T.E Project Exam
(Semester VI)

Vivekanand Education Society's Institute of Technology
An Autonomous Institute Affiliated to University of Mumbai

FPGA Based ESC and IMU

Group Name : ByteBlitzers

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Introduction

The project focuses on developing an FPGA-based Electronic Speed Controller (ESC) and Inertial Measurement Unit (IMU) system for UAVs. The ESC uses FPGA technology for precise motor control, while the IMU integrates advanced sensors to provide accurate attitude and position data. By utilizing FPGA parallel processing capabilities, the system enhances flight stability, control efficiency, and scalability, making it suitable for various UAV platforms. This approach ensures real-time communication and reliable performance, contributing to safer and more efficient drone operations.

Problem Statement

Developing an FPGA-based ESC and IMU system for UAVs enhances flight stability, control, and efficiency. The ESCs use FPGA technology for precise motor regulation, while the IMU integrates advanced sensors for accurate attitude measurement. Key goals include low-latency communication, parallel processing, and efficient motor operation. The system's scalability ensures integration across various UAV platforms, with a focus on reliability and safety through rigorous testing.

Literature Survey

Sr. No.	Title of Technical paper	Name of Author	Year of publication	Name of Journal	Methodology	Results/ conclusions	Drawbacks/ limitations
1.	Efficient Electronic Speed Controller Algorithm for Multirotor Flying Vehicles [1]	Lukasz Przeniosáo, Marcin Hoáub	2018	2018 Innovative Materials and Technologies in Electrical Engineering (i-MITEL)	1. ESC: BLDC motor control without Hall sensors. 2. Back-EMF: Determines shaft position accurately. 3. Integrates: Voltage from non-powered winding. 4. Commutation: Based on integrated voltage threshold. 5. Ensures: Proper timing and operational efficiency.	1. Back-EMF integration: Autonomous with hardware events. 2. Frees MCU processing: For PI or PID loops. 3. Efficient UART: Handles external messages during motor operation.	1. Resource-intensive: Peripherals, processor runtime, and cost. 2. Closed-loop systems increase current and power losses.

Literature Survey

Sr. No.	Title of Technical paper	Name of Author	Year of publication	Name of Journal	Methodology	Results/ conclusions	Drawbacks/ limitations
2.	Comparison of Complementary and Kalman Filter Based Data Fusion for Attitude Heading Reference System[2]	Tariqul Islam , Md.Saiful Islam , Md.Shajid-Ul-Mahmud , Md Hossam-E-Haider	2017	Proceedings of the 1st International Conference on Mechanical Engineering and Applied Science (ICMEAS 2017), AIP Conf. Proc.	1. Data Fusion: Compared Complementary and Kalman filters on MEMS sensors. 2. Implementation: Applied filters to 9DOF MPU-9150 for orientation. 3. Testing: Built AHRS; tested in MATLAB. 4. Metrics: Assessed how filters handle noisy sensor data.	1. Complementary filter: easy, low computation, good for real-time. 2. Kalman filter: high accuracy, complex, needs more power. 3. Complementary suits resource-limited systems. 4. Kalman is ideal for precision-critical tasks.	1. Complementary filter: limited accuracy, needs tuning. 2. Kalman filter: high complexity, power-demanding. 3. Kalman requires precise tuning. 4. Poor tuning harms performance.

Literature Survey

Sr. No.	Title of Technical paper	Name of Author	Year of publication	Name of Journal	Methodology	Results/ conclusions	Drawbacks/ limitations
3.	PynqCopter - An Open-source FPGA Overlay for UAVs [3]	Brennan Cain, Zain Merchant, Indira Avendano, Dustin Richmond, Ryan Kastner	2018	2018 IEEE International Conference on Big Data (Big Data)	1. Autonomous operation in FPGA's PL minimizes CPU interaction. 2. Processes sensor data and remote inputs using IP cores. 3. Formats ESC signals for precise motor control.	1. Coordinates IP cores: Sensor, RC receiver, Normalizing, Controller, PWM. 2. Sensors gather data, RC receiver enables precise control. 3. FPGA-based system ensures effective UAV control and management.	1. Bottom-placed batteries stabilize roll and pitch axes. 2. Poorly tuned controllers cause pendulum-like oscillations. 3. Implementation of data filters lacks clarification in paper.

