

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

ELECTRONIC DESIGN OF A FREE – RUNNING SHIP MODEL



M.Sc. THESIS

Deniz İLKME

Department of Shipbuilding and Ocean Engineering

Offshore Engineering Programme

JUNE 2025

ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL

ELECTRONIC DESIGN OF A FREE – RUNNING SHIP MODEL



M.Sc. THESIS

**Deniz İLKME
(508221213)**

Department of Shipbuilding and Ocean Engineering

Offshore Engineering Programme

Thesis Advisor: Prof. Dr. Ömer Kemal KINACI

JUNE 2025

İSTANBUL TEKNİK ÜNİVERSİTESİ ★ LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ

SERBEST SEYİR YAPABİLEN BİR GEMİNİN ELEKTRONİK TASARIMI

YÜKSEK LİSANS TEZİ

**Deniz İLKME
(508221213)**

Gemi ve Deniz Teknolojisi Mühendisliği Anabilim Dalı

Açık Deniz Mühendisliği Programı

Tez Danışmanı: Prof. Dr. Ömer Kemal KINACI

HAZİRAN 2025

Deniz İLKME, a M.Sc. student of ITU Graduate School student ID 508221213, successfully defended the thesis entitled “ELECTRONIC DESIGN OF A FREE – RUNNING SHIP MODEL”, which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor : **Prof. Dr. Ömer Kemal KINACI**

Istanbul Technical University

Jury Members : **Asst. Prof. Dr. Cihad DELEN**

Istanbul Technical University

Asst. Prof. Dr. Taner COŞGUN

Yıldız Technical University

Date of Submission : 01 June 2025

Date of Defense : 20 June 2025





To my family for their endless support,



FOREWORD

Firstly, I would like to express my heartfelt thanks to my advisor, Prof. Dr. Ömer Kemal KINACI for his help and support. Coming from an academic background that was not closely related to the marine field, I faced various challenges during my Master's studies. I was able to get over my issues thanks to his guidance and encouragement.

I am grateful to Asst. Prof. Dr. Cihad DELEN, PhD student Afşin Baran BAYEZİT, and all members of the ITU Marine Robotics Laboratory for their continuous support throughout my academic journey. Their contributions, including technical assistance, additional workspace, and access to essential equipment, played a significant role in the progress of my research and academic development.

I would like to extend my sincere thanks to Turkish Petroleum Offshore Technology Center for the opportunity to carry out a project within the scope of their research and development activities. I am also grateful to the Research Fund of Istanbul Technical University for supporting my thesis through a scholarship. Project Number: 45614. I wish to acknowledge Marine Cybernetics Advanced Vehicle Technologies for the professional environment and technical insight I gained during my time working with the company. In particular, I would like to thank Asst. Prof. Dr. İsmail BAYEZİT, one of the founder of the company, for his guidance and support during my time there.

Lastly, I am forever thankful to my family for their constant support my Master's education.

June 2025

Deniz İLKME
(Offshore Engineer)

TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	ix
TABLE OF CONTENTS	xi
ABBREVIATIONS	xiii
SYMBOLS	xv
LIST OF TABLES	xvii
LIST OF FIGURES	xix
SUMMARY	xxi
ÖZET	xxiii
1. INTRODUCTION	1
1.1 Literature Review	1
1.2 Purpose of the Thesis.....	6
1.3 Autonomy Level	7
1.4 Evaluation of the Planned Dynamic Positioning System.....	7
1.5 Industrial Impact of a Modular, DP - Capable PSV Electronic Architecture	8
2. SHIP MODEL PRODUCTION	11
3. ELECTRONIC SYSTEM DESIGN	15
3.1 Equipment Elements.....	15
3.2 Actuator, Motor and Drivers.....	17
3.3 Computer, Microcontroller and Sensor	20
3.3.1 Communication and manual control.....	22
3.3.2 Battery.....	23
3.3.3 Auxiliary components.....	24
3.3.4 Electronic control box.....	26
3.4 DP System Power Connection.....	27
3.4.1 Actuator power connections	27
3.4.2 Processor, computer and sensor power connections.....	28
3.4.3 Communication and manual control power connection	29
3.5 PSV Model Ship Signal Connections.....	30
3.5.1 Actuator signal connections	30
3.5.1.1 Connection with control systems	30
3.5.1.2 Propeller propulsion systems	30
3.5.1.3 Rudder systems	31
3.5.1.4 Torque and power management	31
3.5.2 Microcontroller, computer and sensor signal connections	32
3.5.2.1 Microcontroller and computer communication	32
3.5.2.2 Sensors	32
3.5.3 Communication and manual signal connections	33
4. FREE-RUNNING TEST RESULTS	35
5. CONCLUSION	41
REFERENCES	43
APPENDICES	45



ABBREVIATIONS

AI	: Artificial Intelligence
BLDC	: Brushless Direct Current Motor
BMS	: Battery Management System
CAN	: Controller Area Network
CFD	: Computational Fluid Dynamics
CNC	: Computer Numerical Control
COTS	: Commercial Off -The - Shelf
CSI	: Camera Serial Interface
dBi	: Decibels Relative to Isotropic Radiator
DC	: Direct Current
DP	: Dynamic Positioning
DTC	: Duisburg Test Case
DVL	: Doppler Velocity Log
DWA	: Dynamic Window Approach
e.g	: For Example
FG	: Frequency Generator
GPS	: Global Positioning System
IMO	: International Maritime Organization
IMU	: Inertial Measurement Unit
IP	: Internet Protocol
I-RPM	: Integral Term Output (in RPM)
ITTC	: International Towing Tank Conference
i.e	: In Other Words
KCS	: Korea Container Ship
kV	: Kilovolt
LAN	: Local Area Network
LIDAR	: Light Detection and Ranging

MCU	: Microcontroller Unit
MTi	: Motion Tracker Inertial
P	: Paralel
P2P	: Point to Point
PC	: Personal Computer
PCB	: Printed Circuit Board
PID	: Proportional-Integral-Derivative
PMAC	: Programmable Multi – Axis Controller
PoE	: Power over Ethernet
PSV	: Platform Supply Vessel
RC	: Remote Controller
R&D	: Research and Development
ROS	: Robot Operating System
RPM	: Revolutions per Minute
RPS	: Revolutions per Second
R-RPS	: Reference Revolutions per Second
RRT	: Rapidly - exploring Random Tree
RS	: Recommended Standard
S	: Series
SCU	: Steering Control Unit
TCU	: Propeller Control Unit
TCP	: Transmission Control Protocol
UPS	: Uninterruptible Power Supply
USB	: Universal Serial Bus
VESC	: Vedder Electronic Speed Controller
YOLO	: You Only Look Once

SYMBOLS

+	: Positive sign
-	: Negative sign
±	: Plus - minus sign
=	: Equals sign
Ah	: Ampere-hour
B	: Beam
C_B	: Block coefficient
cm	: Centimeter
Fr	: Froude number
g	: Gram
GHz	: GigaHertz
L_{WL}	: Length at waterline
m/s	: Meters per second
mm²	: Square millimeters
N.m	: Torque
P	: Proportional term
s	: Second
S	: Wetted surface area
T	: Draft
V	: Service speed
Wh	: Watt-hour
∇	: Displacement volume
λ	: Scale



LIST OF TABLES

	<u>Page</u>
Table 2.1 : PSV hull form.....	11
Table 3.1 : Ship electronic equipment and actuators.....	16
Table 3.2 : List of electronic equipment used in the ground station.	16
Table 3.3 : Motor data	18
Table 3.4 : Battery technical specification table.....	23
Table 4.1 : Measured relationship between propeller RPS and vehicle velocity.....	39





LIST OF FIGURES

	<u>Page</u>
Figure 1.1 : Electronic system connections of the 7m long DTMB5415 warship	1
Figure 1.2 : Electronic system design of 4.5m long DTC container ship	2
Figure 1.3 : Electronic design software of 3m long KCS container ship model	3
Figure 1.4 : System flow in a model ship	3
Figure 1.5 : Control system architecture of the tanker ship	4
Figure 1.6 : PSV Sancar model ship	6
Figure 1.7 : ITU Lake (left). Image from a previous study in the lake (right).....	6
Figure 2.1 : View of the completed PSV Sancar model	12
Figure 2.2 : Rough model fabrication of the PSV hull	12
Figure 2.3 : CNC-machined wooden ship hull model	13
Figure 2.4 : Finished PSV hull after CNC and priming.....	13
Figure 2.5 : Appearance of a PSV after painting and marking	14
Figure 3.1 : PSV Sancar model ship general layout.....	17
Figure 3.2 : Main motor closed loop motor cycle diagram.....	17
Figure 3.3 : Flipsky motor (left) and VESC 6.9 motor driver (right). Hall effect sensor is located inside the motor	18
Figure 3.4 : Thruster motor drivers (left). Thruster motors are mounted on the propeller hub (right).....	19
Figure 3.5 : Servo motor (left). Dual servo motor assembly for the starboard rudder of the vessel (right)	19
Figure 3.6 : Images of the STM microcontroller (left), ORIN computer (center) and Xsens GPS-IMU (right).....	21
Figure 3.7 : CAN transceiver circuit (left, circled in yellow), PCB design (right)...	21
Figure 3.8 : Remote controller (left), Wi-Fi modem (center) and PoE adapter (right)	22
Figure 3.9 : Battery grouping (left) and BMS connection diagram (right).....	23
Figure 3.10 : Battery pack.....	24
Figure 3.11 : Power distribution busbar (left). Single terminal block on DIN rail (center). Overall view of terminal blocks inside the vessel (right).....	24
Figure 3.12 : Fuse system	25
Figure 3.13 : DC/DC voltage regulators. 24VDC (left), 12VDC (center), 5VDC (right) [13].....	25
Figure 3.14 : PG 7 type cable gland (left) and male/female LP28 waterproof connector (right)	25
Figure 3.15 : Electronic control box	26
Figure 3.16 : Motor and motor driver connection diagram connected to bow and stern thrusters (left). Rudder servo connection diagram (right).....	28
Figure 3.17 : Microcontroller, Orin and sensor connection diagram	29
Figure 3.18 : Communication and manual power connection diagram	29
Figure 3.19 : Actuator signal connection diagram (left). Rudder servos signal connection diagram (right).....	31

Figure 3.20 : MCU, Orin and GPS-IMU signal connection.....	32
Figure 3.21 : Signal connections for remote control communication.	33
Figure 4.1 : Photograph of the towing vehicle at ITU Ata Nutku Ship Model Laboratory during experimental tests.	36
Figure 4.2 : Layout of the electronic control box and lead ballast blocks during the trim-calibration procedure.....	36
Figure 4.3 : Sancar model ship free – running propulsion test results.....	38
Figure 4.4 : Quantitative evaluation of the R-RPS and velocity relationship in the positive domain.....	38
Figure 4.5 : Quantitative evaluation of the R-RPS and velocity relationship in the negative domain.	39
Figure A.1 : Schematic diagram of controlling actuators with STM32 based MCU.	46
Figure B.1 : Flowchart of all system.	47



ELECTRONIC DESIGN OF A FREE - RUNNING SHIP MODEL

SUMMARY

Within the scope of this thesis, the hull form of Sancar, a Platform Supply Vessel (PSV) operated by Turkish Petroleum Corporation, was taken as a reference for the development of a dynamic positioning (DP) system and an original electronic system was designed for this purpose. The model, similar to the previous examples, was constructed from wood and equipped with electronics. Although the software required for the electronic and mechanical parts to work as a whole was developed by the Marine Robotics Laboratory team at ITU Faculty of Naval Architecture and Ocean Sciences, it is outside the scope of this thesis.

The ship has a propulsion system consisting of two propellers, total of four thrusters, two at the bow and two at the stern, and two rudders. The main engines in the planned DP system consist of Flipsky brand, torque-based, brushless motors with a closed-loop control method, and these motors are controlled by VESC drives. In addition, the thrusters at the bow and stern of the ship are supported by lower-power motors.

Due to the ship model is unmanned, a land station is also designed to manage the ship operation. The communication infrastructure, power distribution and signal management between the electronic systems on the model ship and the land station are explained in detail. The ship communicates with the land station via Wi-Fi modems via remote control. The ship's Wi-Fi modem is equipped with a omnidirectional antenna, while the land station uses a 120-degree directional antenna.

The ship's motion control is carried out by control signals sent to the motor drivers via a microcontroller. The model includes GPS and IMU sensors to provide real-time data to the positioning system, and the data from these sensors is processed by the NVIDIA AGX Orin computer. A FlySky brand remote control is also used for manual control and security measures.

There are two lithium-ion batteries with 6S10P configuration on the ship for power management. The power required by the electronic systems is provided by regulating and isolating them via DC/DC converters. A central electronic control box has been designed to ensure the safe and integrated operation of all electronic systems.

The designed electronic system can easily adapt to different mission scenarios and sensor needs with its modular structure, thus increasing the expandability and long-term usability of the system. The microcontroller-based structure used in the hardware layer prepares the ground for fast and accurate operation of artificial intelligence algorithms with its high-precision data acquisition and real-time processing capacity.

In this context, subcomponents such as communication interfaces, power management circuits and sensor integration modules have been optimized to increase the performance of the system. The overall design of the electronic system has been structured to both consider energy efficiency and increase environmental durability. In addition, the synchronous operation of the modules used in the system with the

software increases fault tolerance and ensures stability. Thanks to its modular architecture, the system allows easy upgrades and modifications without requiring a complete redesign, making it adaptable to different mission profiles and hardware configurations. This flexibility also facilitates the integration of additional sensors, control units, or communication protocols depending on the specific requirements of future applications. Moreover, the use of industry-standard components and communication protocols improves interoperability and simplifies the transition from prototype-level implementations to real-world deployments.

As a result, this electronic infrastructure not only meets today's need, but also provides scalable, reliable and high performance foundation for autonomous marine vehicles to be developed in the future. When evaluated in terms of both academic research and industrial applications, it can be said that this system offers a sustainable and strategic solution in autonomous marine technologies.



