controlled auto

- focus lenses, but it will not be effective at the first stage to separate the workforce into this part since the project is not the subject focus. The situation of not being able to take the full pallet image and/or the pallet shifting from right to left at the location should be solved with the image stitching and image mosaicing algorithms. The images will be taken in width x height suitable for the field of view of the camera, and the captured images will be combined from their matching pixels. Obtaining the image of the whole shelf by real - time image mosaicing on an industrial computer is the desired point, but is not within the scope of this project.

2.1 Opto - Mechanical Design

2.1.1 Camera and Selection Criteria

Basically a camera system consists of three main parts: image sensor, lens and image processing circuits. Basically reflected light from objects is collected in the lens, transmitted to the image sensor which converts this light into electrical signals, and electrical signals are arranged in image processing circuits. Electronic circuits that

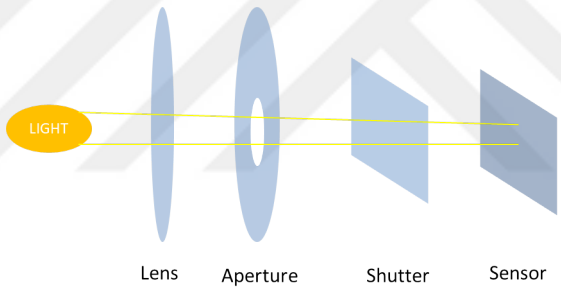

Figure 2.3 Digital camera working principle

convert the reflected light from objects(after breaking the lens as seen in Figure 2.3 and adjusting the appropriate light intensity with the aperture) to electrical signals [14]. Each light beam generates voltage at various powers through this sensor. Processors inside the camera process this voltage, allowing images to appear on the monitor. Each voltage produced by the sensor determines the gray shade of a pixel. Color filters are used to obtain the R, G, B(red, green, blue) color ratios. As can be seen in Figure 2.4, the higher the number of pixels, the clearer the camera image.

There are two types of image sensors known as CMOS and CCD. The sharpness of the images is directly related to the amount of light the sensor processes. Therefore, the larger the size of the sensor, the higher the image quality. Although CCD sensors give better quality images, they have disadvantages such as higher price and higher power consumption. CMOS sensors, on the other hand, require less energy and are cheaper, although there may be a noise problem [15].

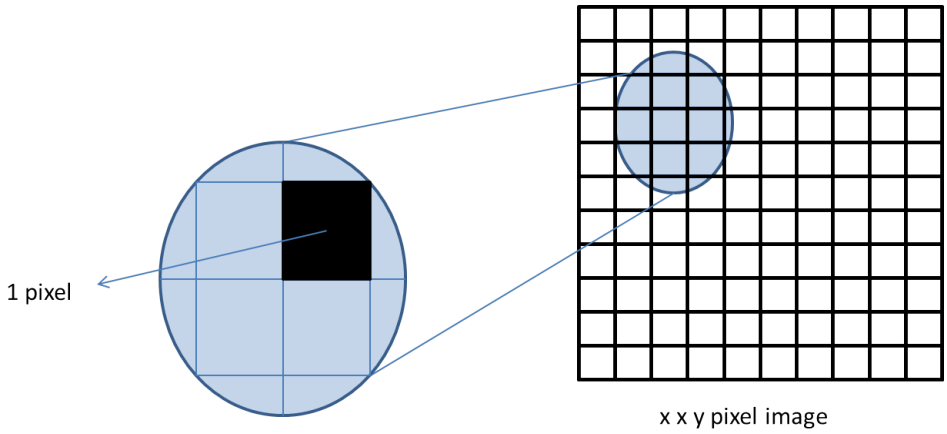

Figure 2.4 Image resolution - pixel size

2.1.1.1 Resolution

The resolution of the image sensor determines the number of pixels of the camera. The voltage value between 0 and 1 taken from the image sensor indicates the grayscale value of the image. The low or high number of these pixels on the sensor affects the image quality. As the number of pixels increases, the number of small squares falling in the area shown in Figure 2.4 will increase, so the details in the image will become evident. For the pixel, we can say that it is the smallest unit in the horizontal and/or vertical of the image. However, the resolution mentioned here should not be confused with the screen resolution. Sensor pixel size is also important in the quality of the image taken from the camera.

$$Pixelsize = SensorSize/Numberof\,Pixels \tag{2.1}$$

The smaller the pixel size, the more light is required to capture an image [16]. Pixel size should be chosen considering the environment in which the camera will be used. In the case of a small amount of light, the small pixels will produce louder images than the large pixel, and the dynamic image response will decrease. Noise for image processing is undesirable. In order to balance the noise, the light intensity adjustable led lighting will be used in the warehouse environment by changing the light intensity to find the appropriate value. Just the high megapixel value of the camera does not mean that the image will be of optimal quality. High resolution lenses are needed for cameras with small pixels. Otherwise, blurred and distant images are obtained with many pixels.

Not all shelves in the corridors in the warehouse are the same. There are also locations with triple, double and single pallets. The dimensions and layouts of these locations are kept up to date with the autocad drawings. There are two types of pallets used in the warehouse(euro pallet and us pallet); euro pallet dimensions are 80 cm x 120 cm,

us pallet dimensions are 100 cm x 120 cm. Shelf height varies according to product types and can be in four different heights: 120 cm, 190 cm, 240 cm, 260 cm.

In the first phase of the thesis project, it is aimed to display a pallet with an average width of 100 cm as pallet - based shooting is targeted as much as possible. To find the resolution value that the barcode can be read, we need to find the pixel/cm ratio in the Figure2.5. Figure2.5 shows a pallet image taken with a CMOS sensor camera

Figure 2.5 Location and pallet barcodes

with a resolution of 5 Megapixels tested in the warehouse. On the side, barcodes to be read by computer vision and their dimensions can be seen. The project aims to read the location barcode and the SSCC of the pallet. The location barcode width is larger than the label width on the pallet. For this reason, calculations should be made according to the label sizes in the pallet, which is a critical variable. The horizontal and vertical resolution calculation of the camera depends on the area to be displayed and the pixel density(ppm) in the image. Resolution calculation is possible with the Equation2.5. At this stage, it is calculated how many pixels should fall to 1 mm in the horizontal axis of the image so that the thinnest barcode bar(or space) on the pallet corresponds to a minimum of 3 pixels. The minimum 3 pixel value here has been determined according to the needs of the barcode reading software to be made with image processing [9].

The actual value of the thinnest bar(or space) in the Code39 barcode seen in the

images above is 1 mm. For the barcode reading software to work effectively, the pixel density must be minimum 3pixel/mm. Euro pallet width is 80 cm, US pallet width is 100 cm and critical pallet US pallet width is selected(100 cm). It has been decided to in this case 10 - 12 Mpx camera will be appropriate.

2.1.1.2 Camera Interface

Computer based machine vision systems are the most used systems due to their best performance and flexibility in terms of price. The common purpose of machine vision architectures is to analyze images from a physical sensor and transfer them to a processing unit. However, the starting point and ending point of all physical architectures are the same, a camera and a processor to create digital images.

There are advantages and disadvantages to use five different major camera buses: USB 2.0, USB 3.0(USB Vision), Camera Link, IEEE 1394 and GigE Vision. Within the scope of the thesis, detailed investigations were made regarding the camera buses in question.

- **Camera Link:** This digital bus specifically designed for machine vision purposes, and this bus has the highest efficiency of any camera path. Camera Link supplies three - layer bandwidth structure to serve to a variety of applications. These cameras prices are higher than low - performance cameras, as Camera Link is designed to produce medium and high - performance images.

  Camera Link defines its own standards. To use Camera Link cameras you need a special camera configuration file to explain how to import images to the camera, how to communicate with the camera, and what features can be changed. Camera Link provides an option known as Power Over Camera Link(PoCL) to power cameras over a cable. Because Camera Link cameras transfer image data to memory using DMA channels(do not load on the computer's CPU), Camera Link cameras use very little of the system CPU. Camera Link cameras are the cameras that offer the most flexibility and capability.

- **USB 2.0 Vision:** Although USB 1.1 does not have enough bandwidth for another camera than a basic webcam, USB 2.0 has enough bandwidth for video streaming. USB 2.0 targets low cost needed machine vision applications. It means, if you don't need industrial features, you can use USB 2.0 cameras due to low costs and ease of use(these cameras will directly work with an USB port plugin). Optimum cable lengths are usually less than 5 m(without a repeater). Main disadvantage of the use these cameras for machine vision applications, there is not standard to video acquisition devices. USB provides power over the

same cable; this does not require a separate power cord. USB 2.0 uses utilities such as DirectShow to import images to the computer. While these tools work well, they create a load on the CPU. Utilities such as DirectShow do not supply any type of interface for triggering or communication.

- **USB3 Vision:** USB 2.0 provides a 60 MB/sec throughput, while USB 3.0 provides a 400 MB/sec throughput. This is faster at 255 MB/sec than Camera Link Base configurations, and approaching the middle configuration Camera Link camera at 510 MB/sec. Cable lengths for USB 3.0 are generally less than 5 m without a repeater, similar to IEEE 1394 and USB 2.0. Although the USB 2.0 standardization is relatively weak, USB3 Vision is based on existing standards such as the standard for GigE Vision and Gigabit Ethernet devices, so cameras will have an XML file that defines supported camera features.

  USB 3.0 also powers up to 4.5W over the same cable, which does not require a separate power cable. USB3 Vision allows to transfer zero copy image data directly to the host memory without CPU usage. Similar to the 1394 and GigE Vision, I/O synchronization is challenging without an image transmitter to mediate communication signals and triggers. Some USB 3.0 cameras provide direct trigger input and output lines. Also, with a few plug - in cards, isolated digital I/O can be provided, which greatly simplifies system synchronization.

- **IEEE 1394:** The IEEE 1394a supplies a maximum data rate of 400 frames/sec. The IEEE 1394b features have doubled the available bandwidth to 800 Mb/sec and the maximum frame rate with 640 x 480 to 200 frame/sec.

  Offering digital image quality, extended features and ease of use, IEEE 1394 cameras are relatively inexpensive. Also, no special image digitizer is required for image transfer to the computer. Considering low cable costs, IEEE 1394 is an affordable image transfer way. IEEE 1394 cameras use commonly available standard and low cost cables. For IEEE 1394a, while point - to - point connections are up to 5m max, it is possible to extend the ranges using repeaters. IEEE 1394 cameras as known as the easiest camera to use camera interface due to the hardware, software and cabling standard. IEEE 1394 cable has power. Most cameras can draw power on the IEEE 1394 bus without the need for an external power supply. An external power supply is required for high power devices.

- **GigE Vision:** Gigabit Ethernet is a relatively new camera digital bus protocol for machine vision systems. It provides relatively high cable length, high bandwidth, security and long - distance. Although in practical the bandwith is 125 MB/sec, in practice the maximum bandwidth is closer to 100 MB/sec due to hardware

and software loses. GigE Vision bandwith is same as IEEE 1394 still Camera Link's bandwith is better.

Although the GigE Vision cameras are more expensive, the total system cost is almost the same as the IEEE 1394 due to the cheaper cable prices. It can be said that GigE Vision is an advanced version of Gigabit Ethernet cameras with its plug and play feature, device discovery, error processing and secure image transfer features. GigE cameras generally have power transmission(PoE) with an ethernet cable. It is recommended to use a power switch, hub or POE injector in cases where Ethernet cards cannot provide enough power.

The USB Vision(3.0) camera can transfer 400 MB images per second(400 MB/s). On other GigE vision cameras, which provide high speed transfer, this value is 125 MB/s. While GigE vision cameras can use longer cable, USB Vision cameras enable shorter cable usage compared to GigE Vision cameras. However, in the system we designed, the cable length(max 5 m) allowed by USB Vision between the camera and the industrial computer is sufficient for us and the more important thing is that it can transfer data faster. In addition, while USB Vision cameras do not use CPU while transferring images, GigE Vision cameras need CPU usage to clean the noise caused by other data in the image.

I/O synchronization is equally demanding for both GigE and USB vision cameras(although connected to the camera). SW triggering is considered to be faster in terms of camera triggering. With all this in mind, a USB Vision camera has been chosen.

2.1.1.3 Frame Rate(FPS)

The value, expressed as frame per second(fps), refers to the maximum number of images you can record with the camera in 1 second. Explaining it in more detail, a video shooted with a 60 fps camera is more fluid than the video shooted with a 30 fps camera. As the number of images that can record per second increases, captured number of images get closer to the real time stream. In this thesis project, the fps value of the machine will not be critical since the system will record 1 image in an average of 1and a half seconds.

2.1.1.4 Shutter type

While shooting with the camera, the rays coming out of the objects pass through the lens and aperture, are digitized on the sensor and recorded pixel by pixel, and the sum of these pixels is perceived as a picture. As CMOS sensor cameras increase the shooting speed(the movement speed of the shot object or the movement speed of the

shooting camera), rolling shutter machines will cause the image to shift [17]. This is because the image recording is made pixel by pixel. On rolling shutter cameras, the process on CMOS is done in the size of horizontal pixels(for example, a 640x480 resolution image consists of a pixel matrix with 640 lines and 480 columns and rolling shutter cameras(1,1),(1,2),(1,3), ... Records the first line in the form of(1,480) and then records the other lines in the same way. For example, if the video of a helicopter in the air is recorded with a rolling shutter CMOS camera, it will be observed that the ends of the propeller have slips and bends. In addition, since digital digitization is performed simultaneously for the entire frame in global shutter cameras, this is not the case. In CMOS rolling shutter cameras, the rolling shutter effect is more clearly at higher speeds. Although it is recommended to use cameras with high fps value, rolling shutter effect cannot be prevented [18].

The Global Shutter camera is preferred because photographs will be taken in a mobile system in the thesis project. This is because the rolling shutter converts the analog image line by line, while the global shutter rotates in one cycle. The use of rolling shutters in a moving system will cause slips. Since the prices of rolling shutter cameras are more affordable at the stage of determining the parameters, the use of rolling shutter cameras is considered. However, when the images taken in the trials in the warehouse were examined(shooting with a moving system), it was decided to use a global shutter camera in spite of the possibility of slipping in the barcode labels.

For the camera selection, sensor size and resolution values were calculated and different cameras were tested with the suppliers in the warehouse environment. As a result of these tests, the resolution was decided to be 12 Megapixels and monochrome of the camera. Two different views of Basler acA4112 - 20um industrial camera are shown in Figure2.6. The camera can provide connection to the lens with a C - type mounting mouth.