Research Gaps and Target Customers/Applications

Research Gaps:

1. ESCs predominantly employ open-loop control.
2. Custom ESCs are minimally available, necessitating market introduction.
3. Kalman/Complementary Filter algorithms should integrate emerging sensor technologies.
4. IMUs enhance position estimation via ESC data fusion.

Target Customers/Applications:

1. Research Institutions and Universities (for further advancements and research)
2. Professional Drone Manufacturers
3. Defense and Security Industries
4. Infrastructure Monitoring

Proposed Solution

1. FPGA-based designs offer unparalleled advantages in parallel processing, customizability, flexibility, and scalability compared to current MCU-based solutions available in the market.
2. The introduction of ASIC FPGA-based ESCs and IMUs promises substantial enhancements in performance optimization, cost efficiency (at scale), and application-specific customization.
3. Back-EMF integration within ESCs enables real-time motor monitoring, providing critical data for Complementary Filter . This integration enhances precision in motor condition assessment and positional tracking.

Complete Block Diagram of ESC

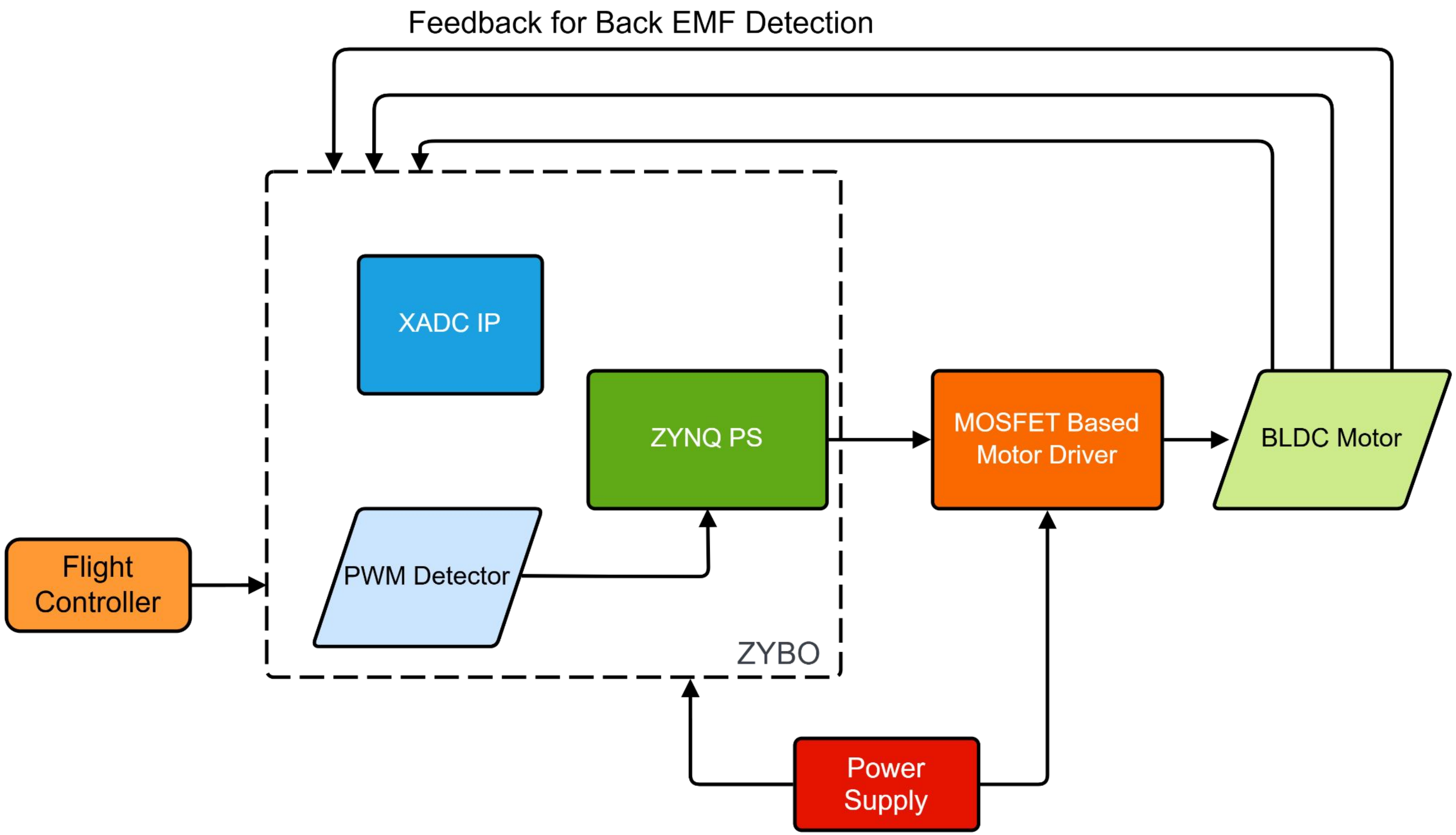


Fig. 1 Block Diagram of ESC

Complete Block Diagram of IMU

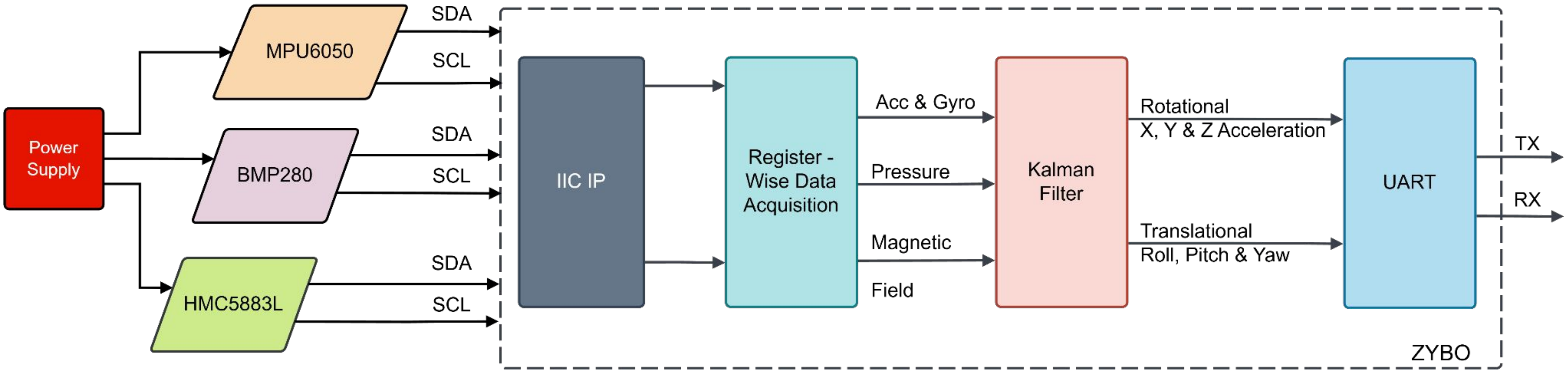


Fig. 2 Block Diagram of IMU