SERBEST SEYİR YAPABİLEN BİR GEMİNİN ELEKTRONİK TASARIMI

ÖZET

Bu tez kapsamında, dinamik konumlandırma (DP) sistemi geliştirmesine yönelik olarak, Türk Petrolleri Anonim Ortaklığı A.Ş. tarafından işletilen bir Platform Tedarik Gemisi (PSV) olan Sancar'ın gövde formu referans alınmış ve bu amaçla özgün bir elektronik sistem tasarlanmıştır. Model, önceki örneklere benzer olarak, ahşaptan inşa edilmiş ve elektronik olarak donatılmıştır. Elektronik ve mekanik parçaların bir bütün halinde çalışabilmesi için gerekli yazılımlar İTÜ Gemi İnşaatı ve Deniz Bilimleri Fakültesi'nde bulunan Marine Robotics Laboratory ekibi tarafından geliştirilmiş olmasına karşın bu tez kapsamının dışındadır.

Gemide iki adet pervane, iki başta iki kıçta olmak üzere toplam dört adet itici motor ve iki adet dümen içeren bir sevk sistemi bulunmaktadır. Geliştirilmesi planlanan DP sistemindeki ana motorlar, Flipsky marka, tork tabanlı çalışan ve kapalı döngü kontrol yöntemine sahip fırçasız motorlardan oluşmakta ve bu motorlar VESC sürücülerini tarafından kontrol edilmektedir. Ayrıca, geminin baş ve kıç kısımlarındaki iticiler, daha düşük güce sahip motorlarla desteklenmiştir.

Gemi modeli insansız olduğundan, gemi operasyonunu yönetmek için bir kara istasyonu da tasarlanmıştır. Model geminin üzerinde bulunan elektronik sistemler ile kara istasyonu arasındaki haberleşme altyapısı, güç dağıtımı ve sinyal yönetimi detaylı olarak açıklanmıştır. Gemi, kara istasyonu ile uzaktan kumanda aracılığıyla Wi-Fi modemler üzerinden haberleşir. Geminin Wi-Fi modemi, yönsüz bir anten ile donatılmış olup, kara istasyonu ise 120 derece yönlü anten kullanmaktadır.

Geminin hareket kontrolü, mikrokontrolcü aracılığıyla motor sürücülerine gönderilen kontrol sinyalleriyle gerçekleştirilir. Model üzerinde konumlandırma sistemine gerçek zamanlı veri sağlamak üzere GPS ve IMU sensörleri yer almakta, bu sensörlerin verileri ise NVIDIA AGX Orin bilgisayarından işlenmektedir. Manuel kontrol ve güvenlik önlemleri için ayrıca FlySky marka uzaktan kumanda kullanılmaktadır.

Güç yönetimi için gemide iki adet 6S10P konfigürasyona sahip lityum iyon batarya bulunmaktadır. Elektronik sistemlerin ihtiyaç duyduğu güç ise DC/DC dönüştürücüler üzerinden regüle ve izole edilerek sağlanmaktadır. Bütün elektronik sistemlerin güvenli ve entegre biçimde çalışmasını sağlamak üzere merkezi bir elektronik kontrol kutusu tasarlanmıştır.

Geleneksel otonom gemi modelleme çalışmalarında pervane, itici ve dümen sistemleri ayrı ayrı test edilerek dinamik özellikleri analiz edilmektedir. Bu tez çalışmasında ise, dinamik konumlandırma yeteneğine sahip bir otonom yüzey aracının geliştirilmesine yönelik ilk adım olarak pervane testleri gerçekleştirilmiştir. Testler, İTÜ Gölet'inde yapılması planlanan saha denemeleri öncesinde, Ata Nutku Gemi Model Deney Laboratuvarı'nda kontrollü koşullarda yürütülmüştür. Bu testler sırasında farklı pervane hızlarındaki performansı analiz edilerek; hız, itme kuvveti ve enerji tüketimi gibi temel parametreler ölçülmüştür. Elektronik sistem, bu test süresince motor

sürücüleri ile mikrodenetleyici arasındaki sinyal iletimini kararlı bir şekilde sağlamış; sistemin gerçek zamanlı çalışabilirliği başarıyla gözlemlenmiştir.

Elde edilen veriler, pervane devri ile gemi hızı arasındaki ilişkiyi ortaya koymuş ve elektronik kontrol altyapısının güvenilirliğini test etmek açısından önemli bir temel oluşturmuştur. Bu veriler, ileri aşamalarda geliştirilecek olan konumlandırma ve yönlendirme sistemlerinin hem elektronik entegrasyonu hem de kontrol algoritmalarına yönelik yapıların kalibrasyonu için değerli girdiler sunmaktadır. Böylece bu çalışma, sadece hareket performansı değil, aynı zamanda elektronik tasarımın doğrulanması açısından da bütünsel bir değerlendirme imkânı sağlamıştır.

Gelecek çalışmalarda, sistemin dümen dinamiklerini ortaya çıkarmak amacıyla kontrollü deneysel ortamlarda dümen testleri yapılacaktır. Bu testlerin sonucunda, pervane sistemi için tasarlanan kontrolörden bağımsız olarak dümen sistemi için özel bir kontrolör tasarımı gerçekleştirilecek; bu kontrolörün yapısı ve kazanç değerleri dümen performansına göre ayrı ayrı belirlenecektir. Tahrik ve dümen sistemi kontrolünün beraber sağlandığında, zor deniz durumlarında dahi yol izleme ve manevra kabiliyetinde etkili sonuçlar vermesi beklenir. Bu çalışmada elde edilen bulguların, küçük ölçekli gemi modelleri için tam otonom kontrol mimarisinin modüler ve yinelemeli geliştirilmesine önemli katkılar sağlayacağı düşünülmektedir.

Bu çalışma, otonom gemi sistemlerinin temelini oluşturan elektronik altyapının tasarımına odaklanmakta olup, geliştirilen sistem; yalnızca mevcut kontrol ve haberleşme ihtiyaçlarını karşılamakla kalmayıp, aynı zamanda gelecekteki ileri seviye yapay zekâ uygulamalarına da entegre edilebilecek esnek bir yapı sunmaktadır. Bu sayede, daha gelişmiş sensör entegrasyonları ile birlikte Pekiştirmeli Öğrenme, Bulanık Mantık ve Yapay Sinir Ağları gibi modern yapay zekâ algoritmalarının uygulanmasına uygun bir elektronik ortam hazırlanmaktadır. Sistem, dinamik çevre koşullarına uyum sağlayabilecek, çoklu veri kaynaklarından anlamlı bilgi çıkarımı yapabilecek ve karar destek mekanizmalarını akıllı hale getirebilecek bir donanım-yazılım bütünlüğü sağlamaktadır. Böylece, yalnızca konumlandırma ve yön kontrolü değil, aynı zamanda çevresel farkındalık, engel tespiti ve adaptif görev yönetimi gibi yüksek seviye otonom fonksiyonların elektronik olarak desteklenmesine olanak tanımaktadır.

Tasarımı yapılan elektronik sistem, modüler yapısıyla farklı görev senaryolarına ve sensör ihtiyaçlarına kolaylıkla adapte olabilmekte, böylece sistemin genişletilebilirliğini ve uzun vadeli kullanılabilirliğini artırmaktadır. Donanım katmanında kullanılan mikrodenetleyici tabanlı yapı, yüksek hassasiyetli veri alımı ve gerçek zamanlı işleme kapasitesiyle yapay zekâ algoritmalarının hızlı ve doğru çalışmasına zemin hazırlamaktadır. Bu kapsamda, haberleşme arayüzleri, güç yönetim devreleri ve sensör entegrasyon modülleri gibi alt bileşenler sistemin performansını artıracak şekilde optimize edilmiştir. Elektronik sistemin genel tasarımı, hem enerji verimliliğini gözetmekte hem de çevresel dayanıklılığı artıracak şekilde arttıracak şekilde yapılandırılmıştır. Ayrıca, sistemde kullanılan modüllerin yazılım ile senkron çalışması, hata toleransını yükselterek kararlılığı sağlamaktadır. Sonuç olarak, bu elektronik altyapı yalnızca günümüz ihtiyaçlarına cevap vermekle kalmayıp, aynı zamanda gelecekte geliştirilecek otonom deniz araçları için ölçeklenebilir, güvenilir ve yüksek performanslı bir temel oluşturmaktadır. Gerek akademik araştırmalar gerekse endüstriyel uygulamalar açısından değerlendirildiğinde, bu sistemin otonom denizcilik teknolojilerinde sürdürülebilir ve stratejik bir çözüm sunduğu söylenebilir. Sistem mimarisinin modüler yapıda tasarlanmış olması, yeni sensörlerin, yazılımların

ve kontrol algoritmalarının entegrasyonunu kolaylaştırmaktadır. Bu yönüyle, hem araştırma laboratuvarlarında deneysel çalışmalara hem de endüstriyel ürün geliştirme süreçlerine entegre edilebilecek esnekliğe sahiptir.

Sistemin açık donanım ve açık yazılım mimarilerine uyumlu olacak şekilde tasarlanmış olması, günümüz teknoloji ekosisteminde oldukça önemli bir avantaj sunmaktadır. Bu tür açık yapılar, sistemin yalnızca belirli markalara veya tescilli teknolojilere bağımlı kalmadan çalışabilmesini sağlamakta, farklı donanım platformları ve yazılım altyapılarıyla sorunsuz entegrasyonunu mümkün kılmaktadır. Söz konusu mimari esneklik, özellikle farklı ölçeklerdeki projelerde, araştırmalarda veya endüstriyel uygulamalarda sistemin kolayca yeniden yapılandırılmasına imkân tanımaktadır. Donanım ve yazılım bileşenlerinin modüler şekilde tasarlanmış olması, kullanıcıların kendi ihtiyaçlarına uygun olarak belirli birimlerde değişiklik yapabilmesine ve sistemin fonksiyonelliğini artırmasına olanak vermektedir.

Bu yapının sağladığı teknik esneklik, özellikle üniversiteler ve araştırma kurumları için büyük bir fırsat oluşturmaktadır. Akademisyenler ve araştırmacılar, sistemin açık yapısı sayesinde kendi özgün algoritmalarını entegre edebilmekte, deneysel çalışmalarını doğrudan gerçek donanım üzerinde gerçekleştirme şansına sahip olmaktadır. Bu durum, hem yüksek lisans ve doktora düzeyindeki projelerde hem de ulusal ve uluslararası Ar-Ge faaliyetlerinde özgürlük ve yaratıcılığı desteklemekte, akademik üretkenliği artırmaktadır. Ayrıca, açık kaynaklı sistemlerin geniş kullanıcı toplulukları sayesinde oluşan bilgi paylaşımı ortamı, yazılım geliştirme ve sistem entegrasyonu süreçlerini hızlandırmakta ve kullanıcıların karşılaştığı sorunlara daha hızlı çözümler bulunabilmesine olanak tanımaktadır.

Sanayi açısından bakıldığında, açık mimariye sahip sistemler ürün geliştirme süreçlerinde önemli ölçüde esneklik sağlamaktadır. Özellikle küçük ve orta ölçekli işletmeler (KOBİ'ler), bu sistemleri kullanarak yüksek maliyetli tescilli çözümler yerine, daha erişilebilir ve özelleştirilebilir platformlar üzerinde Ar-Ge çalışmalarını sürdürebilmektedir. Böylece, firmalar hem ürün çeşitliliğini artırmakta hem de daha kısa sürede pazara çıkabilecek prototipler ve nihai ürünler geliştirme imkânı bulmaktadır. Bu da rekabet gücünün artmasına, teknolojik yeniliklerin hızla endüstriyel uygulamalara dönüştürülmesine ve ticarileşme sürecinin hızlanmasına katkı sağlamaktadır.

Sistemin bu açık ve modüler yapısı, üniversite-sanayi iş birliklerinin güçlenmesinde de stratejik bir rol oynamaktadır. Akademik kurumların sahip olduğu teorik bilgi birikimi ile sanayi kuruluşlarının uygulama deneyiminin bir araya gelmesi, yerli ve milli teknoloji üretimini destekleyen sinerjik projelerin hayata geçirilmesini mümkün kılmaktadır. Ayrıca, bu tür iş birlikleri sayesinde yüksek teknolojiye dayalı ürünlerin geliştirilmesi sürecinde, ortak platformların kullanımıyla maliyetler düşürülmekte ve zaman yönetimi daha etkin yapılabilmektedir.

Sonuç olarak, sistemin açık mimarilere uyumlu tasarımı; akademi, sanayi ve ticarileşme süreçlerinde önemli avantajlar sunar. Bu yaklaşım, inovasyonu teşvik eden ve teknolojik bağımsızlığı destekleyen stratejik bir adımdır. Aynı zamanda, farklı paydaşlar arasında bilgi ve kaynak paylaşımını kolaylaştırarak sürdürülebilir kalkınmaya da katkı sağlar. Açık sistemler, geleceğin iş birliğine dayalı teknoloji ekosistemlerinde kilit rol oynayacaktır.



1. INTRODUCTION

1.1 Literature Review

Free-running ship models are a profound method to assess the hydrodynamics of ships at model scale. Despite captive tests such as resistance, propulsion, seakeeping, and maneuvering, free-running model tests offer extensive test capabilities including all the aspects of ship hydrodynamics. Once launched in lake or sea, hydrodynamic performance of the full-scale ship can be predicted from the model with certain extrapolation models.

Recent projects have been carried out in Istanbul Technical University in an aim to conduct free-running model tests. On top of the wooden bare hull, free-running models require additional capabilities: electronic hardware and codes that run the hardware. In this regard, the first free-running model ship was produced at the Faculty of Naval Architecture and Ocean Engineering under the ITU KATMANSIS project [1]. A 7m long model of the DTMB5415 warship form was tested at ITU Lake and its maneuvering characteristics were examined. The electronic system connections of this ship are given in Figure 1.1.