Figure 2.6 Purchased basler acA4112 - 20um industrial camera

2.1.2 Lens and Selection Criteria

The lens is a very important part of the camera in reaching the desired resolution and angle of view. If the correct lens is not selected, the expected resolution cannot be achieved. A lens contains iris and includes multiple lens adjustments that allow it to focus, zoom in and out. The resolution obtained is determined by the number of pixels on the camera sensor, electronics, compression and lens quality. Even if the camera with a resolution of 5 megapixels is used, the 5 Megapixel image of the camera sensor cannot be achieved if the lens has only 1 megapixel resolution. In addition to the resolution of the camera, the lens system determines how far and/or soon the subject will be displayed. To determine the dimension of the viewing area the angle of the lens is also very important. Figure2.7 shows the focal length and object distances of

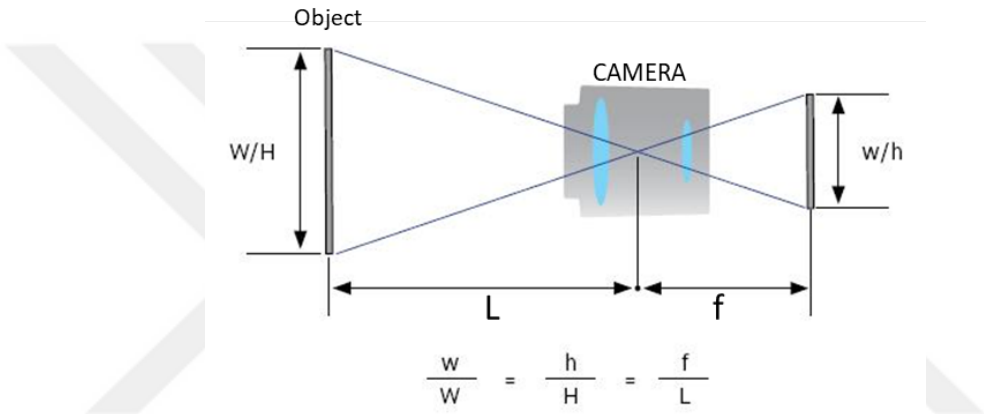

Figure 2.7 Focal length calculation

the camera with the lens. The focal length of the lens to be selected can be found in the simplest form, depending on the distance of the object to the camera, with the 2.2 below:

$$\frac{h(SensorHeight)}{H(ObjectHeight)} = \frac{f(FocalLength)}{L(ObjectDistance)} \tag{2.2}$$

Other factors to consider when choosing lenses:

- The resolution of the lens to be used should not be lower than the resolution of the camera.
- Like cameras, lenses are classified according to their sensor format sizes 1/2”, 2/3”, 1/3”, 1/4” etc. When the lens format is smaller than the format of the camera, the places other than the sensor cannot be seen. It is the most suitable solution to choose the camera format and the lens format as a secondary solution.

- It is very important that the connection types are compatible. If C mount camera is selected, C mount lens should be preferred.
- The F - number specification in lenses defines the amount of light that can pass through the aperture. The lens's ability to collect light is used to adjust the amount of light that falls on the field of view. The lower the number of F for low - light applications, the better the image.
- Lens type should be chosen according to the application. Fixed focus, varifocal, zoom lenses should be chosen.

2.1.2.1 Field of View(FOV):

A fixed focal length lens, also known as a conventional or entocentric lens, is lenses with a fixed "angular field of view(AFOV)". AFOV is usually specified at the full angle(in degrees) associated with the horizontal size(width) of the sensor where the lens will be used. Fixed focus lenses are designed to be used within a single specific working distance [19]. The focal length of a lens defines the angular field of view of

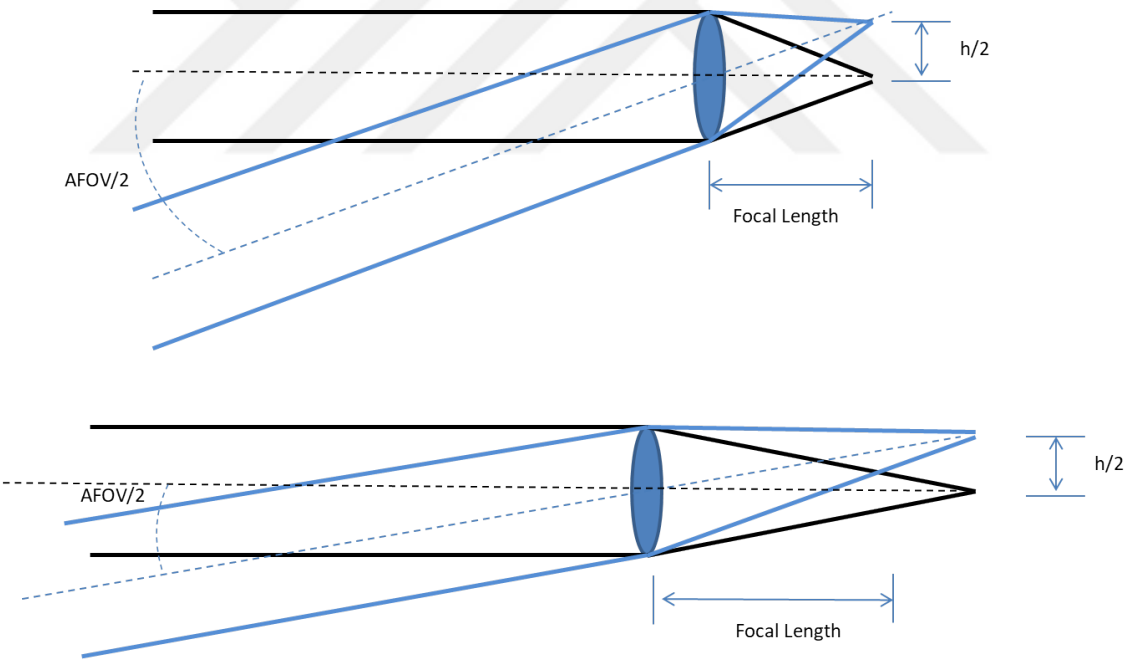

Figure 2.8 Relation between focal length and field of view

the lens. For a given sensor size, the shorter the focal length, the wider the angular area of the lenses(see Figure2.3. For a simple, thin convex lens, the focal length is the distance to the lens plane of the image of an object placed infinitely far in front of the lens behind the lens. From this definition, the angular field of view(AFOV) of a lens

is f(focal length in millimeters) can calculated as Equation2.3 below:

$$AFOV(AngularFieldofView) = 2 \times tan^{-1}\frac{h}{2 \times f} \tag{2.3}$$

When using fixed - focal length lenses, the following can be done to change the field of view of the system(camera and lens):

- Working distance from lens to subject can be changed(moving the lens away from the object plane increases the field of view)
- A lens with different focal length can be used
- The size of the image sensor used can be changed. A larger sensor will provide a wider field of view for the same working distance.

Another way to change the field of view of a system is to use a Vari - Focal Lens or Zoom Lens; such lenses allow adjustment of focal lengths so that variable angular field of view can be obtained. Vari - focal and zoom lenses often have disadvantages in terms of size and cost compared to fixed focal length lenses and often do not provide the same level of performance as fixed focal length lenses.

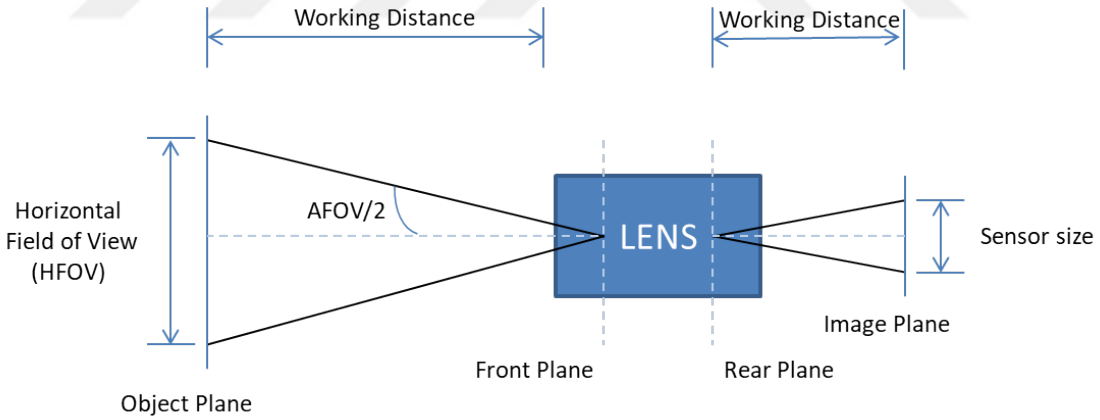

Figure 2.9 Sensor size - working area - angular field of view relationship for a specific field of view

The distance of the object to the camera and the desired field of vision are the values determined in the thesis project according to the requirements(Definitions and descriptions are shown in Figure2.4). Angular field of view can be calculated with these values.

$$AFOV = 2 \times tan^{-1}\frac{HFOV(HorizontalFieldofView)[mm]}{2 \times WD(WorkingDistance[mm]])} \tag{2.4}$$

The horizontal resolution of the image can be found with FOV(field of view) and the number of pixels per millimeter(ppm) as in the Equation2.5.

$$HorizontalResolution = FOV \times PPM \tag{2.5}$$

The project aims to read the location barcode and the SSCC of the pallet. The location barcode width is larger than the label width on the pallet. For this reason, calculations should be made according to the label sizes in the pallet, which is a critical variable. The horizontal and vertical resolution calculation of the camera depends on the area to be displayed and the pixel density(ppm) in the image. To choose camera firstly, it is calculated how many pixels should fall to 1 mm in the horizontal axis of the image so that the thinnest barcode bar(or space) on the pallet corresponds to a minimum of 3 pixels. The minimum 3 pixel value here has been determined according to the needs of the barcode reading software to be made with image processing [9]. The actual value of the thinnest bar(or space) in the Code39 barcode seen in the Figure2.5 is 1 mm. To read barcodes on the images the horizontal resolution must be above 4000 pixels(this value calculated according to basic pixel/cm rate calculation). After finding that a minimum horizontal resolution of 4000 pixels is needed by a basic logic calculation, the accessible camera available on the market was selected according to this value. Then, the selection was verified by retrospective processing with the selected camera features. The f - value of the lens is calculated according to the sensor height of the selected camera with respect to((2.2)).

$$\frac{10,3[mm]}{2600[mm]} = \frac{f(FocalLength)}{1500[mm]} \tag{2.6}$$

$$f(FocalLength) = 5,94[mm] \tag{2.7}$$

According to this calculation, f is equal to 5,9 mm. However, since no lenses with an f value were found on the market, the closest f 8,5 mm was chosen.

Then with respect to((2.3)),((2.4)) and((2.5)) camera's horizontal pixel resolution can calculate.

$$AFOV(AngularFieldofView) = 2 \times tan^{-1}\frac{10,3}{2 \times 8,5} \tag{2.8}$$

$$AFOV(AngularFieldofView) = 61,8 \tag{2.9}$$

$$61,8 = 2 \times tan^{-1} \frac{HFOV(HorizontalFieldofView)[mm]}{2 \times (1500[mm]])} \tag{2.10}$$

$$HFOV(HorizontalFieldofView) = 1795,4[mm] \tag{2.11}$$

Horizontal resolution can be calculated with known HFOV value;

$$HorizontalResolution = 1795,4 \times 3 = 5386px \tag{2.12}$$

With selected camera and lens combination more than needed horizontal resolution value has been achieved.

Lens selection was made in accordance with the resolution, sensor format and connection type of the selected camera. Sensor format 1.1", focal length 8.5 mm, C - mount lens was purchased. The light intensity in the warehouse environment where the image will be recorded was observed and it was thought that selecting a lens with a low F(aperture) value would be appropriate to keep the amount of light entering the lens high. As a result of the tests, "Kowa LM8XC, 4/3", 8.5 mm F2.2 lens, which is seen in Figure2.10, was purchased. Due to the properties of the lens, a large projection area can be provided in the image.

Figure 2.10 Purchased kowa LM8XC lens

2.1.3 Exposure Time Calculations

In machine vision cameras, exposure time optimization is especially critical in applications where the object or camera is moving. Exposure time refers to the time the camera sensor captures the image. The sensor opens and closes for this time and turns the light falling on it into an electrical image. The exposure time has a wide range of change in industrial cameras, when exposure time value reduces the image capture process accelerates however to this the amount of light falling on the sensor is reduced. This situation requires the use of extra lighting, especially in closed and

dark environments. Optimization of exposure time - ambient light intensity is very important as the application developed within the scope of the project will be operated in a warehouse environment illuminated with artificial lights and will be shot while RT is moving.

The reason for the need to keep the exposure time value low is the occurrence of a phenomenon called pixel blur in moving shots. As the exposure time of the sensor increases; the processing time to convert image to electrical signal of the sensor increases, the image recording begins to fail to keep up with the movement speed of the object. In this case, blur occurs in the image. Pallet image taken while RT is in motion without any enhancement can seen on Figure2.11

Figure 2.11 Motion blur on an image

Pixel blur in the obtained image can be calculated with camera resolution in the direction of motion, speed of the object(or camera), exposure time and FOV values. If the calculated pixel blur value is within the tolerance range of 1/1000 when compared to the horizontal resolution, it will not cause a problem for machine vision applications. According to this calculation, the object speed - exposure time(hence the ambient light intensity) can be optimized. Pixel blur calculation can seen on

(2.13)(where V_{object} is speed of the object or camera).

$$BlurinPixels = \frac{V_{object} \times ExposureTime \times HorizontalResolution}{FOV} \tag{2.13}$$

For 1 pixel blur and 3000 microseconds exposure time(minimum speed);

$$V_{object} = \frac{BlurinPixels \times FOV}{ExposureTime \times HorizontalResolution} \tag{2.14}$$

$$V_{object} = \frac{1[px] \times 1795,4[mm]}{0,003[sec] \times 4000[px]} \tag{2.15}$$

$$V_{object} = 149,61[\frac{mm}{sec}] \tag{2.16}$$

For 4 pixel blur and 3000 microseconds exposure time(maximum speed in the range of 1/1000);

$$V_{object} = \frac{4[px] \times 1795,4[mm]}{0,003[sec] \times 4000[px]} \tag{2.17}$$

$$V_{object} = 598,46[\frac{mm}{sec}] \tag{2.18}$$

In order to be able to read barcode with image processing, the RT speed must remain between 149,61 mm/sec and 598,46 mm/sec.

2.2 Localization Sensors Design

2.2.1 Vertical Measurement

Distance measurement on the vertical axis requirement is due to the fact that the vertical distance of the RT is not known while RT is rising and descending. Since the camera will be mounted on the RT, knowing the RT's movement distance is critical in terms of both being able to view the pallets completely without going out of the camera's angle of view and informing the RT operator that the RT should be at the correct distance. This measurement has to be done manually since we do not have the right to intervene in the RT lift motor.

In the early stages of the thesis project, it was thought to take images from a tablet that would stand in front of the RT operator. But as a result of observations, it was found

that the RT operator who both uses RT and controls the image acquisition was risky in terms of the total count time and the accuracy of the images taken. For this reason, the system has been automated with sensors. For the vertical distance measurement reflective laser distance measurement sensor has been used. The solutions that can be developed without the need to make changes in the area where the system will be used have been considered and it has been seen that the distance measurement on the vertical axis can be made with the laser distance measurement sensor. As shown in Figure2.12, a laser distance measurement sensor, which can measure up to 15 meters, and which is suitable for the maximum distance that the RT(without the need for an extra reflector) will come out, has been purchased.