Algorithm of Kalman Filter for Aerial Vehicles

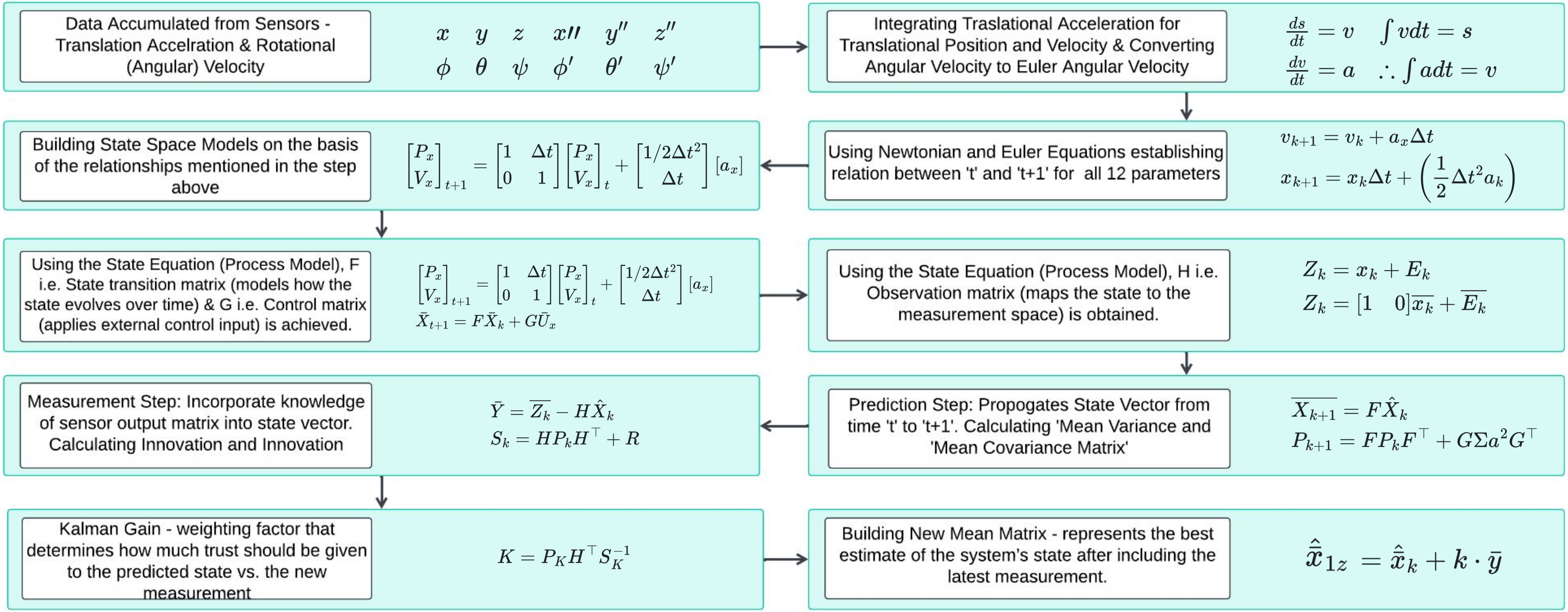


Fig. 3 Algorithm of Kalman Filter for Aerial Vehicles

Methodology of ESC

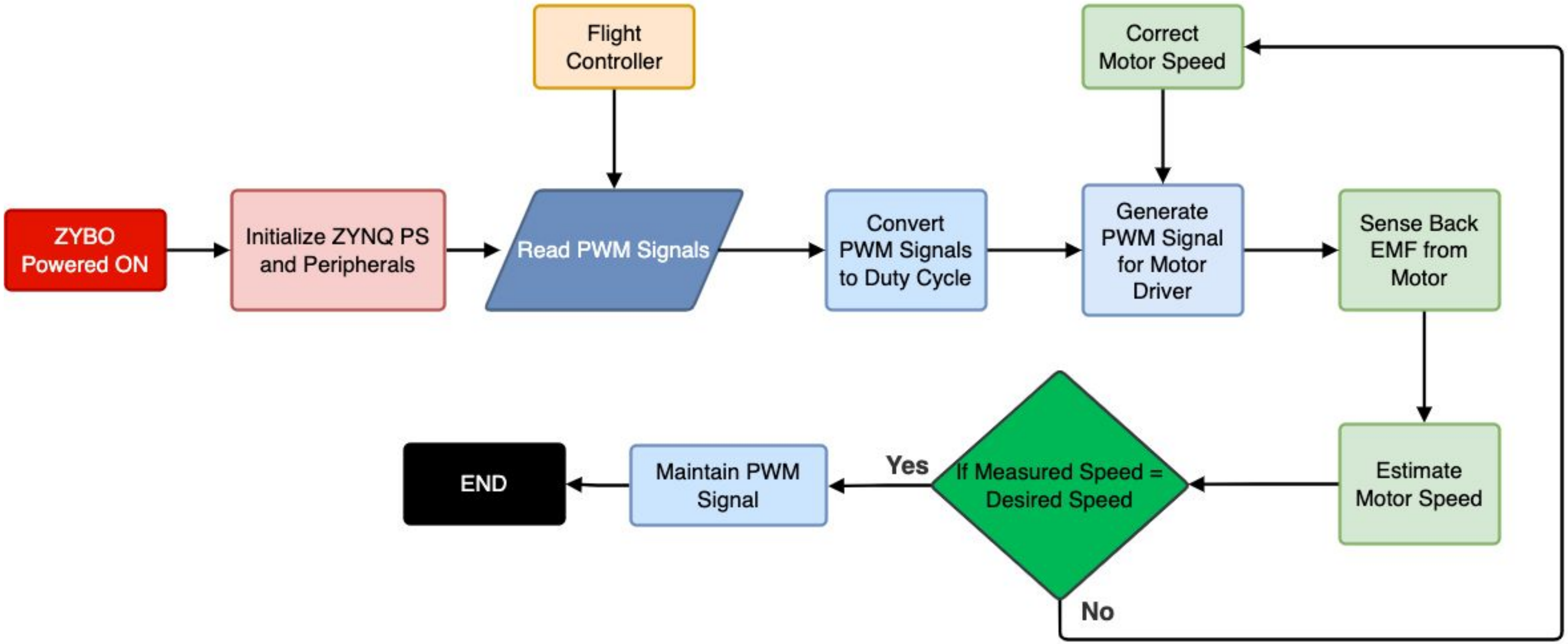


Fig. 4 Methodology of ESC

Methodology of IMU

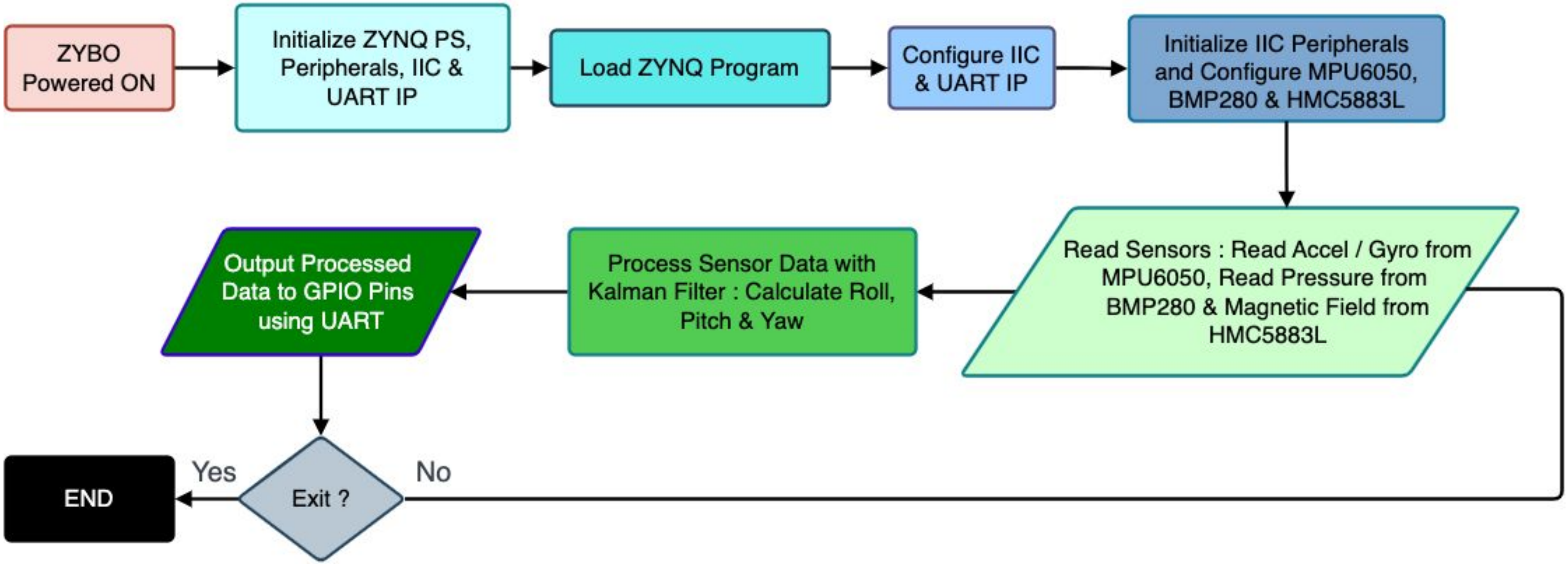
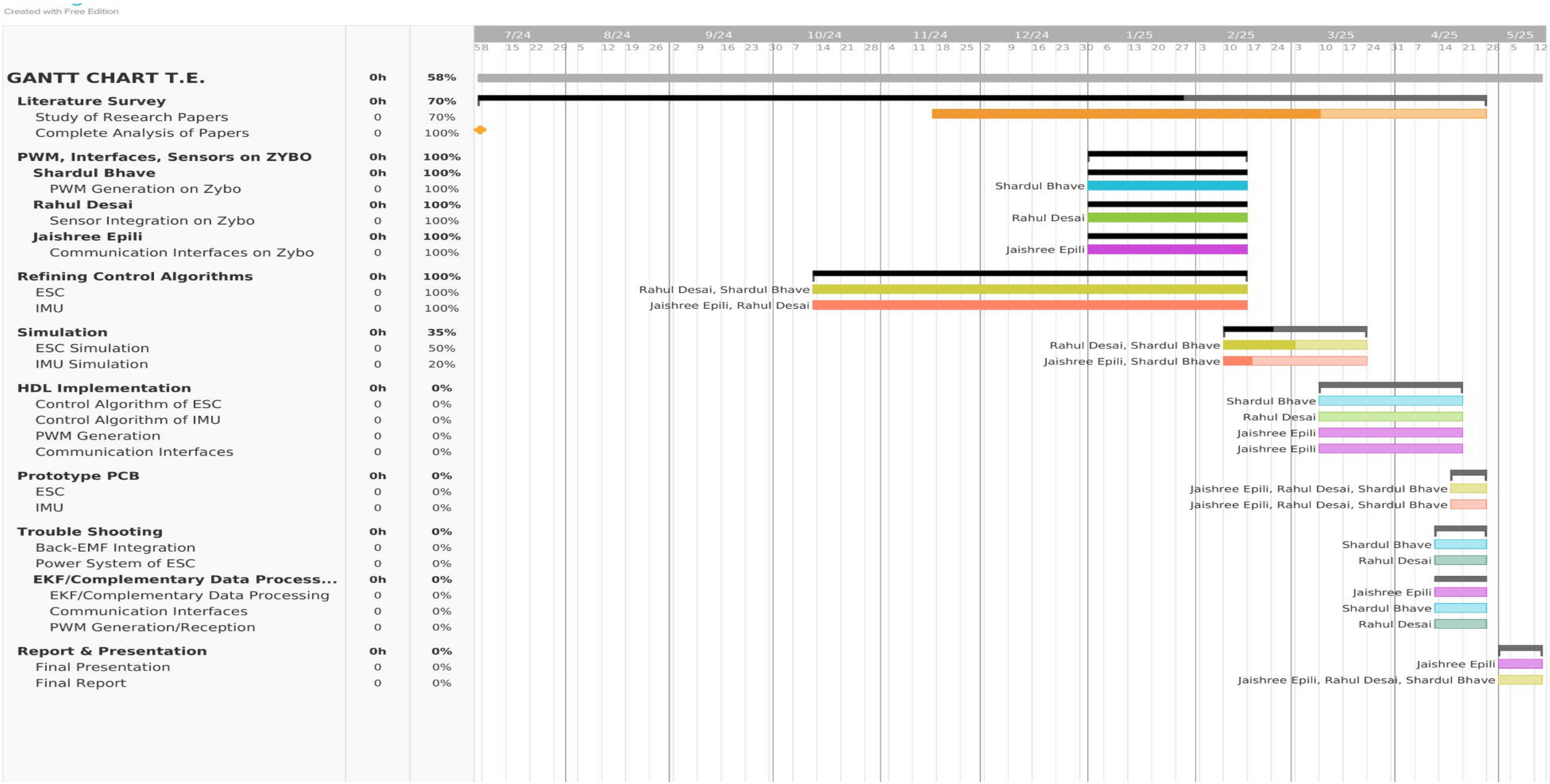