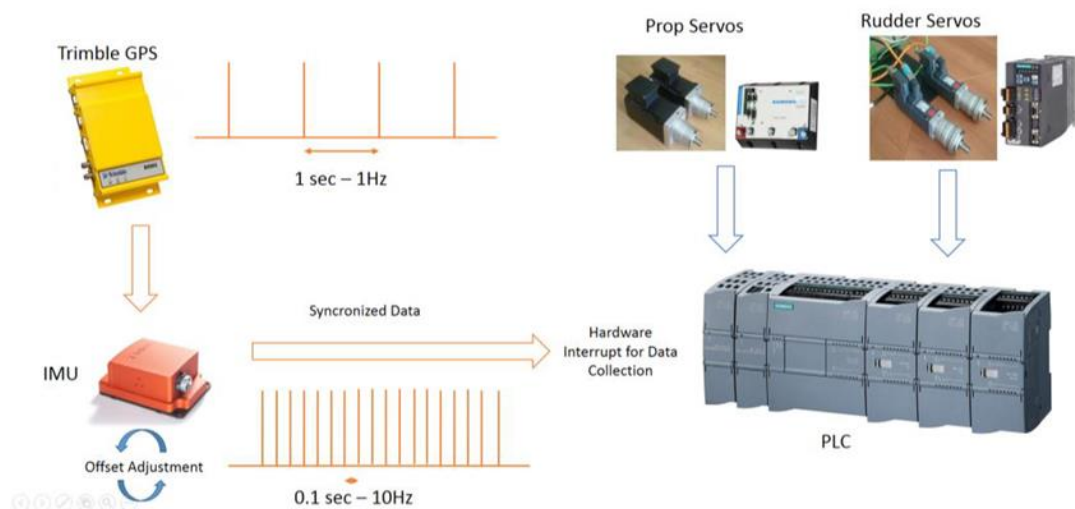


Figure 1.1 : Electronic system connections of the 7m long DTMB5415 warship [1].

A few years after this ship, a 1/80 scale (approximately 4.5 m) free-running model of the Duisburg Test Case (DTC) container ship was produced within the scope of a TUBITAK 1001 project [2]. The project was focused mainly on two aspects:

- measuring the underwater noise of the model and
- testing the maneuvering capabilities of the ship.

The results obtained with numerical approaches were then verified with tests conducted at ITU Lake and the validity of the applied numerical approaches was tested. The electronic design of the ship is given in Figure 1.2.

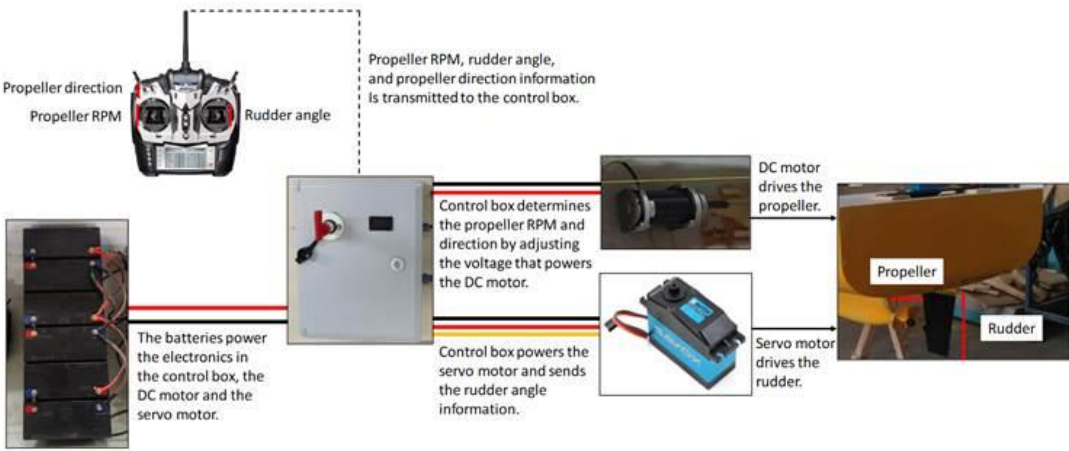


Figure 1.2 : Electronic system design of 4.5m long DTC container ship [2].

Ships that can be controlled by remote control are considered as the first step of the transition to autonomous ships, which has been on the agenda in recent years. Ship motion control is an important issue in terms of the navigation performance and cost of unmanned ships. Conventional ships are propelled with a single rudder and a single propeller (i.e. 2 actuators). When a full ship is considered to have at least 3 degrees of freedom in the horizontal plane, conventional propulsion systems are referred to as “underactuated”. There is no single control test platform specifically developed for the unmanned ships. For a study conducted in 2017 [3], the design and production processes of a test platform where standard tests can be performed automatically on a free-mode ship were described. Ship behavior can be observed during the tests, and control parameters can also be changed. The electronic design scheme of the ship model is given in Figure 1.3.

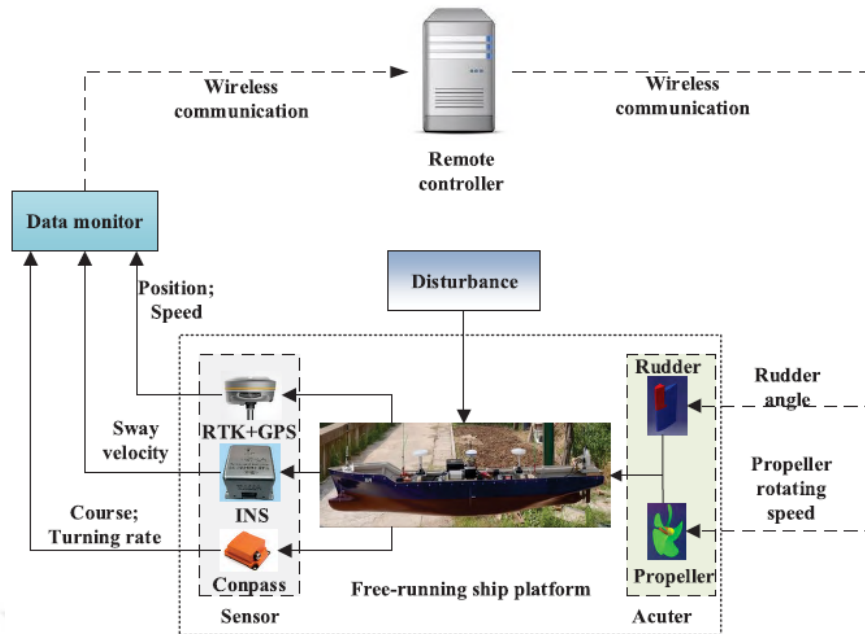


Figure 1.3 : Electronic design software of 3m long KCS container ship model [3].

In addition to these projects, a study have also contributed significantly to the development of electronic system design for free-running ship models. A notable example is the 3-meter-long model ship developed at Mokpo National Maritime University in South Korea [4]. This model was equipped with GPS, IMU, AIS, wireless LAN, and servo motors, and was designed for both manual and autonomous operation. The ship’s control was managed via a laptop onboard, using TCP/IP signals and a PMAC-based motion controller. All control and navigation data were processed and transmitted to the shore station in real time, and emergency fallback was ensured through PWM-based RC override. The modular structure allowed the integration of new sensors and actuators, offering a versatile test platform for advanced maneuvering and collision avoidance experiments. Figures 1.4 shows the electronic hardware design of the study.

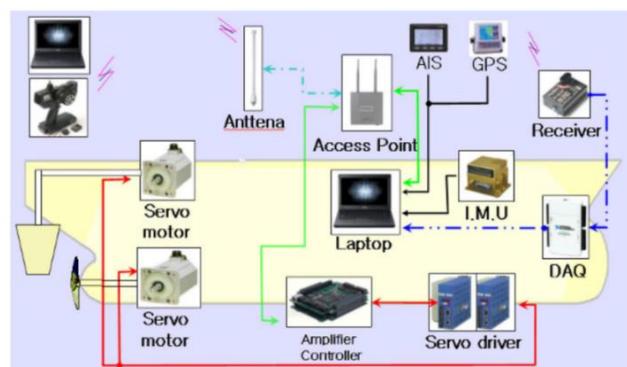


Figure 1.4 : System flow in a model ship [4].

Another advanced study was conducted at the University of Southampton, where a 3.06-meter-long autonomous Ice-Class tanker model was designed and tested [5]. This model emphasized long-duration autonomous navigation in lakes and was equipped with a BeagleBoard-xM processor, Arduino-based sensor acquisition, GPS, strain gauges, and energy monitoring systems. The propulsion system utilized a Maxon DC motor with a high-efficiency PWM motor controller. The control software was built on the Robot Operating System (ROS), supporting modular tasks such as straight-line motion, turning circles, and zig-zag maneuvers. A Simulink-based mathematical simulator was also developed to validate the experimental results and to analyze energy efficiency improvements by testing different trim conditions and bow designs. Figure 1.5 illustrates electronic control system of the study.

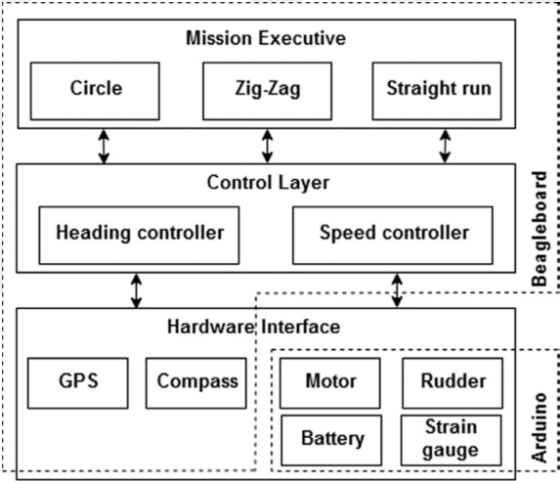


Figure 1.5 : Control system architecture of the tanker ship [5].

This thesis based on the electronic design of a free – running ship model to be tested in a lake. The free – running model is constructed to develop dynamic positioning systems for full – scale ships. The primary goal in the thesis was perform conceptual validation; therefore, it was decided to use a scale model platform at the initial stage as a proof-of-concept. In this context, the model ship with free movement capability;

- The first step is to control it via remote control,
- In the second step, it is aimed to make it able to maintain its position automatically by using a dynamic positioning system.

The only requirement for the model ship in the remote control phase, which is the first phase of the project, is a remote control system that allows it to be managed by an operator at the ground station.

In the second stage, the needs for both the ground station and the electronic equipment on the ship increase significantly. The number of communication equipment must be increased in order to transmit the data produced by the ship to the ground station in real time and to verify that it maintains its position within the specified limits. In line with these needs, additional equipment such as computers, modems and antennas must be used at the ground station.

In this thesis, the electronic equipment of the model ship developed within the scope of the project is detailed. The electronic equipment generally consists of two main parts:

- The equipment on the model ship itself,
- Equipment on the ground station.

Designed at a scale of 1/20,174, the model ship was manufactured in the wood workshop of the Ata Nutku Ship Model Experiment Laboratory within the ITU Faculty of Naval Architecture and Ocean Engineering. In terms of electronic equipment, the PSV Sancar model, which photographed in the laboratory environment is depicted in Figure 1.6, is equipped with the following components:

- two main propeller motors,
- two rudder mechanisms,
- two tunnel type thrusters at the bow,
- two tunnel type thrusters at the stern.

All of these hardware are designed to operate independently of each other. Two basic principles have been observed to ensure high precision operation of the dynamic positioning system:

- All actuators must be able to be controlled independently of each other.
- All systems must operate on the closed-loop control principle.

Having a total of eight different actuators on board is important for analyzing possible failure situations. The two basic principles mentioned above provide high precision and also facilitate the failure modes and their analysis.



Figure 1.6 : PSV Sancar model ship.

The ground station has a complementary structure to the ship operating in the water, and is a center where the ship is remotely controlled, monitored, and the data produced by the ship is simultaneously transferred. While the ship's energy needs are provided by the batteries on it, the ground station's power needs are directly met by city electricity. The selection of electronic hardware and related equipment was made considering that the tests would be conducted at the ITU Lake. However, preparations were made for the possibility of conducting the tests at a different location, and flexibility was provided to support such changes in the electronic equipment. The remote view of the ITU Lake and an image obtained from previous tests are presented in Figure 1.7.



Figure 1.7 : ITU Lake (left). Image from a previous study in the lake (right).

1.2 Purpose of the Thesis

The main objective of this thesis is to design a modular and expandable electronic control system for a small-scale free-running ship model with dynamic positioning (DP) capability and to experimentally evaluate the functionality of this system in the field.

The specific objectives targeted within the scope of the study are as follows:

- To create an embedded system-based electronic infrastructure that can provide real-time control, communication and sensor integration,
- To develop a control box that can precisely control actuators such as propellers, thrusters and rudder,
- To ensure that the battery, motor driver, microcontroller and sensor components to be used on the ship model work in an integrated structure,
- To verify the performance of the created system with free-running tests conducted in a laboratory environment,
- To provide a hardware and communication infrastructure that can form the basis for future artificial intelligence-supported autonomous control algorithms such as image processing-based environmental awareness and obstacle detection.

In this context, the developed system aims to provide a test platform that can be used in academic research and to contribute to the development of small-scale autonomous ship systems in the maritime sector.

1.3 Autonomy Level

This thesis is evaluated by considering the autonomy levels defined by IMO [6-7] and Indian Register of Shipping [8], the free mode ship model. The model is placed between Level 2 (Operational Assistance) and Level 3 (Remote Control) due to its remote control system. The ship can access basic movement commands remotely and implement these commands through electronic systems. In addition, with the dynamic system system that varies, certain changes are provided with the ability to perform without human intervention. This structure provides a appropriate basis for transitioning to higher autonomous levels in the future.

1.4 Evaluation of the Planned Dynamic Positioning System

Within the scope of this thesis, the implementation of the dynamic positioning (DP) system is a study planned to be carried out in the future stages of the project. The aim of the designed system is to ensure that the ship model can automatically maintain its

position according to the data received from the GPS and IMU sensors. These data will be processed with control algorithms and commands will be given to the BLDC thrust motors and rudder servo motors.

Dynamic positioning systems in the ship industry are classified by the IMO and classification societies as follows [9-10]:

- DP-0 : There is no automatic position protection feature; manual control is applied.
- DP-1 : There is an automatic position protection system, but there is no redundancy or fault tolerance.
- DP-2 : It has redundant systems and can continue to operate in the event of a single fault.
- DP-3 : It is resistant to serious faults with high level of redundancy and physically separated systems.

The planned system is initially planned to be designed within the scope of DP-1 level. At this level, the ship will be able to automatically maintain its position in calm environmental conditions, but there will be no redundancy or fault tolerance in the system. This basic structure will form an infrastructure for the integration of more advanced dynamic positioning systems in the future.