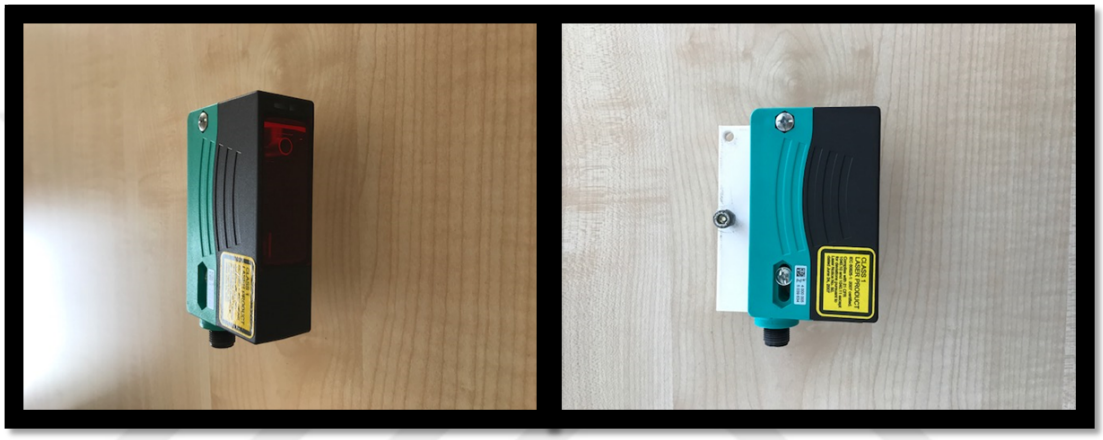

Figure 2.12 Purchased pepperl - fuchs 15m laser distance measurement sensor

An analog to digital converter was needed to transfer the data from the laser distance measuring sensor to the industrial computer. The values taken from the laser distance measurement sensor are analog signals and they must be converted to digital signals in order to be processed on an industrial computer. For this reason, an 8 - channel analog digital converter is purchased as shown in Figure2.13.

2.2.2 Horizontal Measurement

Distance measurement on the vertical axis requirement is due to the fact that the distance it takes in the horizontal is unknown. Knowing the horizontal distance is critical because the camera needs to be triggered at distances appropriate to the horizontal viewing angle. The lens with the viewing angle suitable for the palette width has been selected and accordingly the camera must be triggered every 100 cm on the horizontal axis. In the early stages of the automated system, it is considered to use a laser distance measurement sensor for horizontal axis distance measurement. However, laser distance measurement sensors suitable for warehouse width(up to 300 m);

Figure 2.13 Purchased adam - 4117 8 channel analog to digital converter

- Requires the use of a reflector(using the laser distance measuring sensor with the surface on which the laser beam will reflect). Using a reflector requires extra labor.
- The price of laser distance measurement sensors used at 300 meters is very expensive.
- The fact that the laser beam cut by a person or an object at any time during the counting affects the entire system highly .

A wheeled encoder can be mounted on the rear wheel of RT and position changing of RT can be measured from the number of pulses. Since the encoder cannot be connected to the wheel shaft of the RT, measurement is planned by transferring the rear wheel movement to the encoder wheel. It can be considered as the working logic of wheeled encoders used for fabric measurement in textile. The wheeled encoder has been preferred among other measurement sensors and methods considered during the selection phase of the components, both in terms of price advantage in the final product and with minimum intervention to the warehouse conditions. Wheeled encoder will be mounted on the rear wheel of RT and position change can be measured from the number of pulses. The purchased encoder, its wheel and attachments to the RT rear wheel can be seen in Figure2.14. It was not appropriate to transfer the data received from the encoder mounted on the wheel of RT to the industrial computer in the system mounted on RT by cable. The transfer has done using bluetooth technology.

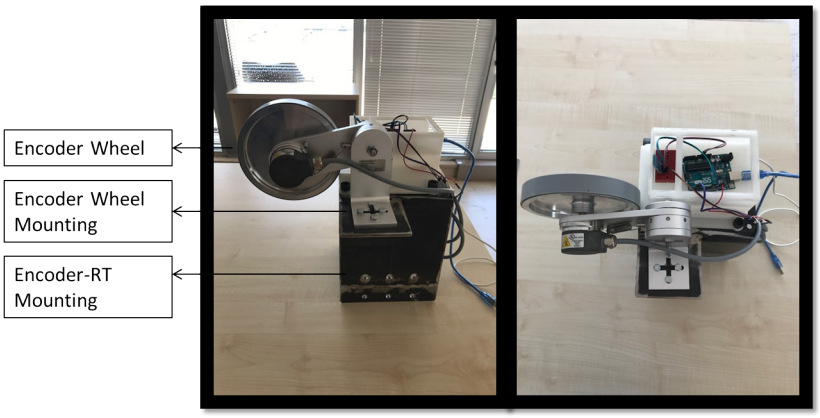

Figure 2.14 Purchased 500 palse kübler incremental encoder

2.3 Mechanical Design

Prototype studies have been carried out to test the functionality of the measures taken and the functionality of the system for the risks have identified as a result of research, field study and forecasting(occupational health and safety, camera stabilization problem, taking pictures suitable for image processing, etc.). The prototype to be assembled in accordance with the RT mast specified in Figure 1.4 has been designed and is shown in Figure2.15.

Figure 2.15 A side view of the reach truck(RT)

Reasons installing the mechanical carcass prototype on the load backrest:

• As seen in Figure2.17, the height of the load backrest is 560 mm high from RT forks. With installation of the carcass, 340 mm height gain will have.

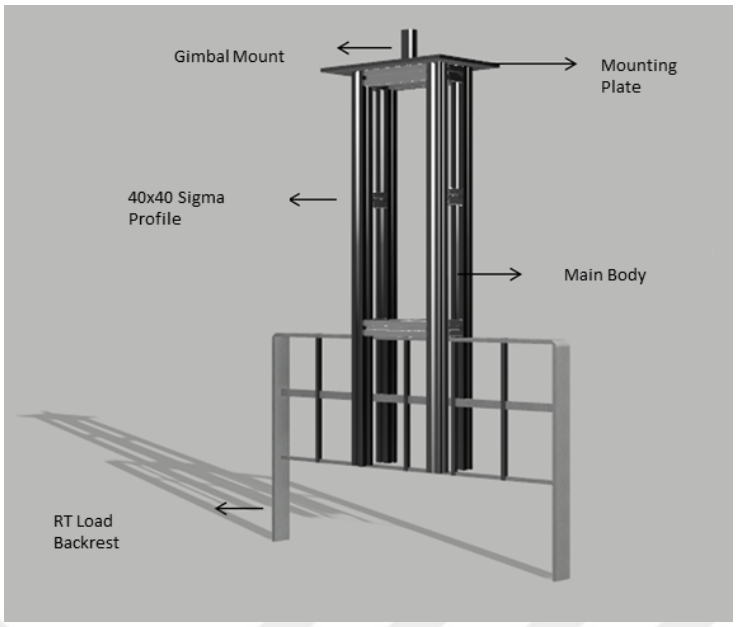

Figure 2.16 Mechanical carcass prototype design 3D model

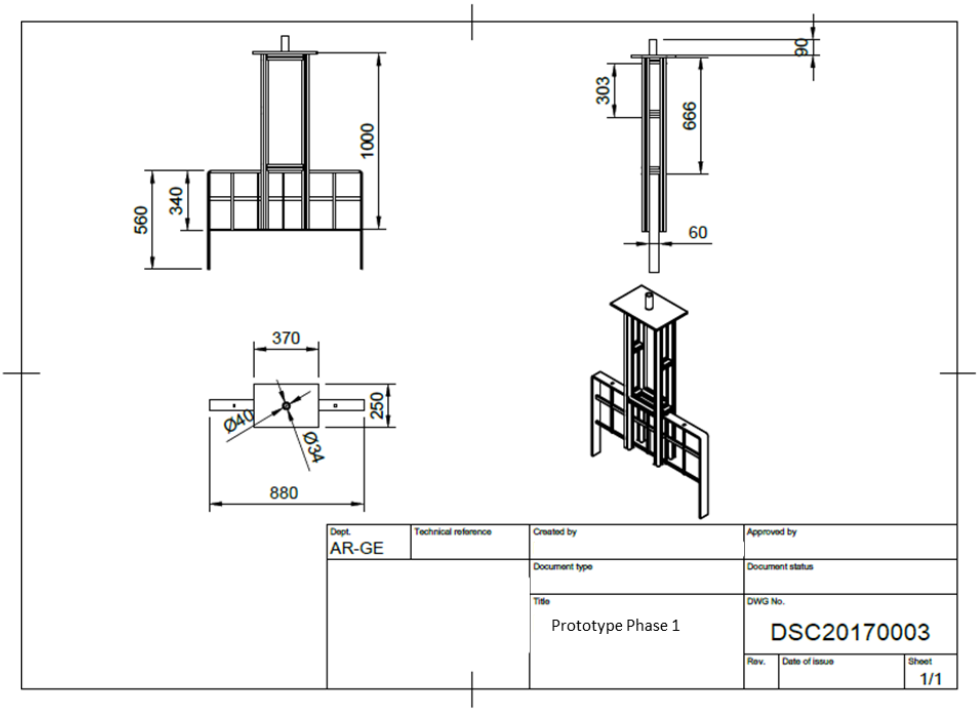

Figure 2.17 Mechanical carcass prototype technical drawing

- It is seen that the stabilization of the RT component, from which we can mount the mechanical carcass , is very important in order to be able to photograph the quality suitable for image processing. It is a load - bearing block with a minimum stabilization and suitable for assembly.
- Mechanical carcass to be mounted on the load backrest will not affect the operation of RT.

The forks of the RT model rise to a maximum of 12 meters. Warehouse rack's maximum stock height is 13.5 meters. For this reason, the mechanical carcass should be able to reach 1.5 meters height from RT forks. Also with the designed technical drawing in Figure2.17, the system will be able to rise 1.66 meters from RT forks and meet our height requirement.

The prototype mechanical carcass' main frame was modeled using 40x40 aluminum sigma profiles as seen in Figure2.16.

Reasons preferring aluminum profile:

- Aluminum profiles have mounting beds for fasteners on all four sides. Thus, easy assembly according to the counting needs of each operation It can be made and has height changeable advantages.
- Aluminum profiles are light materials. It affects the ergonomics positively during installation in the load shelter and ensures that it can be easily mounted.

As a result of the tests, the presence of the risk of contacting and hitting the mast with the rise of the mounting point of the main frame of the RT was observed. Considering the battery dimensions, which are the main power source of the vertical riser system, revisions and improvements were made in the main frame design. The main skeleton has been expanded. The frame that will be mounted on the backrest and the frame that will carry the equipment is separated and a two - stage frame is designed and manufactured. Technical drawings are given in Figure2.19.

On the Reach Truck, the most suitable area of the pre - prototype carcass for installation is load backrest with minimum vibration effect and 600 mm height gain. The main frame structure is designed to be placed on the load backrest. Installing the pre - prototype carcass, which will have to work at a maximum height of 13 meters is critical and poses occupational health and safety risks. At the same time, no machining process can not be carried out for mounting on the reach truck to protect the warranty coverage of the rental models. As a result of research and test studies,

Figure 2.18 Pre - prototype with risks to be integrated into the load backrest during the stage of the Reach truck installation point determination test

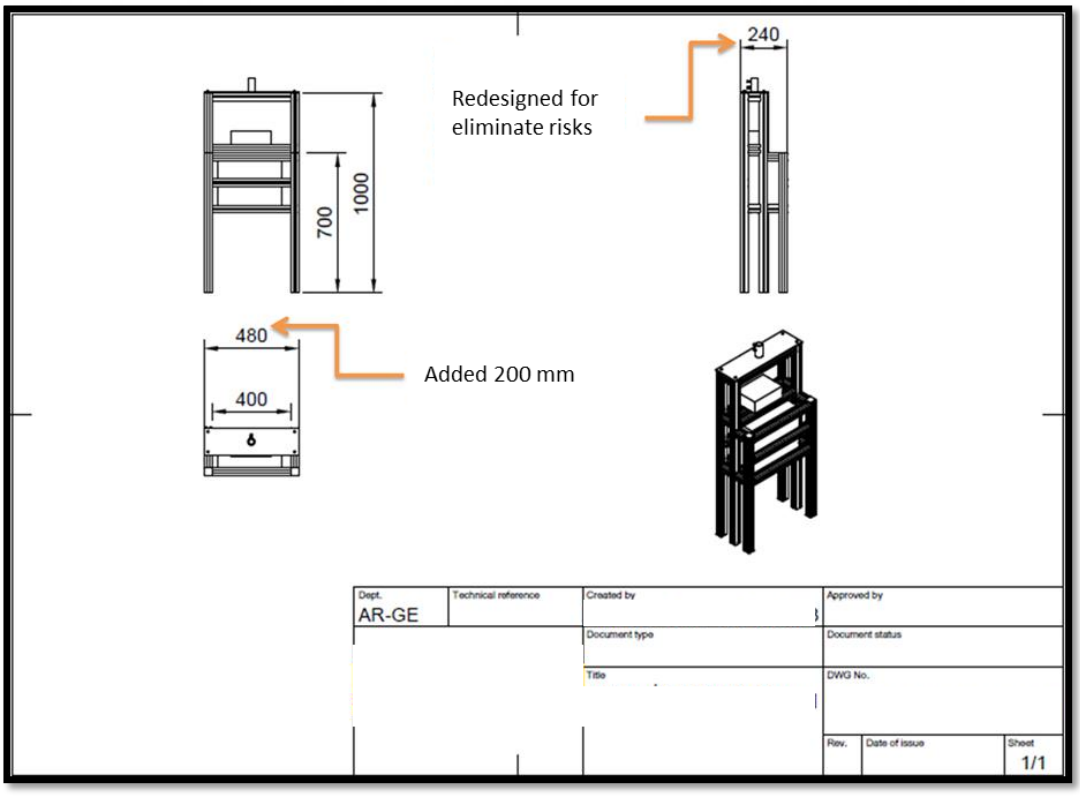

Figure 2.19 Redesigned pre - prototype technical drawing

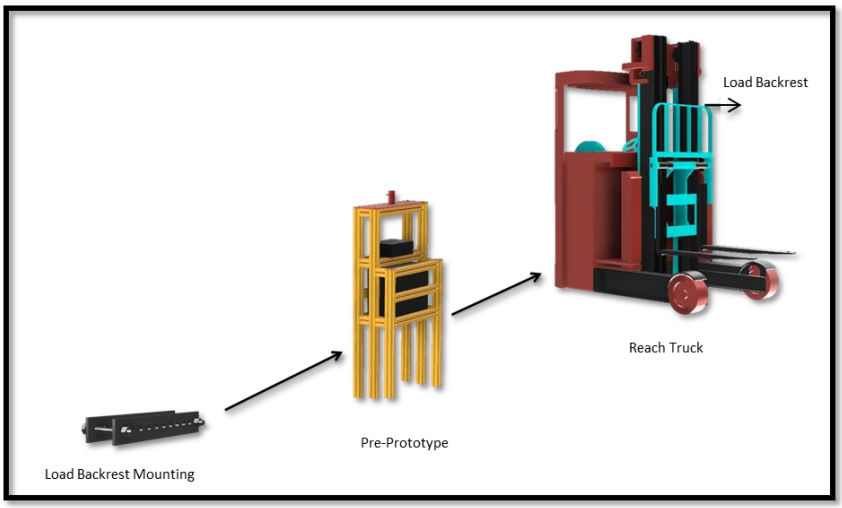

Figure 2.20 Redesigned pre - prototype & reach truck mounting scheme

the mounting clamp method was decided as the most suitable mounting method. The version1 clamp design in Figure2.21 will mount the load backseat by clamping two pillars and one foot of the main frame. Due to every load backseat is not in standard dimensions, it is thought to separate version1 clamps should be designed for each load backseat dimensions. Version2 clamp design in Figure2.22, which can be mounted on each load block and will not require redesign has been designed. Version2 design, which measures dimensions of load backseat sizes in the maximum - minimum range, has been decided and produced. As a result of the test studies, it was decided that the

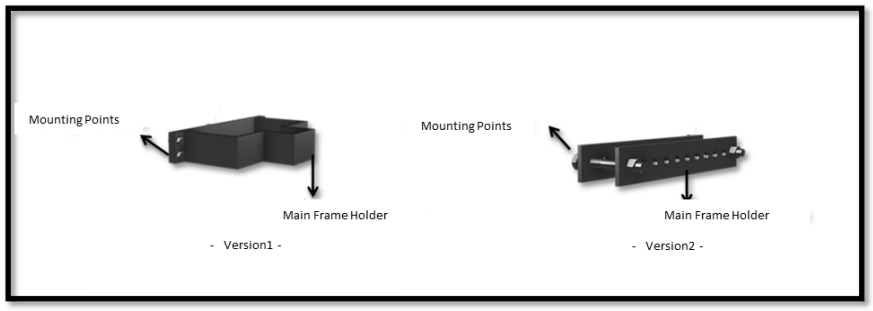

Figure 2.21 Version1 and version2 clamp design 3D model

industrial camera should be mounted by rotating 90 degrees in order to benefit more from the field of view. The camera mounting case designed in Autodesk Fusion 360 program and printed by 3D printer can seen on Figure2.23. In order to provide proper wiring and functional placement, a case that would hold the communication units power supply together was needed. The 3D model shown in Figure2.24 is modelled by using Autodesk Fusion 360.