1.5 Industrial Impact of a Modular, DP - Capable PSV Electronic Architecture

This master's thesis provides multi-dimensional contributions to the Turkish maritime sector with its modular and expandable electronic architecture that provides dynamic positioning capability to a small-scale Platform Supply Vessel model. Thanks to the low-cost COTS components integrated into the wooden hull, shipyards can rapidly develop original autonomous system prototypes, while the propeller speed-speed database obtained from tank and pond tests facilitates the calibration of real ship hydrodynamic simulations and shortens the design cycle. The power architecture, created with 24V, 12V and 5V isolated DC/DC converters, rail type fuses and 80 A distribution bars, provides a safe electrical scheme adaptable to full scale ships; while the CAN bus backbone and PoE supported Wi-Fi infrastructure constitute a reference for remote monitoring and digital twin applications with uninterrupted data transfer

between ship and shore. The development of a DP capable, free-navigation model for the first time in Turkey enables the laboratory scale reproduction of the PSV Sancar used in oil exploration operations, bringing a strategic opening to the domestic autonomy ecosystem. The high processing power of Jetson AGX Orin opens the door to artificial intelligence-supported navigation studies with the plug-and-play integration of sensors such as cameras, LIDAR and DVL. The ROS 2 compatible modular software-hardware design facilitates seamless interoperability of components from different suppliers on the same platform; while the rich data lake consisting of real-time telemetry, energy consumption and location data serves the development of fuel optimization, predictive maintenance and safe operation algorithms. The free-floating model reduces R&D costs by reducing the risk of electronic integration and control algorithms before the full scale prototype is built; the centralized electronics box architecture shortens maintenance and repair processes and saves operating expenses.



2. SHIP MODEL PRODUCTION

For this thesis, the hull design supporting the dynamic positioning system was derived from the hull form of the Sancar, a Platform Supply Vessel (PSV) operated by Turkish Petroleum. The model ship was constructed from wood and electronically equipped within the scope of this thesis. The main and model-scale dimensions of this hull form are presented in Table 2.1. The overall appearance of the final manufactured PSV model is shown in Figure 2.1. The production stages of the developed model are also provided below.

Table 2.1 : PSV hull form.

Parameter	Symbol (unit)	Model	Full scale
Scale	λ	20,714	1
Waterline length	L_{WL} (m)	3,09	64
Beam	B (m)	0,8013	16,6
Draft	T (m)	0,3101	6,425
Wetted surface area	S (m ²)	4,07	1748,1
Displacement volume	∇ (m ³)	0,612	5440
Block coefficient	C_B (-)	0,797	0,797
Service speed	V (m/s)	1,19	5,4
Froude number	Fr (-)	0,216	0,216

The PSV model was constructed at the ITU Ata Nutku Ship Model Laboratory Workshop at a scale ratio of 1/20,714, in accordance with the recommended procedures and guidelines of the ITTC [11]. The production stages consisted of the following steps, respectively:

- rough model fabrication (Figure 2.2),
- CNC machining (Figure 2.3),
- priming (Figure 2.4),
- painting and marking (Figure 2.5)

These stages were carried out with precision in the laboratory’s production workshop. Figures 2.2, 2.3, 2.4 and 2.5 show images of the corresponding production steps. Initially, using the lines plan of the model, Ayous timber planks with a thickness of 5 cm were glued together with marine adhesive to form the rough model. To ensure durability against external environmental conditions, the bonding of the timber layers was performed with great care (Figure 2.2).

Next, the outer surface of the rough model was machined using a 5-axis CNC machine with an accuracy of ± 1 mm, resulting in the raw outer shell of the model (Figure 2.3). In the following stage, to improve watertightness and resistance to external conditions, the outer shell underwent varnishing and priming processes (Figure 2.4).



Figure 2.1 : View of the completed PSV Sancar model.

Figure 2.5 illustrates the painting process of the model’s outer shell, including the addition of stations, waterline, and wave height marks at the bow in preparation for experimental testing



Figure 2.2 : Rough model fabrication of the PSV hull.



Figure 2.3 : CNC-machined wooden ship hull model.



Figure 2.4 : Finished PSV hull after CNC and priming.



Figure 2.5 : Appearance of a PSV after painting and marking.

3. ELECTRONIC SYSTEM DESIGN

In this section, the electronic system design of the free-running ship model with dynamic positioning (DP) system is discussed in detail. The design includes the integration of actuators, sensors and control modules, motor systems and power distribution elements. The purpose is to reveal the functional and structural features of each module to ensure high maneuverability and stability of the ship model.

3.1 Equipment Elements

The electronic equipment selected for the project was evaluated in two separate groups according to their areas of use. The electronic equipment on the model ship is presented in Table 3.1, while the equipment used in the ground station is listed in Table 3.2.

The ship's communication with the land station is carried out via remote control. Real-time data transfer is made from the ship to the computer at the land station. There are Wi-Fi modems on both the ship and the land station to provide this communication. The modem on the ship was chosen as an omnidirectional antenna type that provides 360-degree coverage due to the possibility of the ship turning in any direction. Since the modem used on land only needs to be directed towards the pond area, a 120-degree directional antenna was preferred. Omnidirectional antennas are expensive and have limited range, but they can send and receive signals from all directions. Directional antennas are more economical and can be used at longer distances. However, they can only exchange signals at a certain coverage angle. Although it is possible to use omnidirectional antennas on both sides of the ITU Lake, it was decided that the current antenna selection was the most suitable option when the dimensions of the pond and economic factors were taken into account.

Table 3.1 : Ship electronic equipment and actuators.

Category	Type	Equipment	Quantity
Actuators, motors and drivers	Actuator	4-bladed 14cm diameter propeller	2
		4-bladed 7.9cm diameter propeller	4
		Rudder in NACA0018 form	2
	Motor	6384 190 kV motor	2
		DRF2814 350 kV motor	4
		DS5160 servo motor	4
	Driver	VESC 6.9 motor driver	2
		VESC 6.7 motor driver	4
	Computer, microcontroller and sensors	Microcontroller	STM32F104 microcontroller
Orin PC		AGX Orin AI pc	1
Transceiver		MCP2551 CAN bus transceiver	1
IMU-GPS		Xsens MTi 6710 IMU	1
Communication and manual control elements	Poe	PoE adapter	1
	Modem	Rocket M2 Wi-Fi modem	1
	Antenna	13 DBI omnidirectional antenna	1
Battery	Battery	6S10P Litium-ion battery	2
Auxiliary components	Fuse	63A DC supported B-type otomatic fuse	2
		16A DC supported B-type otomatic fuse	6
	Terminal block	Din rail terminal block	16
	Busbar	Power distribution busbar 2x13, 80A	3
	Connector	LP-28 waterproof connector - female	2
		LP-28 waterproof connector - male	2
	Cable gland	PG-7 cable gland	4
		PG-9 cable gland	6
		PG-11 cable gland	2
	Regulator	DC/DC voltage regulator 24V DDR-60G-24	1
		DC/DC voltage regulator 12V DDR-120G-12	1
		DC/DC voltage regulator 5V DDR-60G-5	1

Table 3.2 : List of electronic equipment used in the ground station.

Type	Equipment	Quantity
Computer	Laptop	1
Modem	Rocket M2 Wi-Fi Modem	1
Antenna	21DBI 120° Directional Antenna	1
PoE	PoE Adapter	1
Remote Controller	2.4 GHz FlySky	1

There are eight actuators on the model ship. The ship performs its main maneuvering using rudders. The ship gains speed through two propellers located at the stern. The thrusters, two of which are located at the bow and two at the stern, are used for dynamic positioning or docking maneuvers. Additionally, the thrusters can be used when the vessel requires sudden maneuvers. The general layout of the actuators in the PSV Sancar ship model is shown in Figure 3.1.

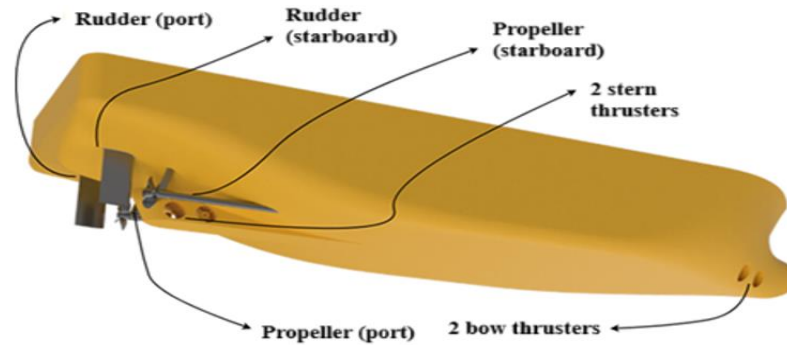


Figure 3.1 : PSV Sancar model ship general layout.

3.2 Actuator, Motor and Drivers

The use of a Flipsky brand 6384-sized, 190 kV, three-phase, externally rotating brushless motor is deemed suitable for use as the main motor. The peak power value of 4000W provided by the manufacturer for the selected motor was chosen because it covers the expected power values for the model scale and provides the required propeller speed of 9 RPS (540 RPM) for the drive speed. The 6384 motors used as the main machine have Hall Effect sensors embedded in them. Thanks to these sensors, the motors can be driven in a closed-loop system. Commands from the user are first transmitted to the motor driver via remote control. The processed signal is then sent to the motor. The Hall Effect sensor communicates the current status of the motor to the motor driver. The motor converts the received signal into power and rotates the propeller. The closed-loop motor cycle diagram of the main machine is shown in Figure 3.2.

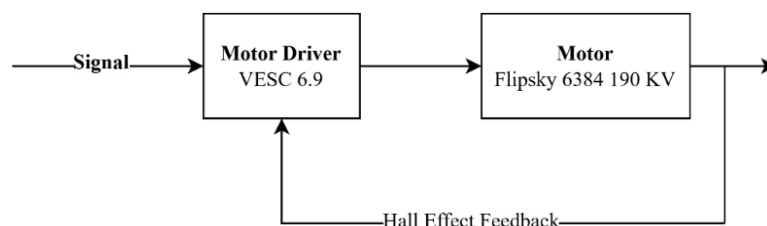


Figure 3.2 : Main motor closed loop motor cycle diagram.

As the driver, the VESC 6.9 was used, which has the capacity to transmit a peak power value of 4000W. Known for being open source, VESC was chosen for this project for the following reasons:

- torque control for motor operation and
- the ability to operate the main machine system in a closed-loop configuration at appropriate PID values.

Images of the motor and driver used in the system are presented in Figure 3.3. In addition, the technical specification of the motor are provided in Table 3.3 to give a clearer understanding of the motor’s performance characteristics and suitability for the control system.



Figure 3.3 : Flipsky motor (left) and VESC 6.9 motor driver (right). Hall effect sensor is located inside the motor.

Table 3.3 : Motor data [12].

Specification	Value
kV Rating	190 kV
Maximum power	4000 W
Maximum current	95 A
Voltage range	14,8 V – 58,8 V
Maximum torque	9 N.m
Motor resistance	0.05 Ohm
Number of poles	14
Wire configuration	Blue = U (A)
	Yellow = V (B)
	Green = W (C)
	Hall sensor wire : Red = 5V
Shaft diameter	8 mm

Due to the small scale of the model, the hardware selection options for the tunnel type thrusters located at the bow and stern are quite limited. Among these limited alternatives, 2814 size, 350 kV, three-phase and underwater operation-friendly motors were preferred. It has been observed that the 450 W peak power specified in the factory data of the motors exceeds the required power when scaled to the model. Designed to operate underwater, these motors are directly integrated into the propeller hub. VESC 6.7 model drivers with lower voltage and current carrying capacity were used for these thrusters, which have lower power and size compared to the main drive motors. Visuals of the motor drivers for a total of four thrusters, two at the bow and two at the stern, and one thruster motor placed in the propeller hub are given in Figure 3.4.



Figure 3.4 : Thruster motor drivers (left). Thruster motors are mounted on the propeller hub (right).

Four servo motors each of which operates with 5V were preferred in order to provide rudder movements. Two servos were used for each rudder to eliminate the mechanical gap caused by the internal gear structure of the servos. The placement of the servo motors used is shown in Figure 3.5.



Figure 3.5 : Servo motor (left). Dual servo motor assembly for the starboard rudder of the vessel (right).

3.3 Computer, Microcontroller and Sensor

There is a need for a microcontroller that can provide signal transmission to the actuators on the ship and integrate safety measures into the system. In this direction, the STM32F104 based Nucleo development board was preferred due to its widespread use and sufficient number of output pins. The visual of the board is on the left side of Figure 3.6. The Appendix A presents the closed-loop electronic control system for the dual-motor actuators, implemented using an STM32-based Servo MCU in the model ship's electronics.

In order for the microcontroller to send commands to the motor drivers it is connected to the signals must be converted to the appropriate format. This conversion process is carried out by a transceiver module that supports the CAN communication standard. In addition, this hardware makes the system resistant to electromagnetic interference and environmental noise. The appearance of the relevant CAN transceiver circuit is presented in Figure 3.7 (left); the module can be clearly seen in the yellow circle. In addition, the project is aimed to have a structure suitable for field conditions, resistant to vibrations and long-term use. In this context, instead of temporarily establishing electrical connections on a breadboard, a more stable and secure solution and the printed circuit board (PCB) design was preferred. Although breadboards are generally used in the development and testing stages, they are not recommended in permanent systems due to loose connections, their inability to carry high currents and their sensitivity to vibration. Therefore, in order to increase the reliability of the system and to demonstrate a professional engineering approach, a special PCB design was carried out for the control and interface circuits in the electronic control box. This design can be seen in Figure 3.7 (right).

In addition to the microcontroller, which undertakes relatively simple tasks, the model ship also needs to have a host computer that can perform the following tasks:

- operating control algorithms of the dynamic positioning system,
- processing data obtained from GPS and IMU sensors,
- and providing a plug-and-play supported structure that will easily integrate sensors such as cameras, LIDAR, DVL that can be included in the system in future projects.

In line with these needs, the NVIDIA AGX Orin computer unit, which stands out with its low power consumption, high processing capacity and compact dimensions, was preferred. The visual of this computer used is shown in the middle section of Figure 3.6.



Figure 3.6 : Images of the STM microcontroller (left), ORIN computer (center) and Xsens GPS-IMU (right).

A ship with a model-scale dynamic positioning capability must have at least one GPS sensor and one IMU (provided that the tests are conducted in an open area). In line with this requirement, the integrated GPS-IMU unit from the Xsens brand, which offers both sensors in a single structure, was preferred.

In the selection of this unit, features such as;

- allowing direct transmission of unprocessed (raw) data,
- accelerating the positioning process in the early stages thanks to the integrated Kalman filter,
- and providing accuracy at a sensitivity level of approximately 0,2 meters.

were prioritized. This device used in the project has all the specified features and the visual of the device is shown on the right side of Figure 3.6.

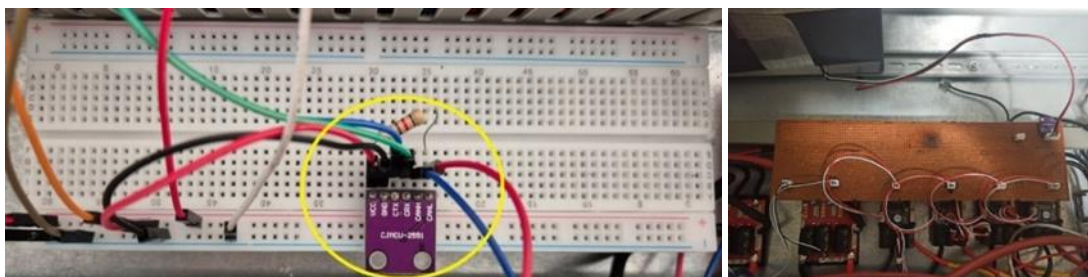


Figure 3.7 : CAN transceiver circuit (left, circled in yellow), PCB design (right).

3.3.1 Communication and manual control

For manual control of the ship, a long-range 2.4 GHz FLYSKY RC type remote control suitable for civilian use was used. The visual of the remote control used is given in Figure 3.8 (left). The remote control receiver connections were implemented in a way that,

- In emergency situations on the model ship, control commands will be given priority,
- If no control command is received, the ship will be stopped safely.

During the operation of the ship on the water with remote control, data such as instantaneous position, speed, and actuator signals must be transmitted to the ground station. In order to transmit this data reliably with low latency and within a wide coverage area, the Rocket M2 model Wi-Fi modem from Ubiquiti was preferred. The Rocket M2 unit integrated into the model ship on the water operates with an omnidirectional antenna with a gain of 13 DBI. At the ground station, a directional antenna with a coverage angle of 120° and a gain of 21 DBI compatible with the Rocket M2 unit is used, directed to the area where the ship operates. The Rocket M2 Wi-Fi modem images used at both points are in the middle part of Figure 3.8. The system communication and flow structure are presented in the Appendix B.

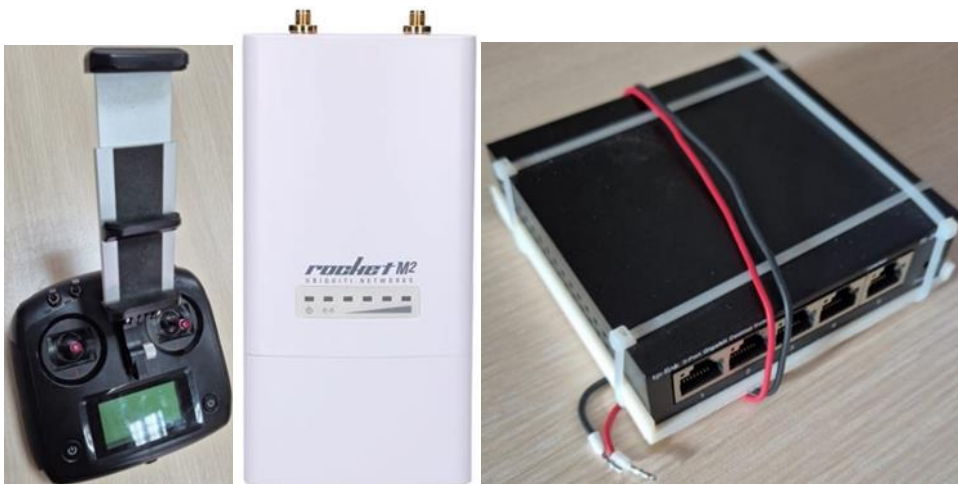


Figure 3.8 : Remote controller (left), Wi-Fi modem (center) and PoE adapter (right).

The power and signal connections required by the modem are provided via the PoE adapter. While this adapter can receive energy directly from the socket when on land, it is fed from the battery with a 24V regulator on the ship and transmits this energy to the modem. The image of the adapter is shown on the right side of Figure 3.8.

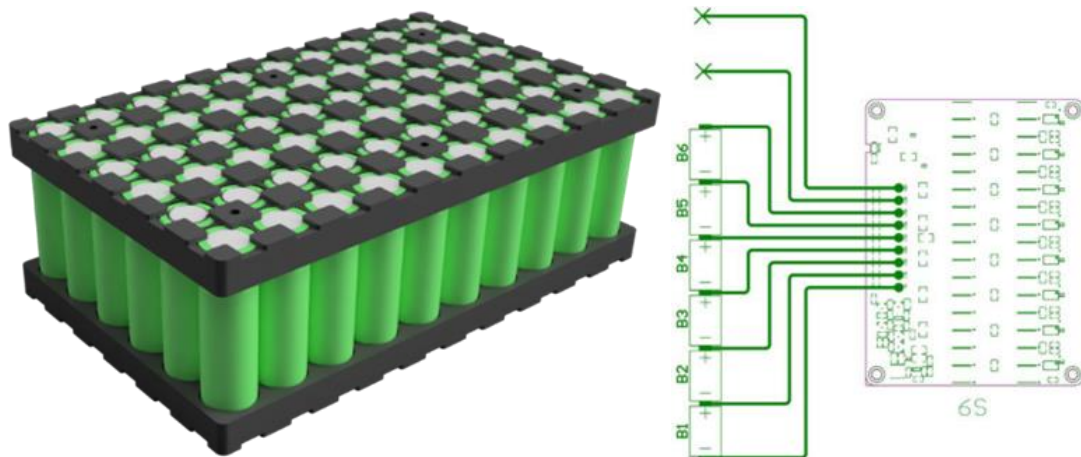


Figure 3.9 : Battery grouping (left) and BMS connection diagram (right).

3.3.2 Battery

In order to meet the energy needs of the model ship and to be compatible with the electronic systems, a lithium-ion battery with a nominal voltage of 22,2V was preferred in the 6S10P configuration. In order to prevent problems caused by charging and discharging during long-term tests, a detachable 6S 40A BMS (Battery Management System) was integrated into each battery. A total of two 6S10P batteries were used to achieve a capacity of 1281,6 Wh, and thus the ship was aimed to complete a full day of testing with a single charge. Figure 3.9 shows the connection diagram of the battery and Figure 3.10 presents a photo of the battery itself. The technical specification features of the battery are given in Table 3.4.

Table 3.4 : Battery technical specification table.

Battery Chemistry	Lithium - ion
Number of cell connected in series	6
Number of cell connected in paralel	10
Capacity	29 Ah
Nominal voltage	22,2 V
Maximum voltage	25,2V
Minimum voltage	18 V
Rated current	145A without BMS /80 A with BMS (10s)
Continuous current	87A without BMS / 40A with BMS
Total energy	1281,6 Wh
Battery dimensions	140*250*90 mm



Figure 3.10 : Battery pack.

3.3.3 Auxiliary components

Standard automation rails are mounted in two rows on the electronic control box used on the model ship. 2,5 mm² and 1,5 mm² type terminals mounted on the rail were preferred for cable connections and fuse operations. The visual of the single terminal structure is in the middle of Figure 3.11, and the collective arrangement of the terminals inside the control box is shown on the right side of the same figure. In addition, C type and DC compatible automatic fuses were mounted separately for each actuator and selected according to 1,5 times the anticipated current consumption. The general view of this fuse system inside the ship is presented in Figure 3.12.

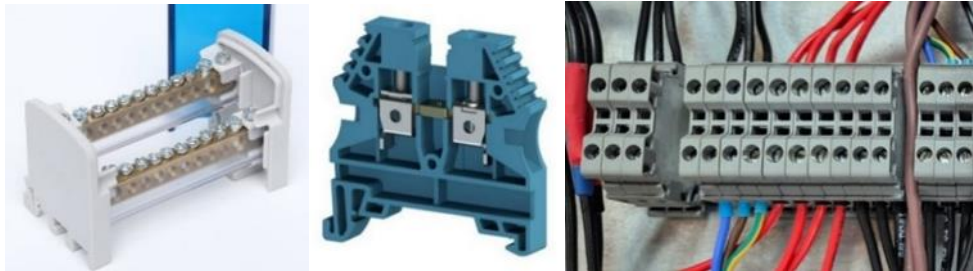


Figure 3.11 : Power distribution busbar (left). Single terminal block on DIN rail (center). Overall view of terminal blocks inside the vessel (right).

In order to ensure safe power distribution, dual rail type distribution busbars with a capacity of 13x80A were preferred (see Figure 3.11 (left)). A total of three distribution busbars were installed inside the panel for 24V DC, 12V DC and 5V DC lines regulated with battery voltage.

For the mentioned regulated 5V DC, 12V DC and 24V DC power needs, DDR series DC/DC converters of Meanwell brand with an input range of 18-36V were used. In order to ensure the safe operation of sensitive electronic components, sensors and main

control unit, isolated type voltage regulators were preferred. The layout of DC/DC converters on the ship are shown in Figure 3.13.



Figure 3.12 : Fuse system.



Figure 3.13 : DC/DC voltage regulators. 24VDC (left), 12VDC (center), 5VDC (right) [13].

Cable exist to the battery and motors located outside the electronic enclosure were made using cable glands. During testing, ensuring the enclosure remained waterproof was crucial so connectors were used to maintain sealing integrity. This approach ensured that all electronic components remained dry. The cable glands and connectors are shown in Figure 3.14.



Figure 3.14 : PG 7 type cable gland (left) and male/female LP28 waterproof connector (right) [7].

3.3.4 Electronic control box

All electronic equipment inside the vessel was consolidated, as much as possible, within a compartment referred to as the electronic control box (also known as a standard automation panel). The mentioned box has dimensions of 80 cm by 60 cm, with a depth of 24 cm. All power and signal connections were made within this control box. It was positioned near the vessel's master station, and the overall layout of the electronic control box is shown in Figure 3.15. As can be seen in the figure, cable exits from the box were made through cable glands installed in side openings.

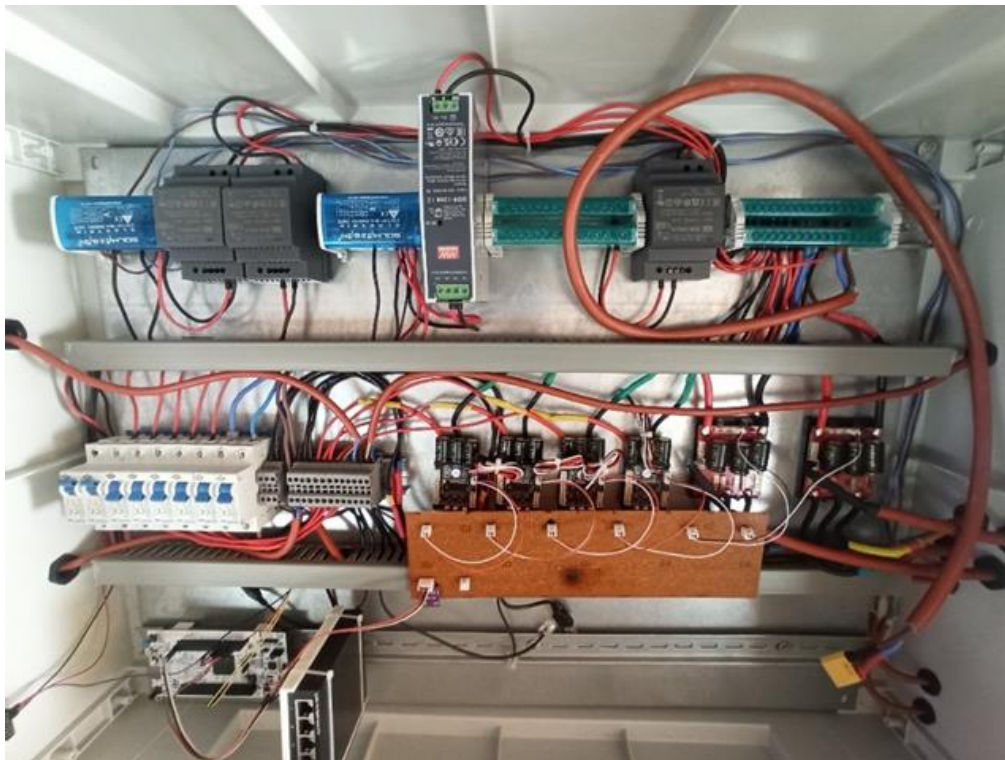


Figure 3.15 : Electronic control box.

The control box is designed in three rows. When viewed from the picture in the figure, the lowest row contains power distribution bars and regulators. The upper row contains the drivers of the motors that enable the propellers and thrusters to operate, and the fuse that will shut down the system in case of danger. The top row contains Orin, the microcontroller and the remote control receiver. The CAN receiver-transmitter, which works in conjunction with the microcontroller and sends signals to the drivers, is located on the second row, connected to a copper plate.

3.4 DP System Power Connection

The Dynamic Positioning (DP) system developed for the Sancar PSV ship uses the rudder, propeller, and front and rear thrusters to ensure that the model ship remains fixed in the desired position and moves in a controlled manner in line with certain tasks. The basic building blocks of the system include actuator units, microcontrollers, computers, sensors and communication modules. Based on the previously presented model, schematic details regarding the power connections of the hardware components to be used in the Dynamic Positioning system of the PSV model ship will be included under the heading "Power Connections". Power connections are of vital importance for DP systems because they ensure that critical components such as motors, thrusters and sensors are supplied with uninterrupted and sufficient energy during the mission. The correct configuration of the power connections of the hardware is an important element that directly affects both the stability and safety of the ship.

3.4.1 Actuator power connections

In the DP (Dynamic Positioning) system, actuators are mechanical units that provide the physical movement of the ship, such as the front and rear thrusters and the rudder. In order for these actuators to operate smoothly, the power connections must be highly reliable. Because these components constantly require high amounts of energy, and any interruption in energy transmission can disrupt the balance of the system and prevent the ship from maintaining its position stable under the influence of environmental conditions.