It is planned to take the drive of the encoder's wheel from the movement of the RT wheel so that the horizontal distance measurement sensor encoder can define

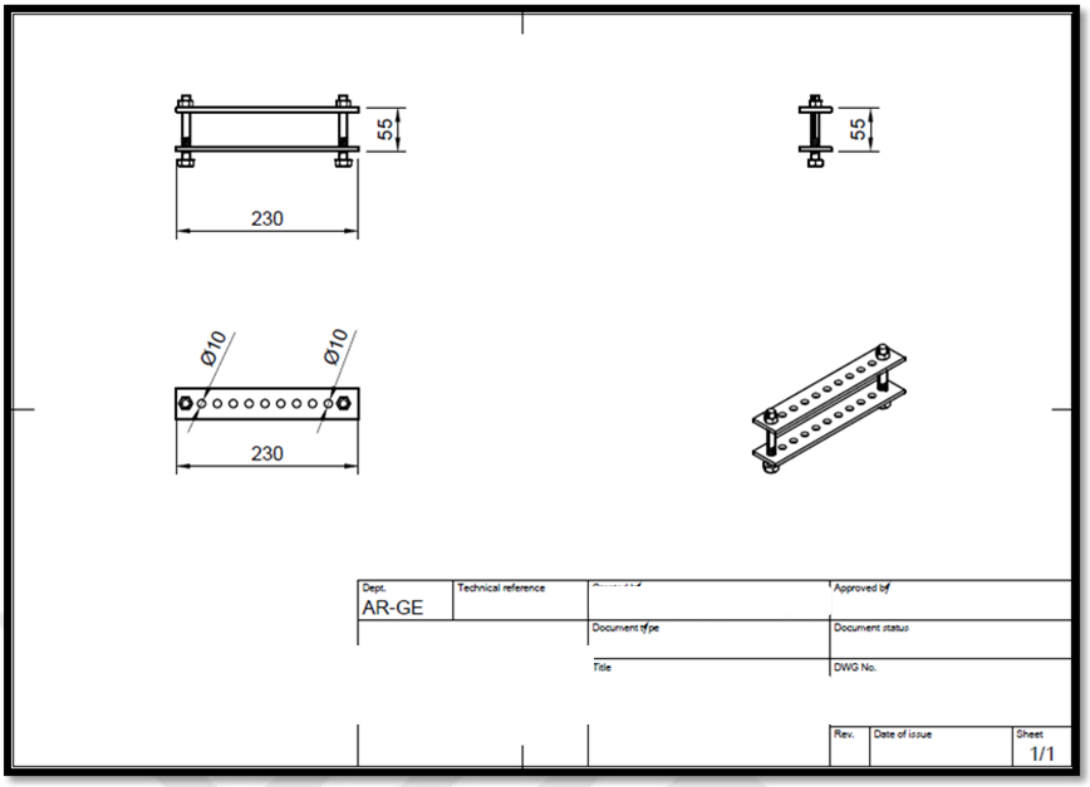

Figure 2.22 Version2 clamp design technical drawing

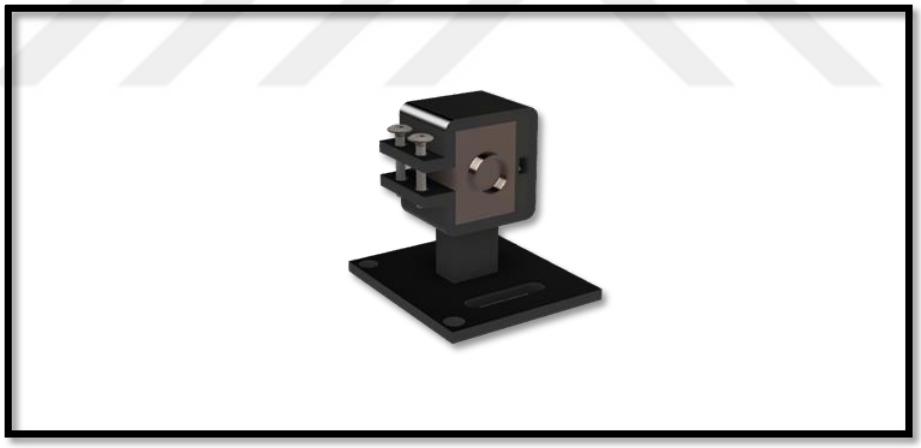

Figure 2.23 Industrial camera mounting apparatus 3D model

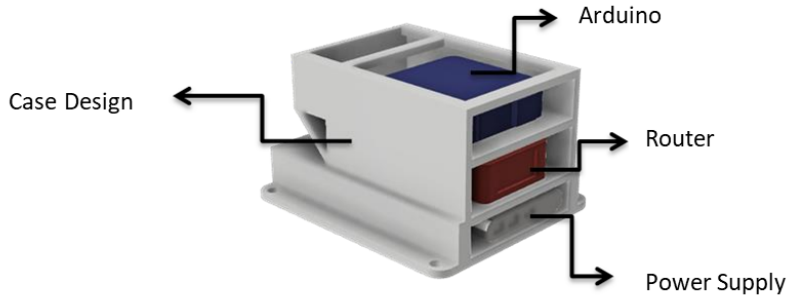

Figure 2.24 Arduino - router - power supply case design 3D model

the distance taken by the RT horizontally. It is decided to mount the wheeled encoder on RT's rear wheel in order to ensure the drive of the encoder. In order to provide this assembly, the fastener with the 3D model in Figure2.24 is designed. Communication units(ardunio and router) and horizontal distance measurement sensor(encoder) provide communication with wired connection. It is aimed to keep the cable connection to minimum. Considering this criterion, connection equipment is designed to allow the communication units, power supply frame and encoder to be mounted on encoder box that is mounted on RT rear wheel case as integrated as seen in the Figure2.26.

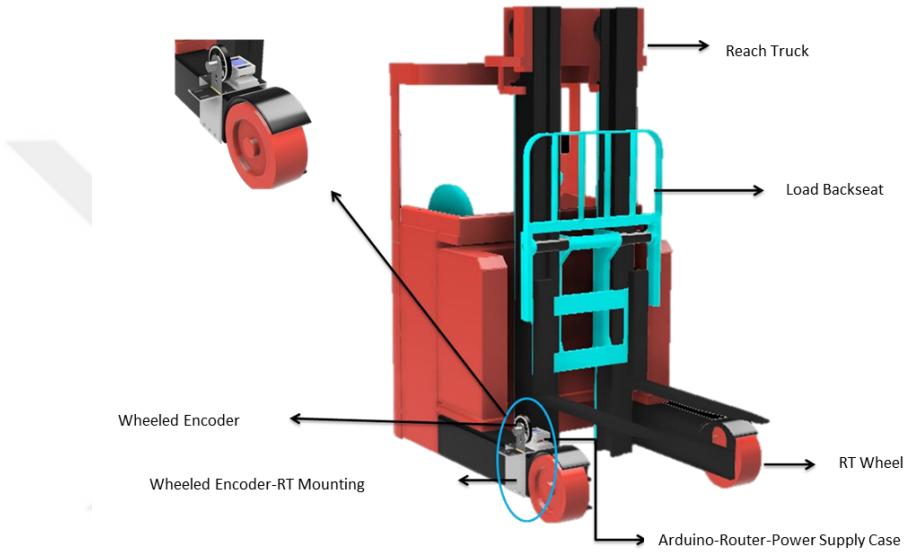

Figure 2.25 Detailed encoder box design and RT mounting

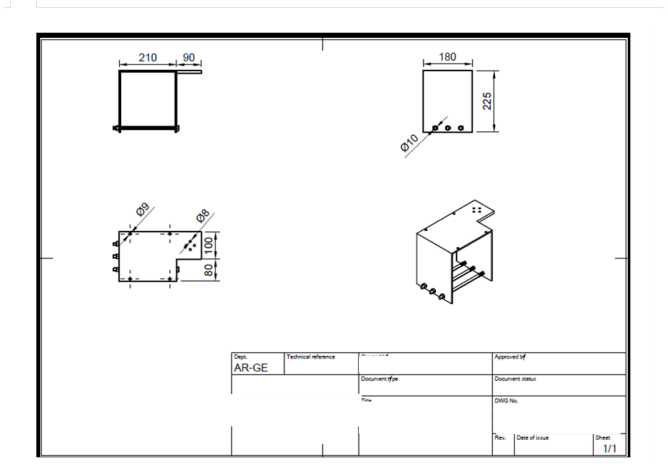

Figure 2.26 Technical drawing of arduino - router - power supply case and encoder mounting connection apparatus to RT

2.4 Electro - Mechanical System Design and Analysis

2.4.1 Control Processing Unit

Automation of the system using horizontal and vertical axis distance sensors will be done by triggering the cameras by processing the data received from the sensors. An industrial computer was purchased as a processor with suitable input ports, a suitable storage capacity, and a processor power was needed to process the data received from the sensors.

Using an industrial computer;

Buffer and storage of the images taken with camera in the system mounted on RT

- Collecting and processing of signals from sensors to be used for horizontal and vertical distance measurement
- The automated stock display system software to be developed will be operated.

The industrial computer offers a system that is more compact, suitable for industrial environments and working conditions, and less affected by noise. With the use of industrial computers, appropriate protection standards, cabling and data transfer solution advantages will be obtained, which will not be affected by warehouse conditions(magnetic field).

The desired features in the industrial computer purchased are determined in accordance with the needs of other components. Since the industrial camera to be used is a USB 3.0 Vision camera, it has a minimum of 1 USB 3.0 port, an RS422 port for transferring data from the laser distance sensor, an RS422 port for transferring data received from the encoder for use during enhancements, an HDMI port to connect to a display during enhancements.

2.4.2 Power Analysis and Battery Selection

In order to meet the power requirement of the system, there are two options such as using the battery of the RT vehicle or feeding the system with an external power supply. The power supply from the battery of the Reach Truck can be taken technically, but there are certain problems here. These problems are;

- The power provided by RT tool will decrease the working time of RT
- Since the vertical riser system will be positioned on the movable fork, power will be carried from the vehicle battery to the system with long cables

- RT vehicles are not allowed to access the battery.

Due to the problems mentioned above it has been observed that it can be covered by a battery located in system. In the light of all these requests, for the selection of the battery to be found on the system; The power consumption of each element of the system was calculated and the battery characteristics that should be used with the average clock that the system should operate were obtained. Power consumption of all components in the system are given in Table2.1.

The power requirements of the components calculated for an average of eight hours of operation were calculated as an average of 919.04 Wh and a maximum of 1303.6 Wh. By examining the operating voltage range of the components a 12V battery is sufficient to operate the entire system. According to this; it has been decided to purchase a 12V, 100 amp - hour dry battery. 100Ah corresponds to 1200Wh for approximately 12V voltage and is sufficient for an eight - hour usage period. Battery types which are divided into water, gel and dry batteries were examined. The dry battery has been found to be more suitable for the system, as it does not require maintenance, no voltage drops, and maintains long - term efficiency.

Table 2.1 System component's power consumptions

Component	**Energy Consumption(W)**	**Operating Voltage**	**Desired Working Time**	**Total Power Consumption**
Industrial PC(UNO - 2484G - 6332AE)	55 - 95.2 W(Max)	10 - 36V DC	8 sa	440 - 761.6 Wh(Max)
Wheeled Encoder	0.2 - 0.45 W(Max)	5 V DC	8 sa	1.6 - 3.6 Wh
Laser Sensor	1.68 - 4.8 W(Max)	10 - 30 V DC	8 sa	13.44 - 38.4 Wh(Max)
Industrial Camera(Basler acA4112 - 20um)	3 W	5 V DC	8 sa	24 Wh
Illuminator	55 - 60 W(Max)	12 V	8 sa	440 - 480 Wh(Max)
			Average Power Consumption	919.04 Wh
			Maximum Power Consumption	1303.6 Wh

2.5 Software Modelling

The software interface which the racks are displayed and images are recorded have been created in accordance with the operating scenario counting procedures. It is predicted that the stock display system software to be developed should have two different modes. In automatic mode, image triggering and recording will be done automatically with the data received from the sensors. In the manual mode of the developed software; created in case of visual disturbances in location photos displayed in automatic mode. The counting process flow is planned as follows;

1. Pre - prototype is mounted on RTs to be used by following the procedures.
2. Encoder box which is in contact with the rear wheel of RTs is mounted in accordance with the procedures.
3. The entire system is controlled and activated by following the procedures.
4. The remote connection with the industrial computer of the tablet is provided by following the procedures.
5. Predefined counting officers enter their passwords and enter the interface of the stock display system software.
6. In the first round of the counting process, the locations where the pallets are located are automatically triggered according to the distance data received from the sensors by the developed stock display system software and saved in the relevant folders.
7. The image data of the completed corridors are moved to the server manually by accessing the relevant folders.
8. The counting staff, who will count the locations by looking at the images, enter the counting software interface with their names and passwords.
9. The location images that are moved to the server from the interface of the stock display system software fall from the created image pool to the screens of the counting personnel available.
10. The counting staff record and count by looking at the images.
11. In the case of visually incorrect images, the census staff transmits the images of the relevant locations to the pool where the images to be shot will be collected by pressing the faulty image button in the counting software interface.