For this reason, it is of great importance that the power connections of the actuator components are redundant and equipped with various electrical protection measures against failures. This ensures that the ship can maintain its stability against external effects such as waves, wind and current. In addition, protective circuit elements such as fuses, circuit breakers and voltage regulators are used against excessive current or voltage fluctuations to ensure that the actuators remain within safe operating limits.

In Figure 3.16, the cable connections and voltage levels of the servo motors connected to the thrusters and rudder are given in detail.

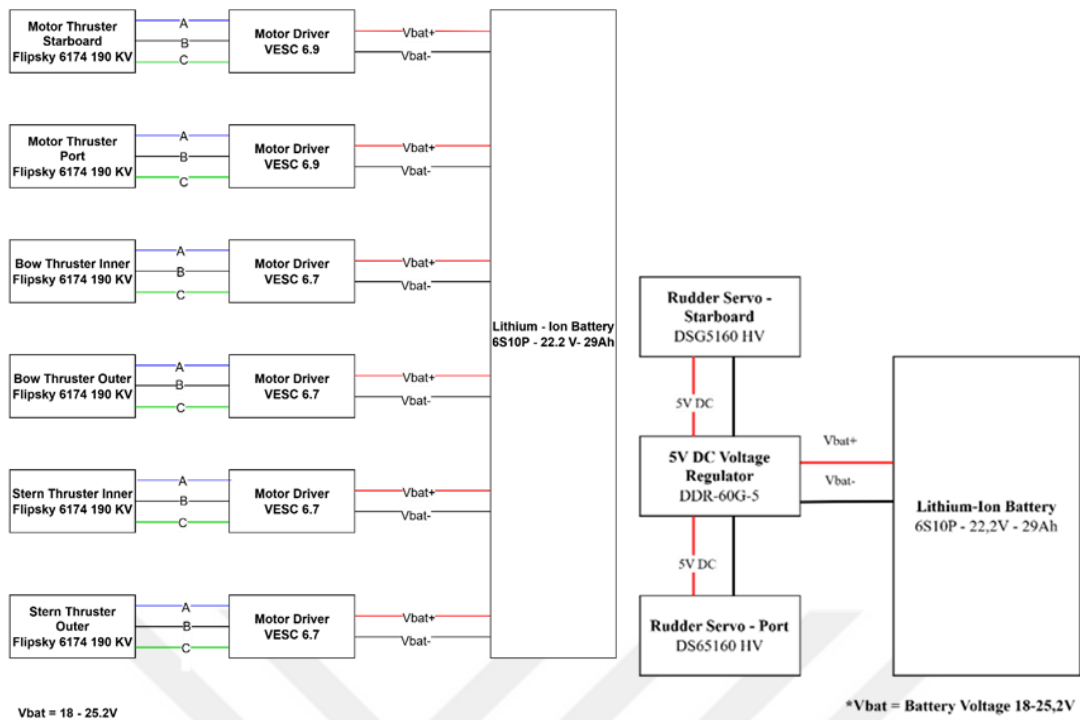


Figure 3.16 : Motor and motor driver connection diagram connected to bow and stern thrusters (left). Rudder servo connection diagram (right).

3.4.2 Processor, computer and sensor power connections

In DP systems, microcontrollers and real-time computers analyze the data from the sensors and keep the ship's position precisely fixed. The uninterrupted and accurate operation of these devices depends on a stable and continuous power supply. The sensors and antenna structure used in the system provide continuous feedback to the DP system by detecting environmental changes around the ship. If there is an interruption in the energy connections of the sensors, the system may receive erroneous data, which may lead to incorrect positioning of the ship.

Although microcontrollers and computer systems generally operate with low voltage, if sufficient and reliable energy cannot be provided, the system may either stop completely or become unstable. For this reason, it is of great importance that the energy infrastructure in marine vehicles is designed as insulated, leak-proof and redundant. In particular, in fully electric marine vehicles, the use of UPS (uninterruptible power supply) is necessary to increase the security of the system.

In Figure 3.17, the power connection diagrams of the Jetson ORIN real-time computer and the microprocessor, which have the capacity to operate all actuators in the DP system simultaneously, are presented in detail.

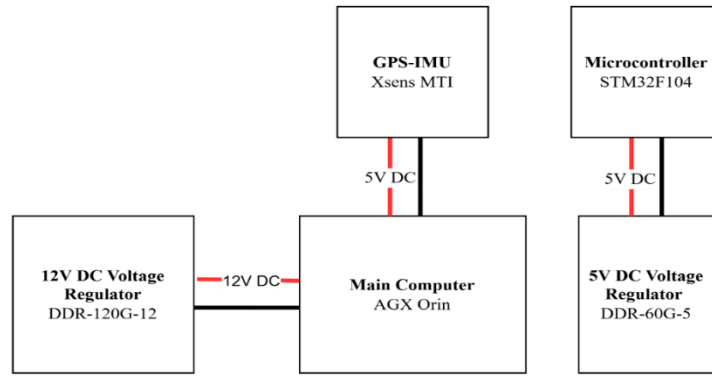


Figure 3.17 : Microcontroller, Orin and sensor connection diagram.

3.4.3 Communication and manual control power connection

PSV's Dynamic Positioning (DP) system also allows the ship's crew to perform manual control and to communicate between different systems. Manual control via an RC pilot is activated via the PoE adapter, especially when the automatic DP system is disabled. It is of great importance that the power connections of both control units operating in real time are active and operational at all times.

On the other hand, the communication unit perform continuous data transmission between the central computers, sensors and actuators of the DP system. Any power outage in this communication line may disrupt the data flow and cause the ship to lose its balance and control. Therefore, the energy connections of both the communication infrastructure and the manual control systems should be designed to be redundant and dual-line.

The selected equipment for communication and manual control purposes had to be fed with potentials of different values. In line with this requirement, the connections of the added isolated and regulated 24V DC, 5V DC voltage regulators were made as in Figure 3.18.

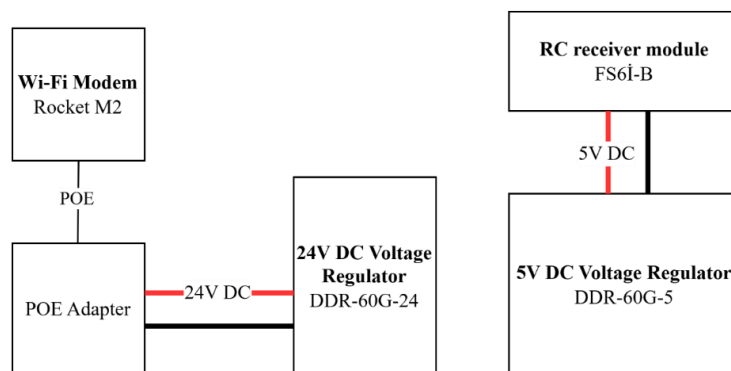


Figure 3.18 : Communication and manual power connection diagram.

Although the connections made do not prevent signal transmission, a rail-mounted grounding and common distribution busbar is also included in the standard panel as a possible solution to the problem of grounds not being common that may arise from isolated circuits.

3.5 PSV Model Ship Signal Connections

In Platform Supply Vessels (PSVs), signal connections play a crucial role in the operation of Dynamic Positioning (DP) systems. The DP system is composed of sensors, computers and actuators that work together to maintain the vessel's position. Actuators include components such as thrusters, propellers, rudders, azimuth thrusters, and propulsion systems that control the vessel's movement. The operation of these components is managed through signal communication. Apart from power connections, the electronic links of onboard equipment on the model vessel differ in terms of physical form, electrical characteristics, and sensitivity. Separating signal connections from power diagrams is essential for enabling quicker intervention, fault detection, and troubleshooting in the event of unexpected or emergency situations.

3.5.1 Actuator signal connections

Control of actuator mechanisms is achieved through the following signal connections:

3.5.1.1 Connection with control systems

The DP (Dynamic Positioning) control system uses a signal transmission line to transmit the necessary commands to the actuators. The transmission line typically carries data using digital signals or industrial communication protocols such as CAN bus, Profibus, or Ethernet/IP. The control system continuously monitors the ship's position and speed and sends the appropriate movement commands to the actuators based on the obtained data.

3.5.1.2 Propeller propulsion systems

Azimuth thrusters or main propulsion systems regulate their speed and direction in accordance with the commands transmitted from the DP system. Commands from the control system are delivered to the TCU, which transmits them to the appropriate actuators, ensuring proper speed and directional control.

3.5.1.3 Rudder systems

Rudders are used to change the ship's direction according to signals sent by the DP system. The DP control system can adjust the rudder angles to achieve the desired course. These signals are transmitted to the SCU.

3.5.1.4 Torque and power management

The power and torque values of the signals sent to the actuators are also carefully controlled. Especially in electric drive systems, not only speed signals but also electrical quantities such as voltage or current under control. In this way, the correct transmission of the required torque to the motors is ensured.

Actuator signal connections on PSV type ships have a very sensitive and complex structure in terms of maintaining the dynamic balance of the ship. The accuracy and security of the signals transmitted in these connections are of great importance so a large part of the systems are designed in a redundant and fault-tolerant manner. In Figure 3.19, the signal connections of all actuators connected to the DP system and the signal diagrams of the rudder servos are presented with all signal details.

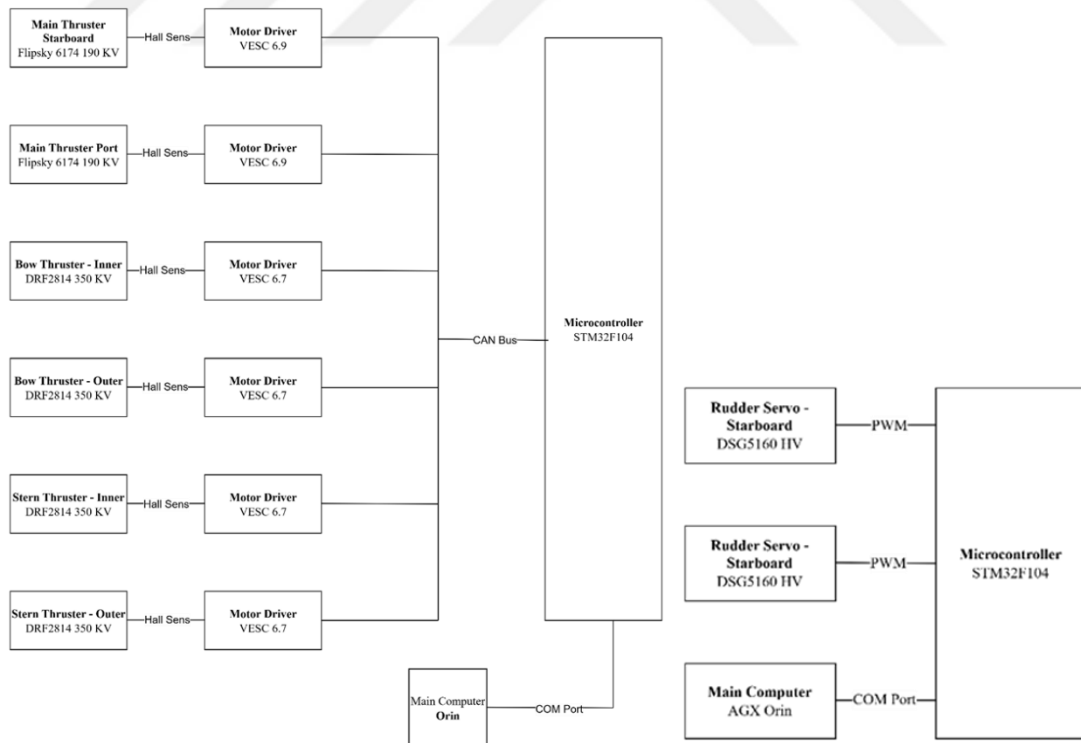


Figure 3.19 : Actuator signal connection diagram (left). Rudder servos signal connection diagram (right).

3.5.2 Microcontroller, computer and sensor signal connections

In a PSV-type model vessel, the signal communication established between the microcontroller, computer, and sensors is critically important for the effective operation of the Dynamic Positioning (DP) system. Sensor data is processed to stabilize the vessel’s position and movement.

3.5.2.1 Microcontroller and computer communication

While microcontrollers handle low-level tasks such as propeller and rudder control, the Jetson AGX Orin-based Linux computer performs computations for more advanced control and stabilization algorithms. Data transfer between the microcontroller and the computer is usually achieved through industrial communication protocols such as CAN bus, Ethernet or RS-485.

3.5.2.2 Sensors

XSENS-based IMU and GPS sensors are integrated into a single module and communicate via CAN bus. IMU measures the angular movements and accelerations of the ship, while GPS determines the absolute position of the ship. This information is transferred to the DP system, ensuring that the ship's position is maintained with high precision.

This structure minimizes signal delay and ensures reliable data transmission, thus continuously optimizing ship dynamic control. Figure 3.20 shows the signal connections of the Xsens MTi type sensor, microcontroller and host computer.

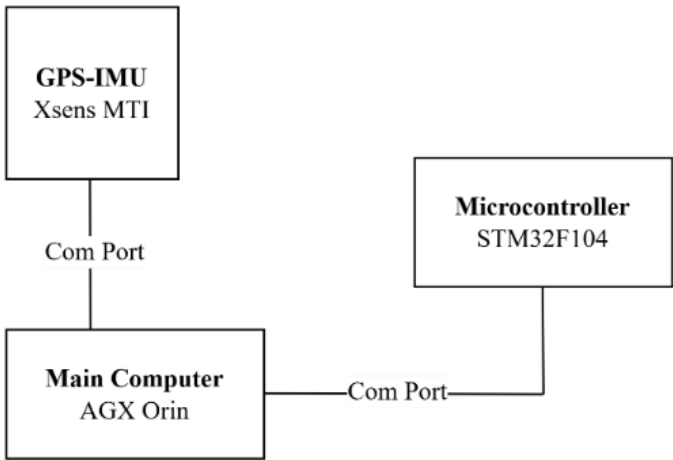


Figure 3.20 : MCU, Orin and GPS-IMU signal connection.