12. This process continues until the last location is completed on the count software interface.
13. The first round of the counting process is completed.
14. In the second round of the counting process, the images of the locations that are visually reported incorrectly are displayed using the manual mode of the developed stock display system software, recorded with the location code.
15. The wrong image is deleted from the server and the correct image is recorded.
16. Incorrectly reported images are reprocessed by counting operations.
17. These operations continue until there are no images in the faulty image pool.
18. After all images are counted in the counting software interface, a counting report is issued.
19. In the report, the inventory quantities that appear in the system and are actually counted are automatically compared, and the differences are communicated to the operation officer.
20. Different amounts are checked again.

3
PRODUCTION, ELECTRONICS AND SOFTWARE INTEGRATION

In the photograph taken during the tests in the pilot warehouse; the warehouse corridor to be count, the pallets to be counted during the counting process and stock counting device which is mounting to the reach truck can seen on Figure3.1. Stock

Figure 3.1 Stock counting device

counting device is shown in counting in warehouse. Stock counting device which is mounted on reach truck device's forks record images of product pallets to be counted later, to an industrial pc via C# software. The device which has seen on Figure3.2 and Figure3.3 is designed to be easily mountable to the forks of widely used reach

truck vehicles in warehouses. The bottom of the device is suitable for forks and can be locked on the forks. The camera and the lighting are positioned 1.5 meters higher in areas where the maximum lift height of the Reach truck is not sufficient for image acquisition. As a result of the image quality tests, camera mounting angle was determined as 22 degrees. The camera was mounted on a 22 degree inclined part. The processor was placed on the main tray, with the laser distance measurement unit and the power unit balanced. The encoder box which is shown in Figure3.3 is designed to be mounted on the reach truck wheel. A wheel has connected to the encoder shaft to contact with the reach truck's rear wheel. The main system and the encoder box have drawn in Fusion 360.

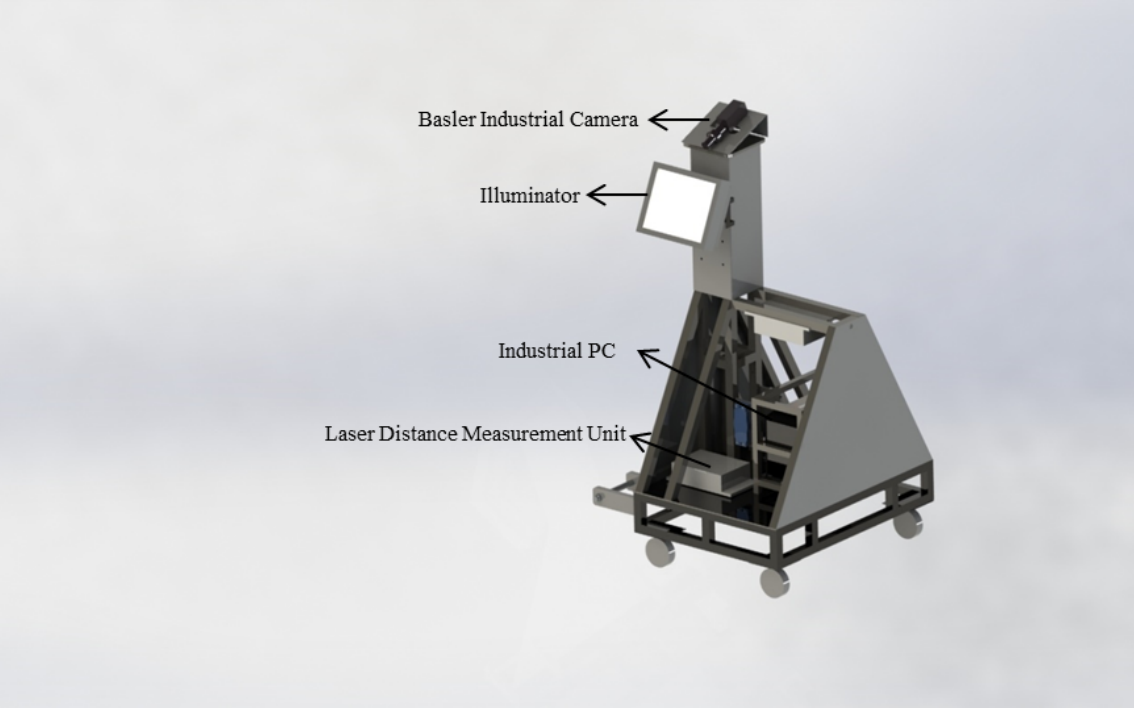

Figure 3.2 Main device's drawing and component explanations

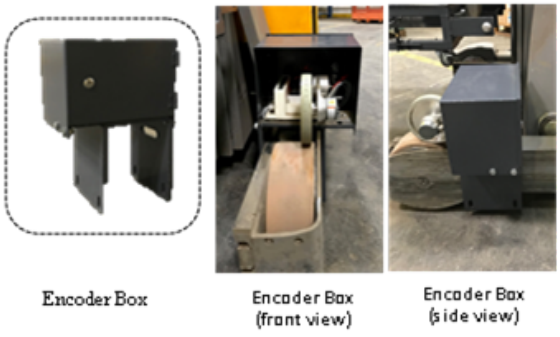

Figure 3.3 Encoder and encoder's wheel mounted on reach truck

3.1 Encoder and Laser Sensor Data Interpretation

There are eight cable outputs for the incremental encoder to be used in the horizontal distance measurement from the sensors used to calculate the position of the system in the horizontal and vertical directions. At least four cables are needed to use an encoder for forward and reverse position detection. These cables are divided into CH - A, CH - B, + 5V and ground ends. During the rotation of the encoder shaft from CH - A and CH - B ends, there are square wave outputs with 90 degree phase difference between them.

The encoder to be used on the system produces 1024 square waves for one full turn of the shaft. It can be seen from here that each square wave corresponds to a rotation of approximately 0.35 degrees. Only the CH - A or CH - B outputs can be used in the position calculation, and both outputs must be used at the same time to understand the difference between forward and reverse turns. Accordingly, there is a 90 degree forward phase difference from the CH - A output in clockwise motion compared to the CH - B output, while a 90 degree reverse phase difference occurs in the counterclockwise motion compared to the CH - B output from the CH - A output. The phase difference from the CH - A and CH - B outputs is shown in Figure3.4: In the

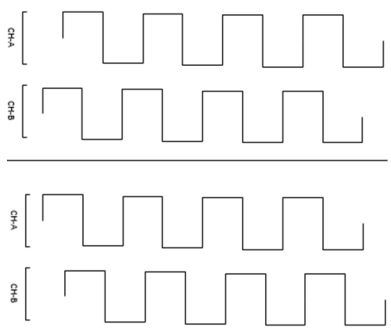

Figure 3.4 Encoder output square wave for clockwise and counterclockwise

light of all these claims, square waves coming from an encoder with a microcontroller were read, the forward and reverse motion was determined according to the phase difference between CH - A and CH - B. Then a mathematical equation was established between the number of square waves read and the distance the RT tool would go horizontally. Accordingly, the following mathematical equation, which expresses the angle of rotation depending on the number of square waves given by the selected encoder in one full turn and the number of pulse waves measured, has emerged:

$$\alpha = \frac{numberof\,palse \times 2\pi}{1024} \tag{3.1}$$

Looking at the Equation3.1, 1024 square waves are read every 360 degrees and a square wave corresponds to an angle of 0.35 degrees. Considering the laws of motion, the rotational object travels as far as the circumference of the spring corresponding to the angle of rotation in the horizontal movement, relative to the reference point selected from the rotational body. In Figure3.5, the horizontal distance traveled as a result of the rotational movement of the wheel is given. As "d" distance traveled

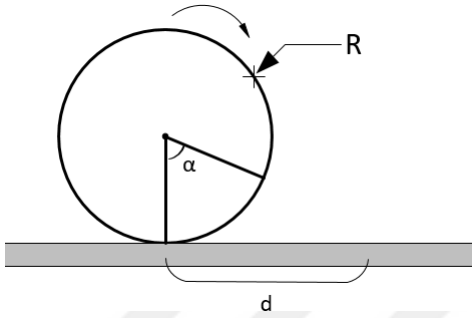

Figure 3.5 Rotational translation and horizontal traveled distance

horizontally is expressed by the Equation3.2:

$$d = \frac{\pi r \times \alpha}{360} \tag{3.2}$$

The encoder, which will measure the distance by driving from the wheel of the RT vehicle, will be positioned in a position close to the wheel. The sensor data is read by a microcontroller and the microcontroller calculated the data as the distance "d" and sent it to the industrial PC with the UDP socket connection. In this way, a safe and fast data flow is provided without cable clutter with a wifi router and udp connection protocole instead of data transfer along long cables. Laser sensor used for vertical distance measurement as it will perform measurements through the system will mount on the counting device. The laser sensor used for the project gives an analog output between 4 - 20 mA(milliamps). The sensor with three cables has Vin, GND and data cables. The laser sensor has a minimum measuring range of 20 cm and a maximum of 13 meters. In the use of laser sensor without reflector, it measures approximately 6 meters depending on the reflective surface being matte colors. For this reason, a reflector made of plexiglass is designed to the point where the laser reflects and the measuring range has been increased to 13 meters. In Figure3.6, the minimum and maximum values of the laser sensor measurement range and analog output values are shown: While receiving laser sensor data, ADAM 4117 Analog - Digital Converter module was used, and the analog value measured between 4 - 20 mA was converted to digital and sent its data to the industrial PC via RS - 485 communication. For this purpose, the laser sensor data cable is connected to the input of ADAM 4117 module and the analog value taken between 4 - 20 mA is read digitally from the module output.

Figure 3.6 Output values of the laser sensor in the maximum and minimum measuring ranges

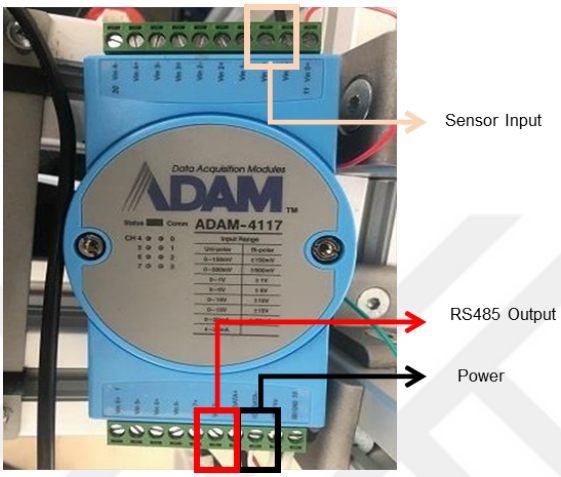

Figure 3.7 Laser sensor connection - adam 4117 module connection

The received analog value was interpolated; the height “h” at which the system is measured at any measured milliamp value was calculated. Accordingly, the visual of the height to be calculated at any “x” mA value is depicted in Figure3.8. Instantaneous

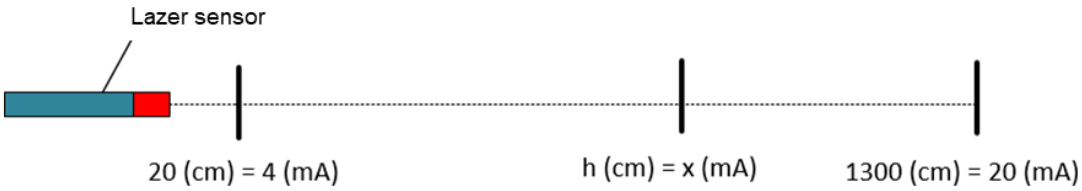

Figure 3.8 The distance h corresponding to the measured “x” analog value

analog output, “h” value to be measured at the sensor output; corresponding to the analog output is the height in centimeters and using the linear interpolation equation, the value of "h" is calculated as shown in Equation3.4.

$$\frac{x-4}{h-20} = \frac{20-4}{1300-20} \tag{3.3}$$

$$h = \frac{1280 \times (x-4)}{16} + 20 \tag{3.4}$$

3.2 Software Interface and Integration

The defined RT users login screen of the developed stock display system software is as shown in Figure3.9.

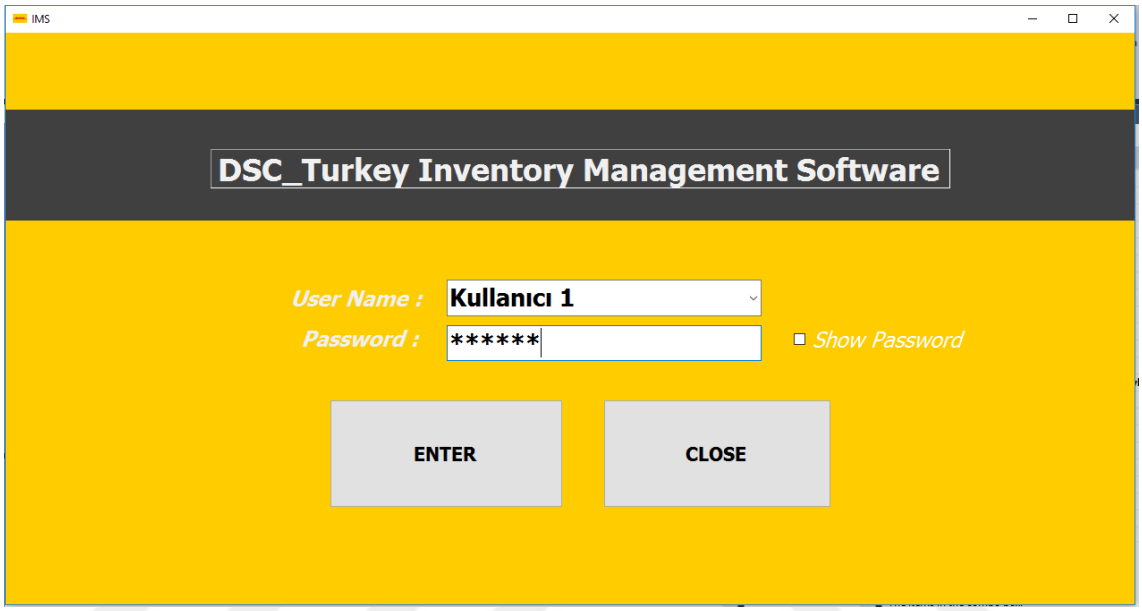

Figure 3.9 Inventory display system software entering screen

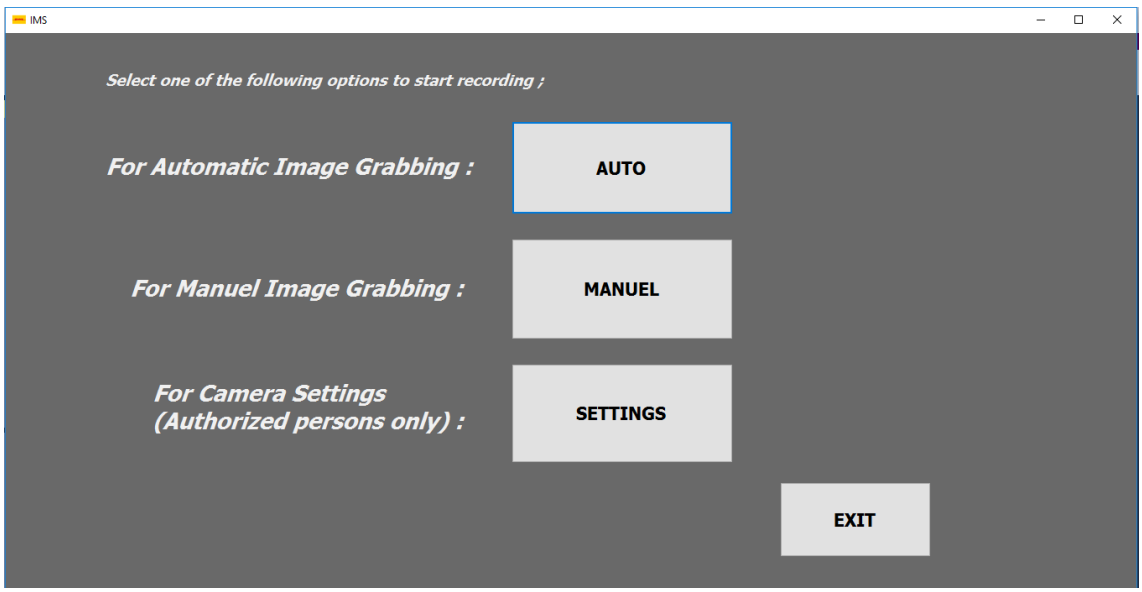

Figure 3.10 Mode selection screen of inventory display system software

According to the counting process flow explained on the interface, automatic or manual mode should be selected from the interface screen shown in Figure3.10.

3.2.1 Auto Mode

It is the mode that record the location photos automatically according to sensor data while RT is on the move.

- In this case, the external memory which includes Corridor_database.csv" must be removed and installed. The display shows the name of the next location to be taken (Destination Location: AX002 - 1).
- The RT vehicle driver is guided by forward, backward, up and down arrows on the screen.
- RT vehicle driver must drive the vehicle at a constant speed at the corridor. When speed is high for shooting warning "Slow down!" is seen on the screen. It is important that RT moves at a constant speed and in a straight line that software will not gives the warning.
- The product photos which are transferred to the external memory must be uploaded to the corresponding folder by the authorized officer. The operation's counting officer should consult the IT team for the folder authorization identification.

When RT enters to the aisle device will first read the aisle qr code label which contains the name of the aisle. The view of the screen where the qr code matrix is read is as in Figure3.11. When the corridor information in the data matrix is read and the ok

Figure 3.11 QR code reading screen of inventory display system software

button is clicked, this screen is closed and the automatic mode screen is opened. The

automatic mode interface view is as in Figure3.12. On the automatic mode screen

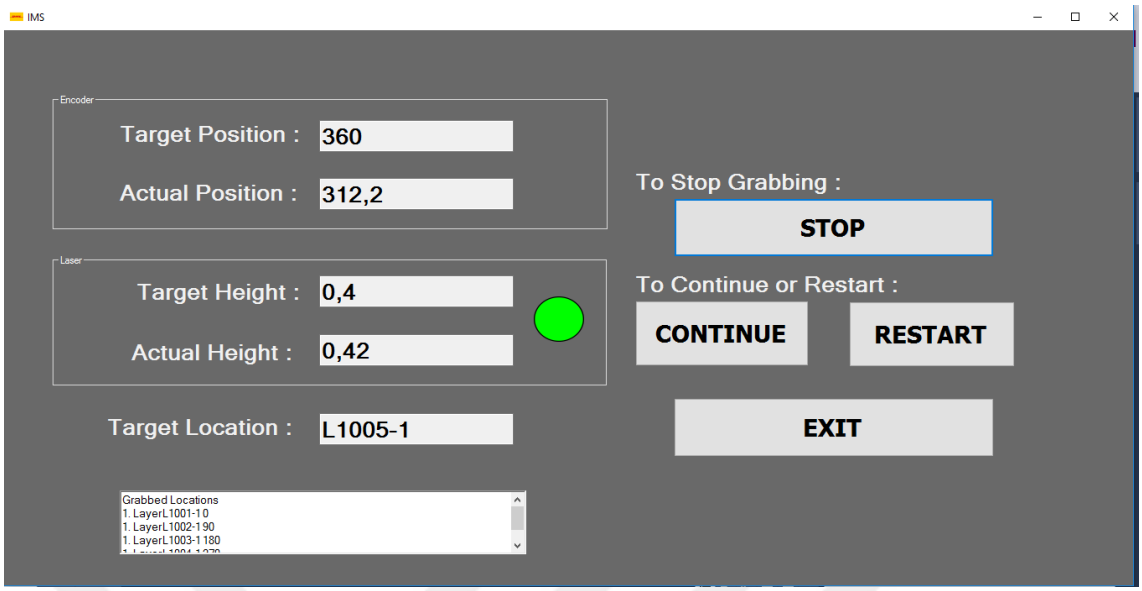

Figure 3.12 Automatic image recording screen of inventory display system software

shown in Figure3.12, the target height and target horizontal distance, instantaneous height and instantaneous position are shown to the RT operator. If the target height is equal to the height of the laser sensor on the RT lift and a certain tolerance value, the green circle appears on the screen. When it is necessary to go upstairs, the target height changes, the green circle disappears, and when the correct height is reached, the green circle reappears. In addition, the upper section shows the target horizontal distance and instant horizontal position. While RT is moving at a constant speed, the camera is triggered in the right positions and the image taken is recorded with the location code. The images taken and recorded can also be seen in the list at the bottom left. System can be stopped and resumed image recording at any time with the stop and continue buttons. Image recording can be resumed from where it left off by recording the data received from the senders. During the tests, a restart button has been added to reset the sensor data. User can exit from this screen with the exit button and return to the mode selection screen of the stock display system software in Figure3.10

3.2.2 Manual Mode

In the manual shooting mode, the RT operator can manually capture the images to update the reported images where incorrect images are reported and enter the location code.

On the manual shooting mode screen shown in Figure3.13, the cameras connected to the industrial computer are listed in the upper left. The selected camera streaming

Figure 3.13 Manual mode interface of stock display system software

is seen on the right. Thus, during manual shooting, RT will be able to go to the relevant location, stop the vehicle, and view the location image on the screen. Laser and encoder sensor data can be seen instantly on this screen. It is thought that the sensor data put in order to help during the tests will also help the operator. The location code of the relevant image is written by clicking the on - screen textbox and saved in the relevant folder. You can exit from this screen with the exit button and return to the mode selection screen of the stock display system software in Figure3.10.

The settings button has been added to the mode selection screen of the stock display system software in Figure3.10 to be used during the tests. This button is only active when the authorized user logs in with the correct password. When the button is pressed, the setting screen of the camera used is displayed and camera settings can be made from this screen.

4
RESULTS AND DISCUSSION

4.1 Image Processing Studies and Results

It was aimed to the pallet barcode information(the SKU number, batch number, expiry date information of) are automatically compared with the information in the system; through image processing leave the user only the quantity control over the pallet image displayed on the counting interface. During these studies, Aforge, zbar libraries were used to work in C# and python languages. After the raw image is converted to grayscale image, threshold and erosion filters are applied, blobs(regions) that can be contains the barcode in the entire image are entered into the algorithm using the Aforge blobcounter library. When determining blobs, standard aspect ratio of barcodes are used. Since the barcodes in the image are rectangular, the regions that are below and above a certain tolerance of the value we determined from the rectangles to be found were determined. Barcode reading process was carried out by using zbar library to the detected blobs. Although the Zbar library can read EAN - 13/UPC - A, UPC - E, EAN - 8, Code 128, Code 39, Interleaved 2 of 5(ITF) and QR Code, it is impossible to read the pallet barcodes of Code128 and Code39 types in the raw image due to motion blur. It can be seen in Figure4.1 that it cannot be read.

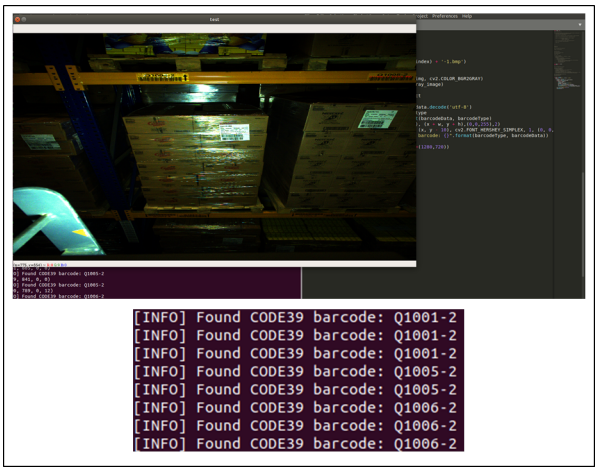

Figure 4.1 Code39 and Code128 reading studies

Figure4.2 shows the test barcode and printouts; in the barcode reading attempts made on the webcam with the zbar library, it is seen that the unreadable barcode can be read in the raw image taken with the counting device since the webcam is kept at close distance despite its low resolution.

Figure 4.2 Pallet barcode and printouts that are read from close range with webcam

It was observed that healthy reading could not be done over raw image data. Thereupon, various image processing methods were used to improve the raw image data. Planned actions can seen as below:

1. Improving the images obtained for warehouse counting to reduce the errors that the personnel can make during the counting by improving the images obtained from the camera.
2. Detection of target barcodes on the image by accessing the barcode on the parcels, accessing the data needed for the inventory count more quickly.
3. Digitizing the data on the barcode to speed up the comparison of barcode data with database data and to enable the system to be autonomous.

OpenCV is an open source library for image processing and computer vision. It supports engineering languages such as C, C, C#, Python, Java, MATLAB as support for programming language. It is frequently preferred as it can work in Windows, Mac OS, Linux distributions and mobile operating systems.

Since it is assumed that the barcode pieces expected to be obtained in the targeted operation will be lost and have low resolution, it is aimed to improve the images

over the pre - trained classes over neural networks. Python language, 3.6 version is preferred for basic and advanced operations to proceed in harmony. It may be necessary to convert the image data from one color space to another for the desired operation.This process is used to change the properties sought from all pixels on the image, such as luma, chroma, saturation, as there are changes in the values, since the transformations between some color spaces occur nonlinearly and this it shows some effects on operation performance. Greyscale, black and white, is the name given to displaying the image in shades of gray without color value. It is a frequently used format for the detection and calculation of color - independent geometric features on the image. RGB (red, green, blue) is used as a basic format in computers. R, G and B parameters take values between 0 and 255 and are recorded as separate (R, G, B). Some imaging environments may give transparency value for the image. The new color space specified as differently contains the value of A (Alpha) and, like other parameters, is between 0 and 255.

HSV (hue, saturation, value) or HSB (hue, saturation, brightness) is a color space often used in image histograms due to its parameter properties. Histograms show the number of pixels with low and high brightness values on the image and the brightness and contrast values of the image are examined. H, hue is used for the appearance of target colors. S, saturation is a parameter that allows adjusting the tone value for the target color. V, value indicates the illumination value for the color. Color spaces transformations on OpenCV can done with the function cvtColor(). Unlike the standard RGB display, OpenCV saves the read files as BGR. For this reason, it should be done from BGR while making the conversions.

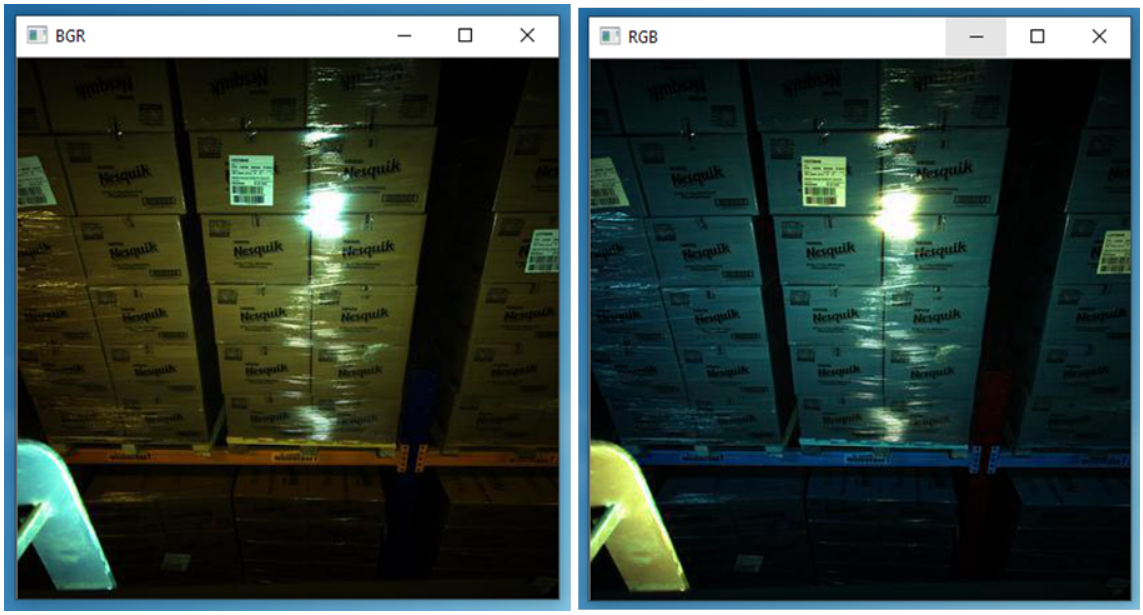

Figure 4.3 RGB and BGR transformatted images

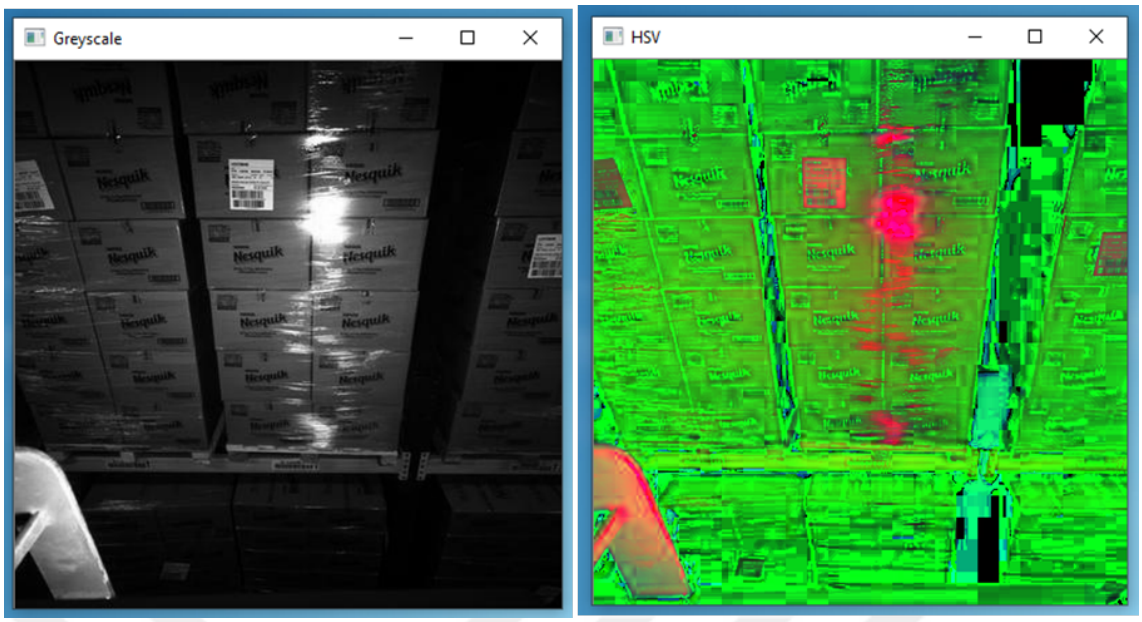

Figure 4.4 Greyscale and HSV transformatted images

A collection of non - linear operations related to the shape or morphology of features in an image is known as Morphological Operation in Image Processing. Erosion and dilation filters have used to raw images for preprocessing of barcode reading purpose. The cv2.erode() function narrows the area of pixels, allowing the study of thick geometries. The cv2.dilate() function expands the area of pixels, allowing thin geometries to thicken. With the function cv2.morphologyEx(), we can use the properties known as MORPH_OPEN and MORPH_CLOSE. These features are actually the use of erode and dilate functions. Thanks to these features, we can reduce the noise in the target image or in the background. MORPH_OPEN function for background noise, MORPH_CLOSE target geometry As all morphological operations are used, odd - length kernels are created by using the numpy library as they act convolutely.