3.5.3 Communication and manual signal connections

The only device where power and signal lines cannot be transmitted separately between communication units is the Rocket M2 modem. The main reason for this is that many long-range devices designed for network connection and P2P (point-to-point) communication use the PoE (Power over Ethernet) standard. PoE is a technology that physically provides both data transmission and electrical power transfer over an Ethernet cable. Figure 3.21 shows the signal connections for communication related to the remote control system.

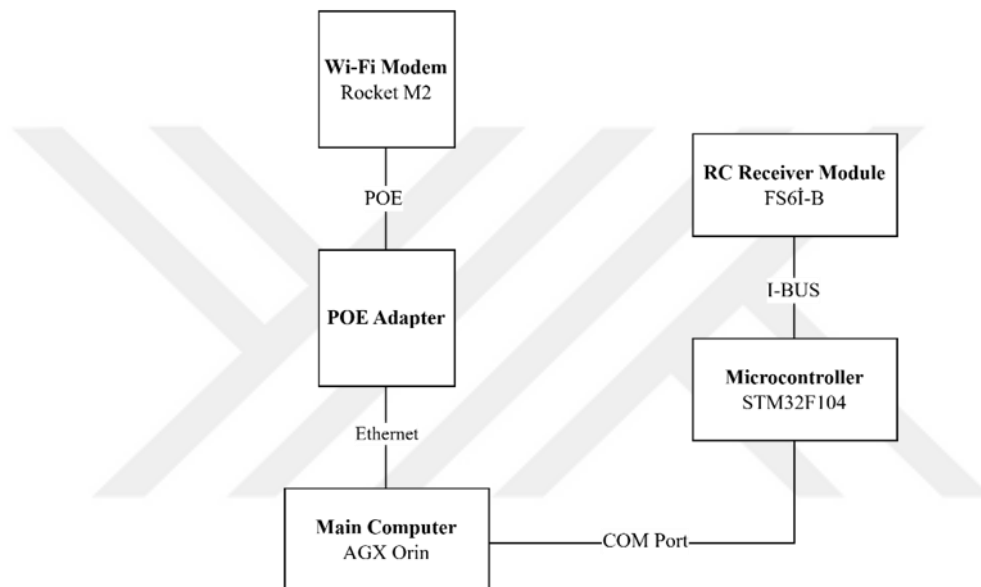


Figure 3.21 : Signal connections for remote control communication.



4. FREE-RUNNING TEST RESULTS

Within the scope of this thesis, the devices used for the electronic equipment of the PSV Sancar ship, the introduction of these equipment and the reasons for their use, and power and signal connections were presented in detail. The mechanical structure of the ship was previously completed and its electronic system was designed in this study for the first free-running tests. The propulsion tests were carried out in the towing tank of the Ata Nutku Ship Model Test Laboratory in accordance with the operation [14-17]. The towing tank has a length of 160 m, a width of 6 m and a water depth of 3,5 m. The maximum speed of the towing vehicle is 5,5 m/s. The blockage effects (in order to prevent the tank walls to interfere with the hydrodynamics of the ship) were considered prior to the ship model's construction and its dimensions were selected to be the largest possible. According to the previously mentioned advisory guide, the withdrawal tank depth and model draft rate are well above the minimum value providing deep water capacity [14-17]. Thus, the tests were carried out without side wall and bottom effects. The picture of the towing vehicle is presented in Figure 4.1. The trim adjustment ensures that the electronic control box is perfectly centered and horizontal to the body axis; thus, the power converters inside cool evenly, the cable/connector voltages are balanced and the cover seals remain at the same height against wave splashes. In this way, both thermal stability and water tightness are maintained, and the risk of voltage drops or sudden resets in the sensor and actuator feeds is prevented. The proper trim achieved with this ballast placement is shown in Figure 4.2.



Figure 4.1 : Photograph of the towing vehicle at ITU Ata Nutku Ship Model Laboratory during experimental tests.



Figure 4.2 : Layout of the electronic control box and lead ballast blocks during the trim-calibration procedure.

The control of the rudder angle required to keep the course is not among the objectives of this test. Therefore, the rudder angle was set to zero in the tests. However, the model was closed to lateral ship movements such as sway and yaw by the guides (due to the asymmetrically bent rudder, which reduced the course keeping ability of the model) [18].

During the experiments, the model ship's motors and steering system were controlled through an electronic control box. This box has a structure that includes motor drivers, sensors and communication modules. The control box generated control signals for adjusting the ship's speed, direction, and maneuverability. These signals were then used to operate the propeller and steering mechanisms. During the experiments, operations were performed at different motor speeds and directions; parameters such as the ship's speed, thrust force, power consumption and maneuverability were measured. The obtained data were used in the analysis of the ship's dynamic behavior.

The data obtained within the scope of the propulsion experiments allowed the model ship to analyze its hydrodynamic performance at different speeds. It was observed that as the speed values (V_m) measured in the experiment increased, the Froude numbers (Fr) corresponding to these speeds also increased; this situation shows that the wave effect on the hull becomes more pronounced with increasing speed and the resistance components change. The obtained data will be used both in modeling the dynamic behavior of the ship hull and in the calibration of control algorithms to be developed in the following stages. Additionally, the trends observed in the resistance characteristics provide valuable insight for predicting fuel consumption and optimizing operational efficiency under different sea states. These findings are also essential for validating numerical simulations and ensuring the consistency between physical model tests and computational fluid dynamics (CFD) analyses. Furthermore, the experimental results can serve as a reference for evaluating the performance of alternative hull designs or propulsion configurations in future studies.

The relationship between thrust, speed, and resistance helps develop accurate models for maneuvering and positioning. Test results reveal nonlinear behaviors and optimal operating ranges. The propulsion test results are shown in Figures 4.3, 4.4, 4.5 and Table 4.1.

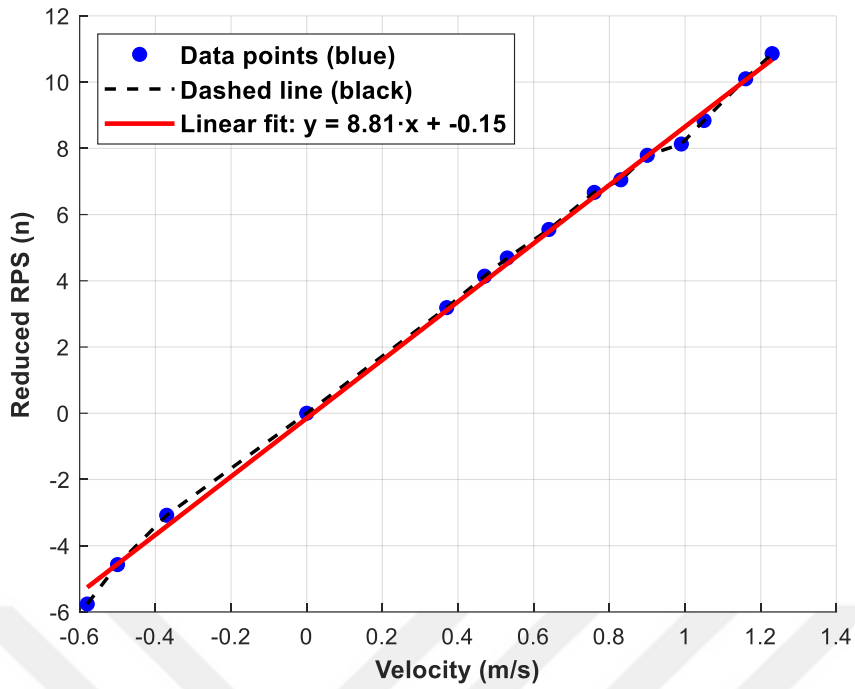


Figure 4.3 : Sancar model ship free – running propulsion test results.

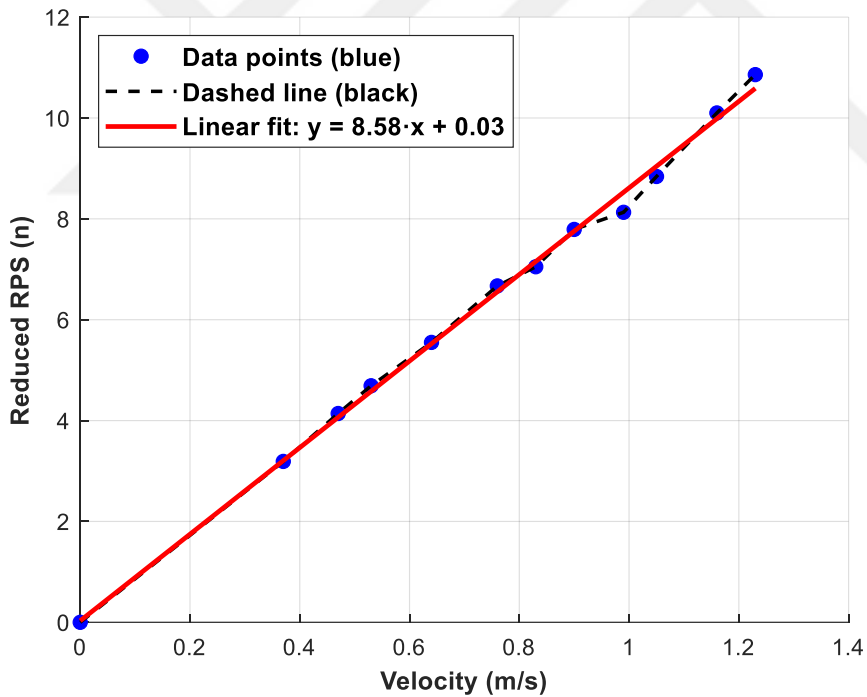


Figure 4.4 : Quantitative evaluation of the R-RPS and velocity relationship in the positive domain.

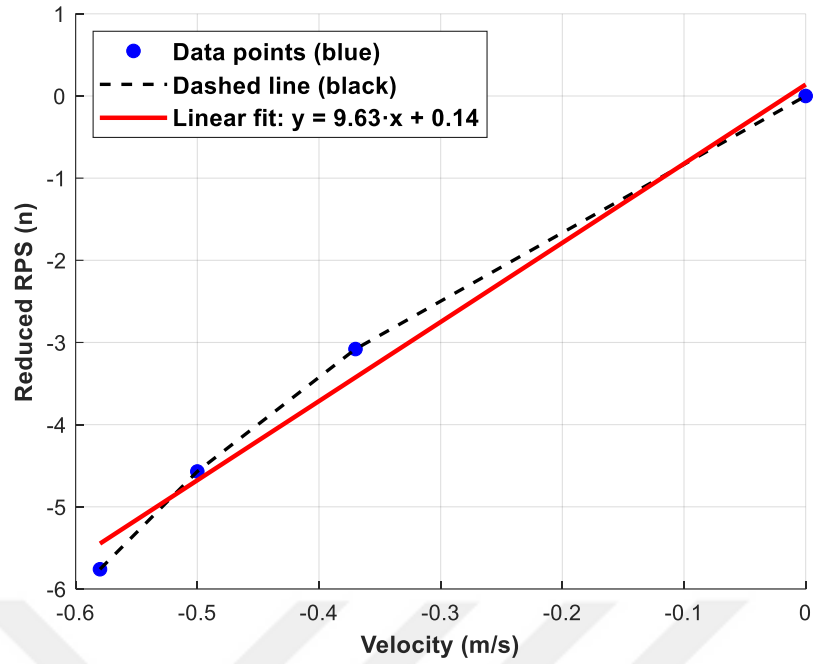


Figure 4.5 : Quantitative evaluation of the R-RPS and velocity relationship in the negative domain.

Table 4.1 : Measured relationship between propeller RPS and vehicle velocity.

I-RPM	RPS	R-RPS	m/s
-3025	-7,2	-5,76	-0,58
-2400	-5,71	-4,57	-0,5
-1615	-3,85	-3,08	-0,37
0	0	0	0
1675	3,99	3,19	0,37
2175	5,18	4,14	0,47
2460	5,86	4,69	0,53
2915	6,94	5,55	0,64
3500	8,33	6,67	0,76
3700	8,81	7,05	0,83
4090	9,74	7,79	0,9
4270	10,17	8,13	0,99
4640	11,05	8,84	1,05
5300	12,62	10,1	1,16

The values presented in Table 4.1, were not measured directly but computed through a set of transformations applied to the input rotational speed (I-RPM). The following equations summarize the steps used to estimate motor speed, propeller speed, and the resulting linear velocity:

$$Motor\ RPM = \frac{I-RPM}{7} \quad (4.1)$$

I-RPM is the electrical rotational speed input from the ESC, divided by 7 to obtain the mechanical speed for a 14-pole (7 pole pair) BLDC motor.

$$RPS = \frac{Motor\ RPM}{60} \quad (4.2)$$

It converts the motor RPM to revolutions per second (RPS).

$$R - RPS = RPS \times 0,8 \quad (4.3)$$

0.8 is an efficiency factor that accounts for mechanical and transmission losses.



5. CONCLUSION

In this thesis, the electronic system design of the PSV Sancar model ship was realized and applied for the first time for free mode sailing tests. The mechanical structure of the ship was previously completed, and the electronic hardware, power distribution, sensor integration and communication infrastructure were structured in detail within the scope of this thesis. The basic components of the system, microcontroller, motor drivers, IMU-GPS sensors, battery systems and communication units, were combined in a central control box.

The conducted free-running tests were carried out to observe the reliability of the electronic system under field conditions, the continuity of the communication infrastructure, and the performance of the motor-driver integration. During the tests, the propeller RPMs and power consumption corresponding to the ship's speed were measured; through these measurements, the real-time operability of the electronic infrastructure was validated. Since maintaining a fixed heading was not a target during the tests, rudder control was kept passive; however, the electronic infrastructure was designed in a modular manner, enabling future integration of the rudder system.

The obtained data will be evaluated in order to understand the hydrodynamic response of the ship's hull at different speeds and to form the basis for future control algorithms. In this context, not only the motion performance but also the holistic performance of the system's electronic infrastructure was analyzed through tests. As a result, this study has presented a flexible, modular and expandable electronic system infrastructure that can form the basis of dynamic positioning systems for a small-scale model ship. This infrastructure provides a solid foundation for advanced autonomous control studies, sensor fusion systems and artificial intelligence-supported algorithms to be carried out in the future.