4.1.1 Improvements of Raw Images

In this step, by changing the density values on the raw image, we ensured that the details in the current image are not visible.

The raw image is shown (on the left1) is transferred to the target image depending on the gamma parameter via the power - law conversion. In the images obtained, the upper and lower shelf images have improved, and the boxes between the shelves can be distinguished.

Figure 4.5 Images with modified gamma value

4.1.2 Barcode Blob Detection

In this step, it is expected to find the target barcode area on the raw image and improve it in the next step and subject it to the optical character recognition system. The

Figure 4.6 Detected pallet barcode label area on the raw image

barcode image is scanned using a convolutional neural network model trained with barcode images in the target image, and areas with high similarities are rectangular. Detected barcode areaa can seen on Figure4.6.

4.1.3 Image Enhancement

In this step, the resolutions of the barcodes detected will be edited and upgraded, and will be made applicable for character recognition(enhanced image can seen on Figure4.7). For image enhancements, the resolution will be increased by using SRCNN or Super Resolution Convolutional Neural Network model. This method has

been preferred to be more effective than functions used to increase resolution in professional image programs.

Figure 4.7 Enhanced image

4.2 Digitizing the Enhanced Image

The improved image was passed through gradient enhancement to facilitate character detection. After the edge properties are increased with the gradient enhancements, the image obtained is then measured to be suitable for digitizing.

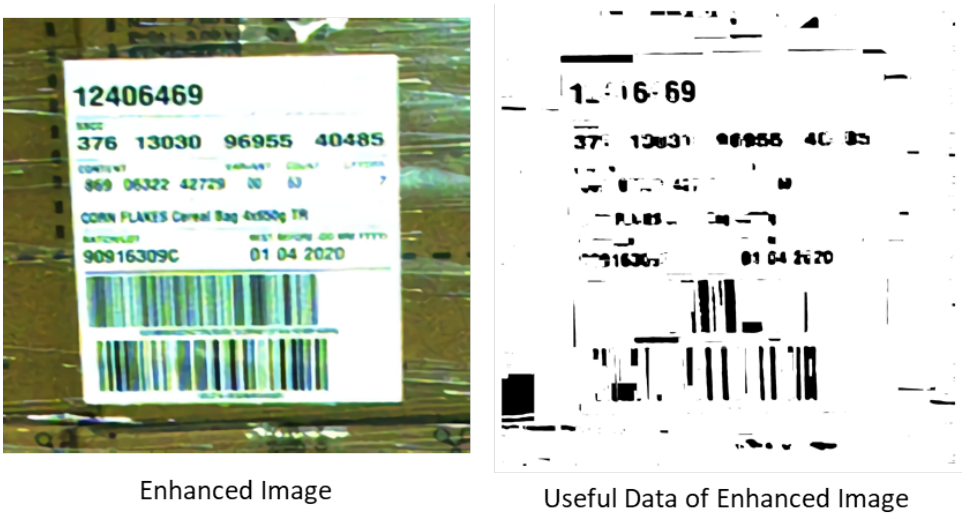

Figure 4.8 Useful pixel data on enhanced image

4.3 Sensor Calibrations and Hardware Tests

In this section, the results of the laser distance measurement sensor and encoder used in the automatic imaging module to calculate the positions of the system in the horizontal and vertical plane, and the results obtained as a result of comparing the theoretical values and the actual values obtained by experiments are evaluated.

Laser distance measurement sensor on the system; it is a sensor with analog output and gives a variable output depending on the measurement distance between 4 - 20 milliamps. As a result of the tests, it has been determined that the value of 15 meters, which is the maximum measurement value written in the product catalog, is 13.6 meters. Again, although the mentioned catalog indicates the measuring range as 0 - 15 meters; It has been observed that it is possible to get wrong results due to the instability of the current value taken from the output between 0 and 30 cm values, and the minimum measurement distance has been reduced to 30 cm with software adjustments.

In order to examine the accuracy of the calculations, the measurements of the target points whose real distances are known were performed, and the measurement accuracy was maximized by software adjustments.

The encoder measurement accuracy obtained as a result of the calculations that has been calculated under ideal conditions(the ground is smooth and flat), at the same time all the transmitted square waves can be considered complete by the microcontroller. However, it is not possible for the vehicle to move on a smooth and smooth surface under warehouse conditions. In addition, high quality and cost microcontrollers should be used in order to count all square waves with zero error.

Since it is not possible to use a high quality microcontroller alone to solve the problem caused by a bad ground, it has been studied that the error in measurement tests can be eliminated with a widely used microcontroller.

All studies to improve the encoder measurement results were carried out on a standard aisle selected for the test. It has been studied to take an image every 90 centimeters, which is thought to be the ideal situation. As a result of the calculation, it was seen that the shelf length, which was set as 95 meters 40 centimeters, was read by the encoder as 93 meters 38 centimeters. The result of the location display test for the ideal situation is given in Figure4.9:

It was concluded that the results of the test for the ideal situation were worse than expected, and position measurement was tried with different methods in the ongoing

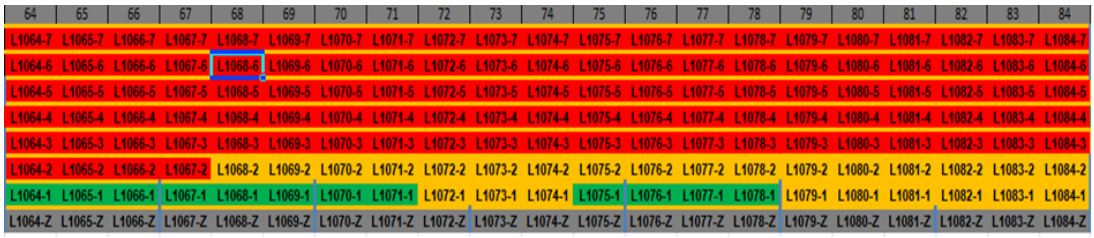

Figure 4.9 Imaging results for the ideal situation. Each box indicates the pallet area on a shelf surface(gray: not taken, green: displayed properly, yellow: can seen on right/left shelf picture, red: displayed incorrect).

studies. In the second test study for optimization of measurement values when the vehicle is in line with each location, it has been studied to record the location measured by the sensor with a test program. In this case, the position was recorded after the vehicle was stopped at the point corresponding to each location, and then continued its movement until it centered the next location.

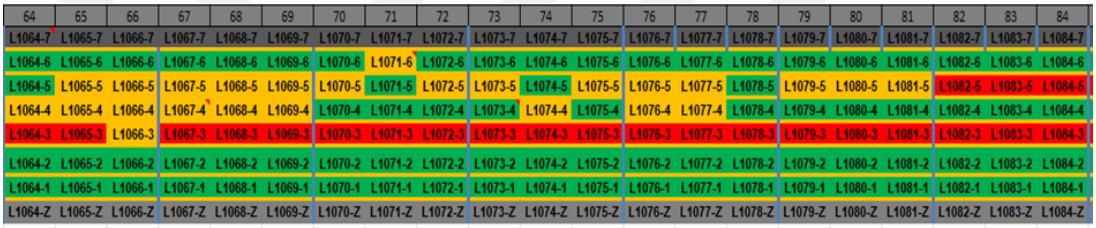

Figure 4.10 Imaging test result after first optimisation. Each box indicates the pallet area on a shelf surface(gray: not taken, green: displayed properly, yellow: can seen on right/left shelf picture, red: displayed incorrect).

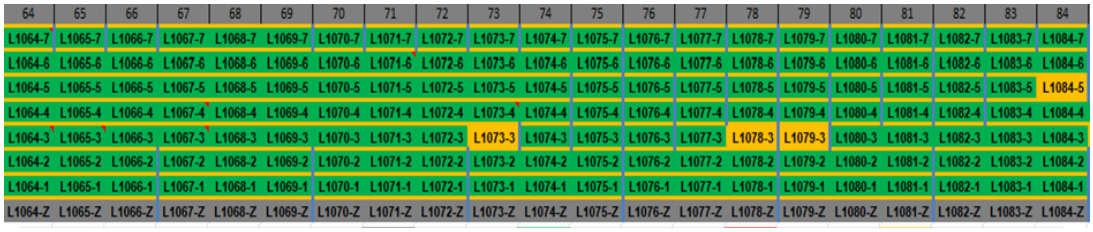

Figure 4.11 Imaging test result after second optimisation. Each box indicates the pallet area on a shelf surface(gray: not taken, green: displayed properly, yellow: can seen on right/left shelf picture, red: displayed incorrect).

After the second test, an improvement was observed in the imaging process and a third test was carried out to increase the optimization to the desired level. In the third test study with the position recording software used in the second test, the position value corresponding to each location was recorded when the vehicle moved without stopping. For location recording, 4 times samples were taken from all locations and imaging test was performed with the values that seemed to be the most appropriate.

As a result of this test, it was seen that by reaching the most optimized result, all locations can be displayed without any shift in the image. The visual of the imaging test result is given in Figure4.10 and Figure4.11.

4.4 Wireless Communication Tests

In the prototyping process, the HC - 05 Bluetooth module which is used to transfer the encoder information to the industrial computer does not cause any problems during the communication when the first prototype is open. While the communication of the new prototype's outer frame was covered with metal, interruptions occurred in communication when the device went up to 6 meters above the ground. At the same time, wireless WiFi communication, which provides the connection between the tablet used for interface image transfer and the industrial PC, has been found to have connection problems at similar heights with the Bluetooth problem and interruptions in the interface image transfer. As a result of the researches carried out to solve the problems, it was decided to move two wireless antennae belonging to the industrial computer inside the device before. The antennas were moved to the bottom of the device with the transportation process using antenna extension cables, and the wireless disconnection problem between the tablet and the industrial computer was fixed. As a result of the conversation with the supplier company, it was found that it is not possible to change the antenna of the bluetooth module mounted inside the industrial computer. For this reason, alternative communication methods have been considered in the use of the bluetooth module and as a result it has been concluded that this problem can be avoided by using the currently used wireless network with the UDP communication protocol.

4.5 Software User Acceptance Tests and Optimisations

The use of the C# interface developed using the .NET architecture in the first system prototype continued throughout the system tests. Displaying the sensor values on the screen provided convenience and traceability for improvements and made it easier to detect errors during the tests. In the later stages of the project, when the developments were over, it was seen that the current program has a mixed structure and does not appeal to the end user. Therefore, the need to create a more modern structure, user - friendly, plain and error - free interface has emerged. In line with these requests, the interface called "WPF", developed by "Windows Presentation Foundation", came to the fore. WPF interface, to the user; It offers an interface with .NET architecture that is more free in design than C#.

While programming objects such as text box and button have a uniform structure in the C# interface, many objects with different structures created by users can be accessed with the help of the Internet in the WPF interface. The building in question; it helps to design the interface more original and modern. With the transition to the WPF interface, all main and sub - menus have been redesigned, and the codes of the previous application created on C# have been used in the new structure. The developed interface has an easy - to - understand and easy - to - use structure that guides the user only with visual signs. Regarding the developments, the ideas of RT operators working together during all imaging tests were taken, and the studies were shared with the operators and arrangements were made according to the feedback received. Thus, it is ensured to create a program with a simple structure and an end user focus.

The developed program has started to be used with the second system prototype. Image examples of two program interfaces are given in Figure4.12 and Figure4.13:

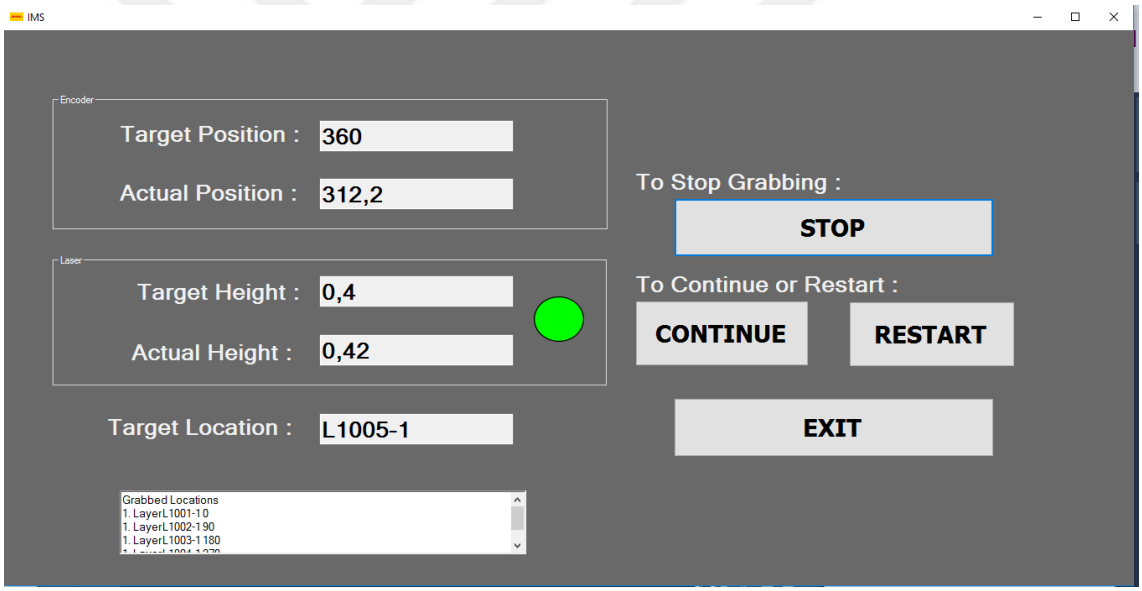

Figure 4.12 Interface of the first design of auto shooting mode

After the improvements made for the last prototype interface have been terminated, the stable working status of the interface has been observed through the location imaging tests, and interlibrary problems used in the software have been encountered, and the program has shown errors. Continuous improvements have been made for about a month. All errors occurring in the tests were recorded and then resolved. In the last case of the application, the program was constantly forced to give an error and it was seen that no errors were encountered. Thus, the last version of the program has been determined as the most stable running version and it has been made sure that it is suitable for use. The screenshots of the most stable version of the new interface developed are given in Figure4.14 and Figure4.15.

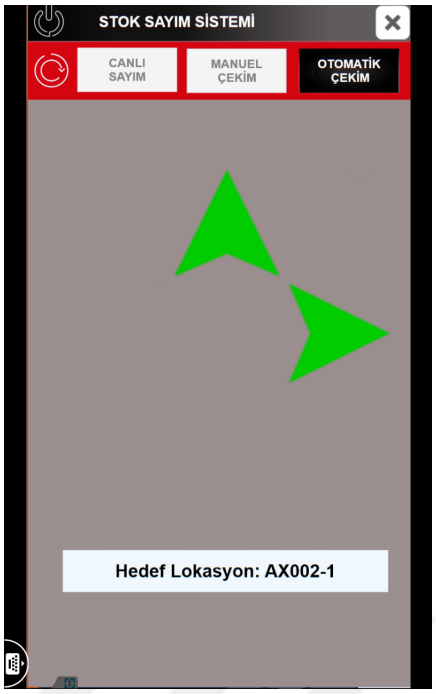

Figure 4.13 Interface of the revised design of auto shooting mode

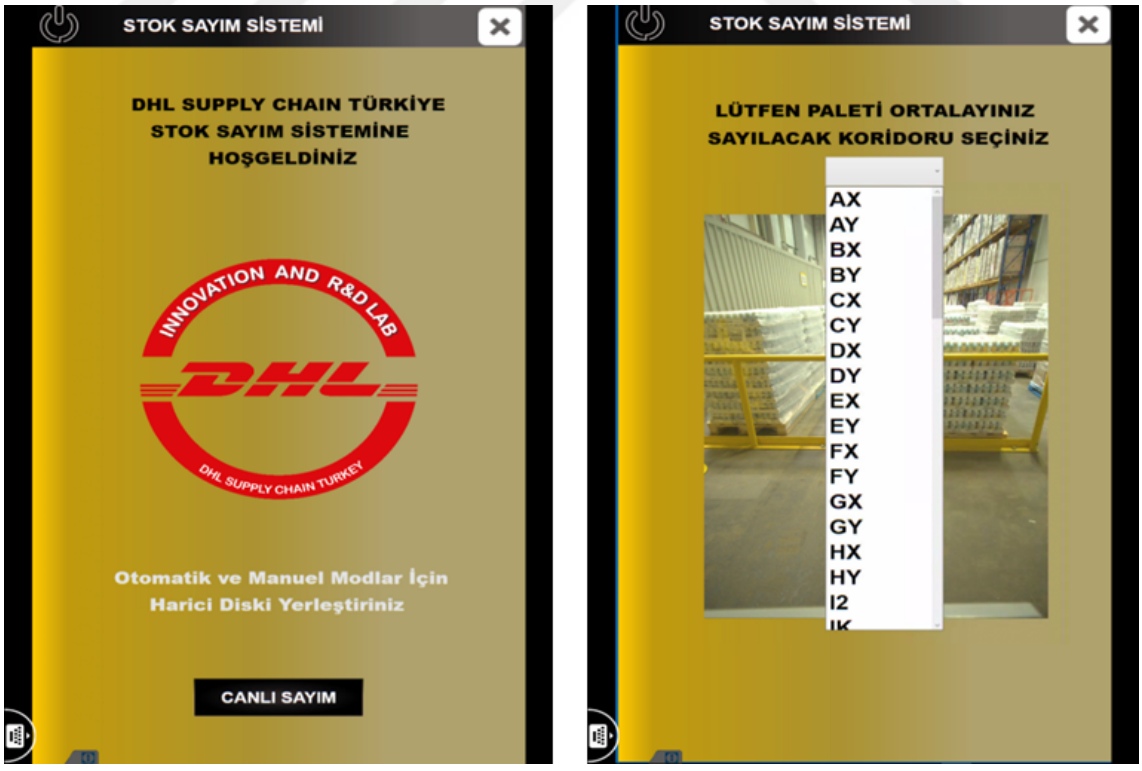

Figure 4.14 Interfaces of the revised software

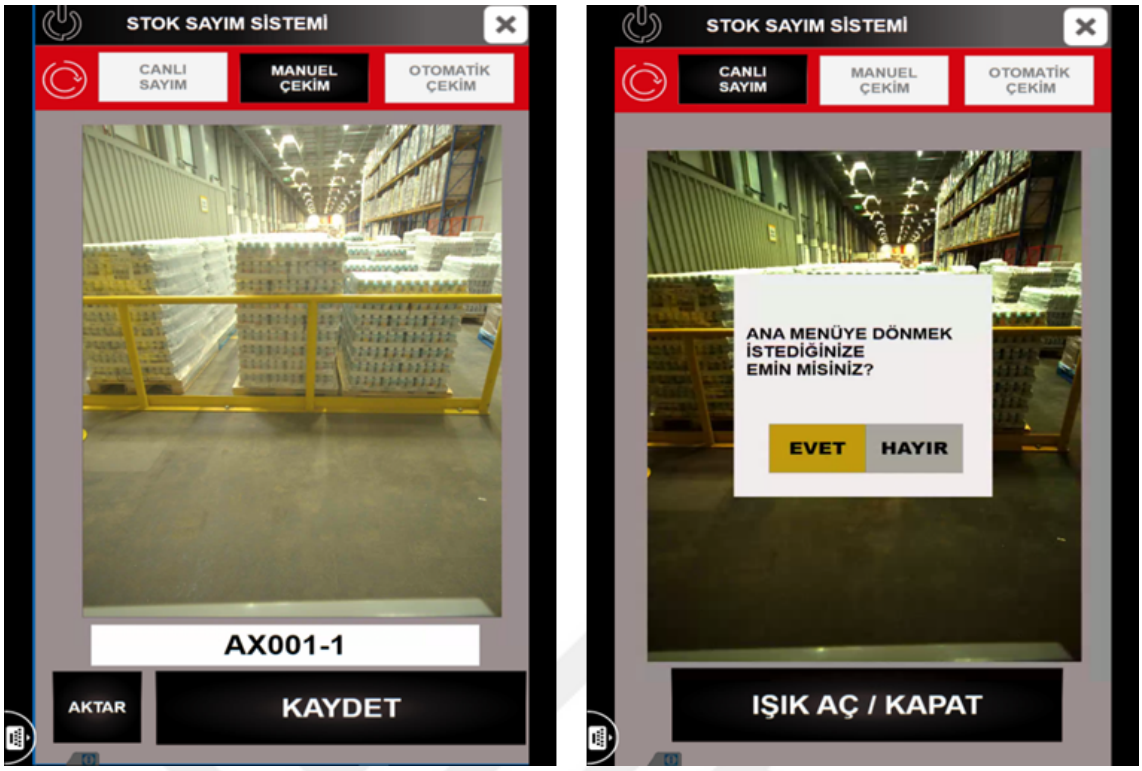

Figure 4.15 Interfaces of the revised software

4.6 Corridor Location Database System Integration Tests

The heights of the sleepers in the warehouse are determined according to the dimensions of the products. While determining these dimensions, the height of the products that appear when the products are lined up are given in the stock list of the customer. After determining the appropriate tolerance value according to these heights, the height calculations of the shelves; While the warehouse layout is being established, it is carried out by the operation officer. The equivalent of the heights in the warehouse system is determined as R1, R2, R3 and R4, which are expressed according to the difference between the two racks. These values obtained from the operation give information about the average shelf heights. The minimum and maximum values of the rack types determined by the operation are given in Table4.1:

Table 4.1 Rack heights according to shelf types

Shelf Type	Minimum Height	Maximum Height
R1	0 cm	120 cm
R2	120 cm	190 cm
R3	190 cm	240 cm
R4	240 cm	270 cm

In the initial design process of the warehouse, there are support bars that allow the sleepers to lift high weights and which are mounted according to static calculations. While the shelves were physically mounted after the shelf heights were determined in

the warehouse, the shelves had to be mounted 20 cm lower or upwards because they corresponded to these irons in the calculated areas. Due to this physical condition, the dimensions of the racks do not have a standard in the calculated values. Also, as the floors increase, the margin of error increases.

Height values are important in making location analyzes within the project. It was seen that the image quality taken due to the height values that do not have a certain standard are not suitable for counting as a result of imaging tests. For this reason, an optimization study was needed. Optimization studies involve two different processes. These processes are physical tests and software algorithms created as a result of these tests. When determining the height value of a location, the "R" values of all shelves are determined as shown in Figure4.16, and the height of the iron located between the two racks(intermediate bar) is added and the height of the location below and the height of the location are added. With this method, the physical heights of the shelves are obtained. For the optimization of the height values, sample height values were taken

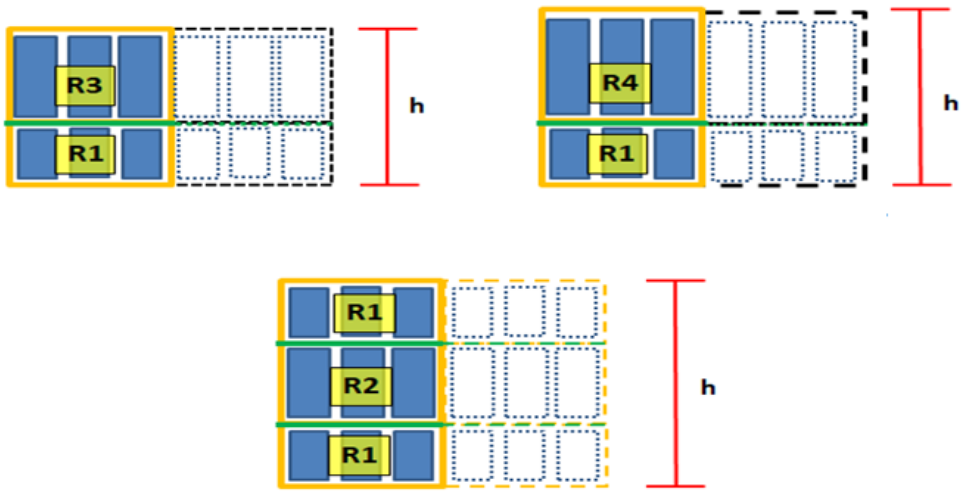

Figure 4.16 Rack height scheme

by performing imaging tests at the locations in the warehouse. The photographs taken and the heights of the shelves on which they were found were examined both with their R values and their actual heights. As a result of the investigations, it was understood that the rack arrangements with R1 - R2 heights gave less error than the R3 - R4 rack arrangements. It was observed that the margin of error in the shelf arrangement of R3 and R4, whose height value is more than R1 and R2, is high. This is due to the fact that the products placed in high shelf order are not present in the customer stock data with maximum height data and expressed over minimum values. In other words, products

that are higher than 270 cm come to the R4 shelf arrangement, and therefore the R4 shelf arrangement can be 40 to 50cm higher than the specified 270 cm on average. A converter program which has named as master data format conversion software has been written that enables the R values from the imported stock report excel file, and converts the excel cells into formats suitable for the system. With this patch program, 3 different csv files needed in the count were created by using the stock report from the operation. Among these generated csv files, the report containing the height and distance information of the locations of all aisles are loaded into the counting device.

As a result the images obtained with the new method developed after all the tests and the comparison of the images before the study are given in Figure4.17.

Figure 4.17 Pallet that cannot be fully viewed before optimization (left), post - optimization status (right)

4.7 Conclusion and Future Works

Success criteria targeted and realized in the project document are listed as follows.

Output 1: Number of occupational accidents in the counting process
Previous Case 1: High
Targeted 1: 0
Actual 1: 0
Explanation 1: Risks arising from working at height are reduced to zero.

Output 2: Counting time per location
Previous Case 2: 25 sec
Targeted 2: 10 sec

Actual 2: 17.21 sec
Explanation 2: 3,57 seconds of the time measured as a result of the first count with the new system is spent on the field; 10.77 seconds is the time spent in the office. The time spent in the office (10,77 sec) is predicted to decrease by 50% with the increasing habit of using the new system.

Output 3: Average time of entry of each location to the system
Previous Case 3: 8.1 sec
Target 3: 5.1 sec
Actual 3: 10,77 sec
Explanation 3: In the previous process, manual entries took an average of 8.1 seconds per location. The entry of thousands of locations into the system was open to human error. In the new system, system entries are made by the program output developed. The risk of human error has been eliminated. It is predicted that the adaptation of the new process will fall below the targeted value.

Output 4: Ratio of time spent on the field to total count time
Previous Case 4: 70%
Target 4: 51%
Actual 4: 20%
Explanation 4: The time spent in the field was reduced by more than expected with the automatic photographing system developed.

Output 5: Increased productivity expected with the new process
Previous Case 5: -
Target 5: 29.5%
Actual 5: 24%
Explanation 5: It is foreseen that the adaptation of the new process will exceed 24%.

Output 6: Expected inventory location accuracy with the new process
Previous Case 6: 94%
Targeted 6: 99%
Actual 6: 98.2%
Explanation 6: As a result of counting test performed with the new system, pallets without label were detected. If this situation was not an operational problem, inventory location accuracy would be 99.05%.

As a result of the evaluations, the reasons for unreadable raw images and possible solutions were determined and listed in order to provide information to the next studies. Reasons of barcodes not being read;

- Data losses on barcode bars due to moving shots from a distance of 150 cm
- Barcode printing quality is not sufficiently good and even if the quality is improved, the handprints formed when sticking the barcodes to the pallet stretches cause data loss.
- The barcodes adhered on the pallet stretches are folded and folded as a result of stretch slippage during product collection, causing data loss.
- The stretch of the products collected from pallets is broken and there are no barcode labels

Solutions as Future Works;

- An algorithm to detect and combine parts of barcode bars that do not have data loss in existing raw images should be developed with a medium or low level programming language such as C or C and acceleration should be done. This study is at a level that can be the subject of another project.
- Barcode reading can be done instantaneously in the field, so that more than one image can be taken at t to increase the readability rate. However, since this method will slow down the speed of the current system and will require extra powerful processor for snapshot processing, it will increase the product price at this stage of the project.
- In the current system, the camera system can detect the barcode area and take two separate images that are automatically zoomed and wide - angle, and the barcode can be read from the zoomed image. However, it should be remembered that this zoom should be done optically, not digitally. It has been decided that this improvement can be made in the productization works of the project and that this additional workforce is not affordable at this stage.

As a conclusion, it was decided that post - barcode reading is not effective considering both the price/performance ratio of the device and the available workforce resource adequacy in the short term. Comparing the product information in the barcode labels with the information in the request is a mandatory requirement in the developed process. This need has been met by bringing the system data uploaded to the counting software to the counting software screen and enabling the user to check this information with the zoom option. In order to speed up the process even further, an affordable barcode reader module is planned to be added to the counting device.

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