As a future work, it is planned to conduct rudder tests in controlled experimental environments and to design an independent controller specific to these tests in order to better understand the steering performance of the system. The electronic system infrastructure developed within the scope of this thesis has been designed in a modular

structure to form a foundation for future integration of advanced autonomous navigation capabilities, such as image processing-based environmental sensing and collision avoidance. If such a system is implemented, a PoE-supported IP camera or a USB/CSI-compatible imaging unit can be integrated into the ship model to obtain real-time visual data. The electronic system infrastructure designed in this thesis consisting of the high-performance NVIDIA Jetson AGX Orin, STM32-based microcontroller, closed-loop BLDC drivers (VESC), and CAN bus-based communication architecture provides a strong technical foundation for the implementation of such autonomous functionalities. In the event that a study is carried out in this direction, the visual data obtained from the camera can be processed using deep learning models (e.g., YOLOv5 or YOLOv8) on the AGX Orin. After detecting obstacles, safe navigation routes can be generated using a suitable path planning algorithm (e.g., DWA or RRT). The corresponding commands for these routes can then be transmitted to the microcontroller over the existing CAN communication line to enable motor control. The software foundation of such a system can also be expanded using a modular framework like ROS 2 when necessary, allowing sensor data, perception, and decision-making mechanisms to be managed in an integrated manner. Additionally, environmental sensors such as LIDAR or ultrasonic sensors can be considered in the future to detect obstacles beyond the camera's field of view.

REFERENCES

- [1] **Özden, C., Kurdoğlu, S., Demir, E., Sariöz, K., & Gören, O.** (2023). *Design, development and validation of a new free-running manoeuvring system*. 7th International Conference on Advanced Model Measurement Technology for the Maritime Industry (AMT'23), İstanbul, Türkiye.
- [2] **Kinaci, O. K., Delen, C., Bitirgen, R., Bayezit, A., Bayezit, I., Ozturk, D., & Gunguder, B.** (2021). Free-running tests for DTC self-propulsion—An investigation of lateral forces due to the rudder and the propeller. *Applied Ocean Research*, 116, 102877.
- [3] **Zheng, J., Meng, F., & Li, Y.** (2017). Design and experimental testing of a free-running ship motion control platform. *IEEE Access*, 6, 4690-4696.
- [4] **Im, N., & Seo, J. H.** (2010). Ship manoeuvring performance experiments using a free running model ship. *TransNav, International Journal on Marine Navigation and Safety of Sea Transportation*, 4(1), 29-33.
- [5] **Bassam, A. M., Phillips, A. B., Turnock, S. R., & Wilson, P. A.** (2019). Experimental testing and simulations of an autonomous, self-propulsion and self-measuring tanker ship model. *Ocean Engineering*, 186, 106065.
- [6] **International Maritime Organization.** (2021, June 3). *Outcome of the regulatory scoping exercise for the use of Maritime Autonomous Surface Ships (MASS) (MSC.1/Circ.1638)*. <https://wwwcdn.imo.org/localresources/en/MediaCentre/PressBriefings/Documents/MSC.1-Circ.1638-Outcome-Of-The-Regulatory-Scoping-Exercise-For-The-Use-Of-Maritime-Autonomous-Surface-Ships.pdf>
- [7] **International Maritime Organization.** (n.d.). *Autonomous shipping*. Retrieved June 20, 2025, from <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx>
- [8] **Indian Register of Shipping.** (2021, December). Guidelines on remotely operated vessels and autonomous surface vessels.
- [9] **International Maritime Organization.** (1994, June 6). Guidelines for vessels with dynamic positioning systems (MSC/Circ. 645).
- [10] **International Maritime Organization.** (2017, June 16). Guidelines for vessels and units with dynamic positioning (DP) systems (MSC.1/Circ. 1580).
- [11] **ITTC.** (2011). *Recommended procedures and guidelines - Fresh water and seawater properties - 7.5-02-01-03*. International Towing Tank Conference.

- [12] **Flipsky.** (n.d.). *Flipsky BLDC belt motor battle hardened6384 140KV/170KV/190KV 4000W for electric skateboard.* Flipsky. Retrieved April 29, 2025, from <https://flipsky.net/products/flipsky-bldc-belt-motor-battle-hardened-6384-140kv-170kv-190kv-4000w-for-electricskateboard?variant=40867032400059>
- [13] **Karakoy Elektronik.** (n.d.). *DDR-60G-24, DDR-120B-12, and DDR-60G-5 DC/DC converter product pages.* Retrieved April 29, 2025, from <https://karakoyelektronik.com>
- [14] **ITTC.** (2014a). "Example for Uncertainty Analysis of Resistance Tests in Towing Tanks - 7.5-02-02-02.1". International Towing Tank Conference.
- [15] **ITTC.** (2014b). "General Guideline for Uncertainty Analysis in Resistance Tests - 7.5-02-02-02". International Towing Tank Conference.
- [16] **ITTC.** (2014c). "Practical Guide for Uncertainty Analysis of Resistance Measurement in Routine Tests - 7.5-02-02-02.2".
- [17] **ITTC.** (2014d). "Recommended Procedures and Guidelines- Practical Guidelines for RANS Calculation of Nominal Wakes -7.5-03-03-02". International Towing Tank Conference
- [18] **Sukas, O. F., Kinaci, O. K., & Bal, S.** (2021). Asymmetric ship maneuvering due to twisted rudder using system-based and direct CFD approaches. *Applied Ocean Research*, 108, 102529.

APPENDICES

APPENDIX A: Schematic diagram.

APPENDIX B: Flowchart.



APPENDIX A

The following schematic diagram represents the closed-loop electronic connection for controlling actuators with two motors using an STM32-based MCU for the developed model ship electronics.

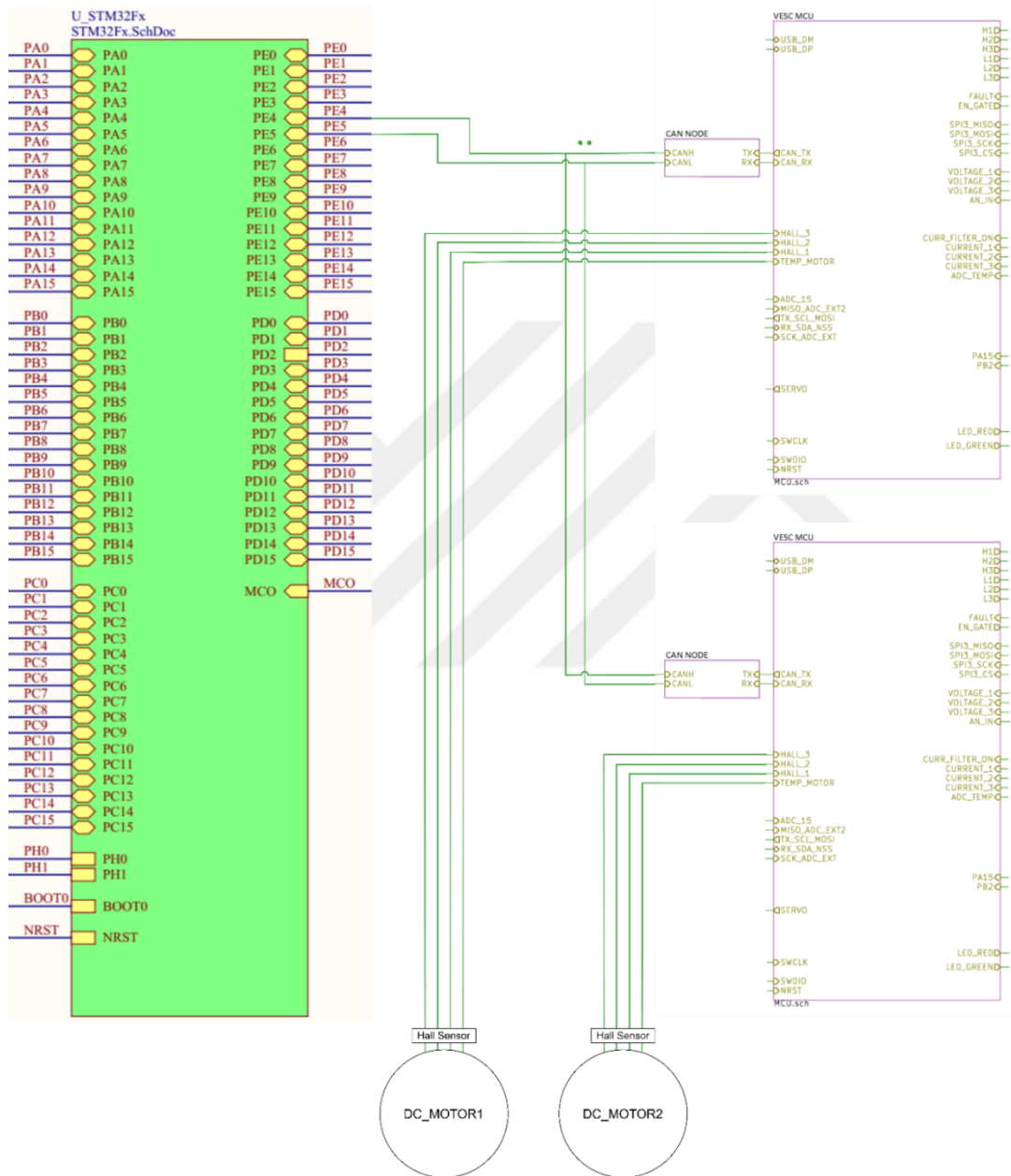


Figure A.1 : Schematic diagram of controlling actuators with STM32 based MCU.

APPENDIX B

This flowchart outlines the communication architecture between the ground station and the onboard systems of the model ship.

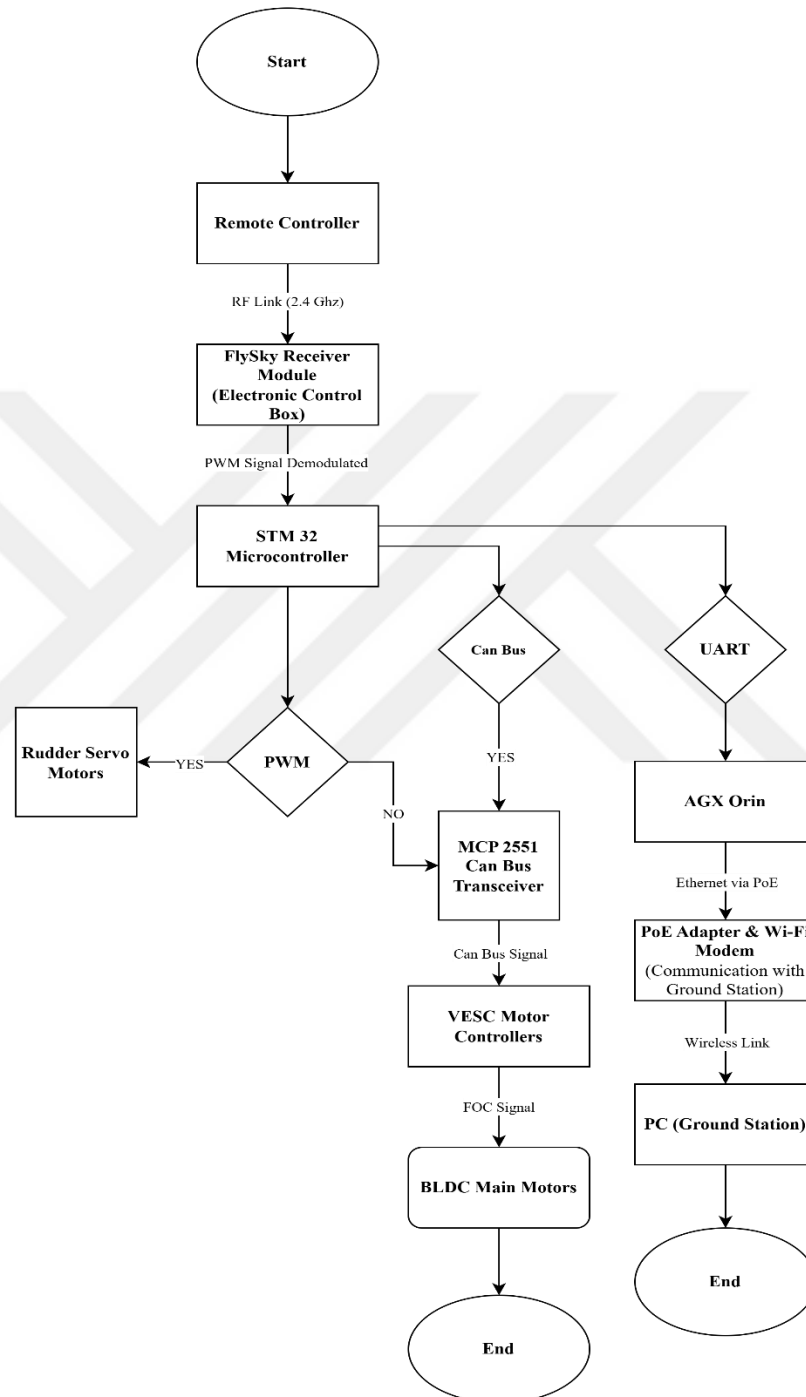


Figure B.1 : Flowchart of all system.



CURRICULUM VITAE

Name Surname : Deniz İLKME

EDUCATION:

- **B.Sc.** : 2021, Afyon Kocatepe University, Technology Faculty, Electrical Electronic Engineering

PROFESSIONAL EXPERIENCE AND REWARDS:

- 2019, Arcelik Global, Intern, Worked on schematic design, PCB layout, and design verification.
- 2020, Referans Mechatronic, Intern, Focusing on automation control panel wiring, including cable routing, electrical connections, and system integration.
- 2020-2021, Propan Automation Systems, Intern, Actively participated in the wiring, commissioning, and design stages of electrical panels. Developed strong skills in the correct use of testing equipment for system verification.
- 2023, Marine Robotics Lab, Researcher, Designed an electronic control box for autonomous marine vehicles using embedded systems and sensor fusion approaches.
- 2024, Marine Cybernetics Advanced Vehicle Technologies, Project Engineer, Developed an electronic control unit for autonomous marine vehicles, utilizing embedded systems and sensor fusion techniques to enable real-time navigation and decision-making.

PUBLICATION, PRESENTATIONS AND PATENTS ON THE THESIS:

- **Ilkme, D., & Kinaci, O. K.** Electronic Design of Free-Running Ship Model for Manual Control. Global Maritime Congress, May 20-21, 2024, Istanbul, Turkey.