Fig. 5 Methodology of IMU

Proposed Project Components and Expenditure

Sr.no	Component Type	Name of component	Quantity	Cost in Rupees	Reference (Data sheet)
1.	Hardware	FPGA (ZYBO Board)	1	*30000	https://www.realdigital.org/doc/02013cd17602c8af749f00561f88ae21
2.	Hardware	BLDC Motor	1	600	https://www.rhydolabz.com/documents/26/BLDC_A2212_13T.pdf
3.	Hardware	IRF3205 MOSFETs	6	180	https://www.infineon.com/dgdl/Infineon-IRF3205-DataSheet-v01_01-EN.pdf?fileId=5546d462533600a4015355def244190a
4.	Hardware	IR2101 Gate Driver	3	333	https://www.infineon.com/dgdl/Infineon-ir2101-DS-v01_00-EN.pdf?fileId=5546d462533600a4015355c7a755166c
5.	Hardware	MPU6050	1	100	https://invensense.tdk.com/wp-content/uploads/2015/02/MPU-6000-Datasheet1.pdf
6.	Hardware	BMP280	1	50	https://cdn-shop.adafruit.com/datasheets/BST-BMP280-DS001-11.pdf
7.	Hardware	HMC5883L	1	130	https://cdn-shop.adafruit.com/datasheets/HMC5883L_3-Axis_Digital_Compass_IC.pdf
8.	Software	Vivado Design Suite	1	Standard free version	https://docs.amd.com/r/en-US/ug910-vivado-getting-started
TOTAL				*31393	

Time Chart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7/24 8/24 9/24 10/24 11/24 12/24 1/25 2/25 3/25 4/25 5/25
GANTT CHART T.E. 0h 58%
Literature Survey 0h 70%
Study of Research Papers 0 70%
Complete Analysis of Papers 0 100%
PWM, Interfaces, Sensors on ZYBO 0h 100%
Shardul Bhave 0h 100%
PWM Generation on Zybo 0 100%
Rahul Desai 0h 100%
Sensor Integration on Zybo 0 100%
Jaishree Epili 0h 100%
Communication Interfaces on Zybo 0 100%
Refining Control Algorithms 0h 100%
ESC 0 100%
IMU 0 100%
Simulation 0h 35%
ESC Simulation 0 50%
IMU Simulation 0 20%
HDL Implementation 0h 0%
Control Algorithm of ESC 0 0%
Control Algorithm of IMU 0 0%
PWM Generation 0 0%
Communication Interfaces 0 0%
Prototype PCB 0h 0%
ESC 0 0%
IMU 0 0%
Trouble Shooting 0h 0%
Back-EMF Integration 0 0%
Power System of ESC 0 0%
EKF/Complementary Data Process... 0h 0%
EKF/Complementary Data Processing 0 0%
Communication Interfaces 0 0%
PWM Generation/Reception 0 0%
Report & Presentation 0h 0%
Final Presentation 0 0%
Final Report 0 0%
Shardul Bhave
Rahul Desai
Jaishree Epili
Rahul Desai, Shardul Bhave
Jaishree Epili, Rahul Desai
Rahul Desai, Shardul Bhave
Jaishree Epili, Shardul Bhave
Shardul Bhave
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Jaishree Epili, Rahul Desai, Shardul Bhave
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Jaishree Epili
Jaishree Epili, Rahul Desai, Shardul Bhave

Prototype

Video. 1 ESC Prototype without Back EMF

Prototype

Video. 2 Implementation of IMU

Observations

1. **Real-Time Performance Enhancement**: The FPGA-based ESC and IMU system improves real-time response by leveraging hardware-accelerated processing for motor control and sensor data fusion.

2. **Precision Motor Control**: The integration of back-EMF sensing in the ESC ensures efficient speed and position regulation, enhancing motor responsiveness.

3. **Efficient Sensor Data Fusion**: The Kalman filter provides robust noise reduction and accurate attitude estimation, improving system stability.

4. **Scalability and Adaptability**: The FPGA-based architecture allows flexible customization, making it suitable for UAVs, robotics, and automation systems.

Conclusion

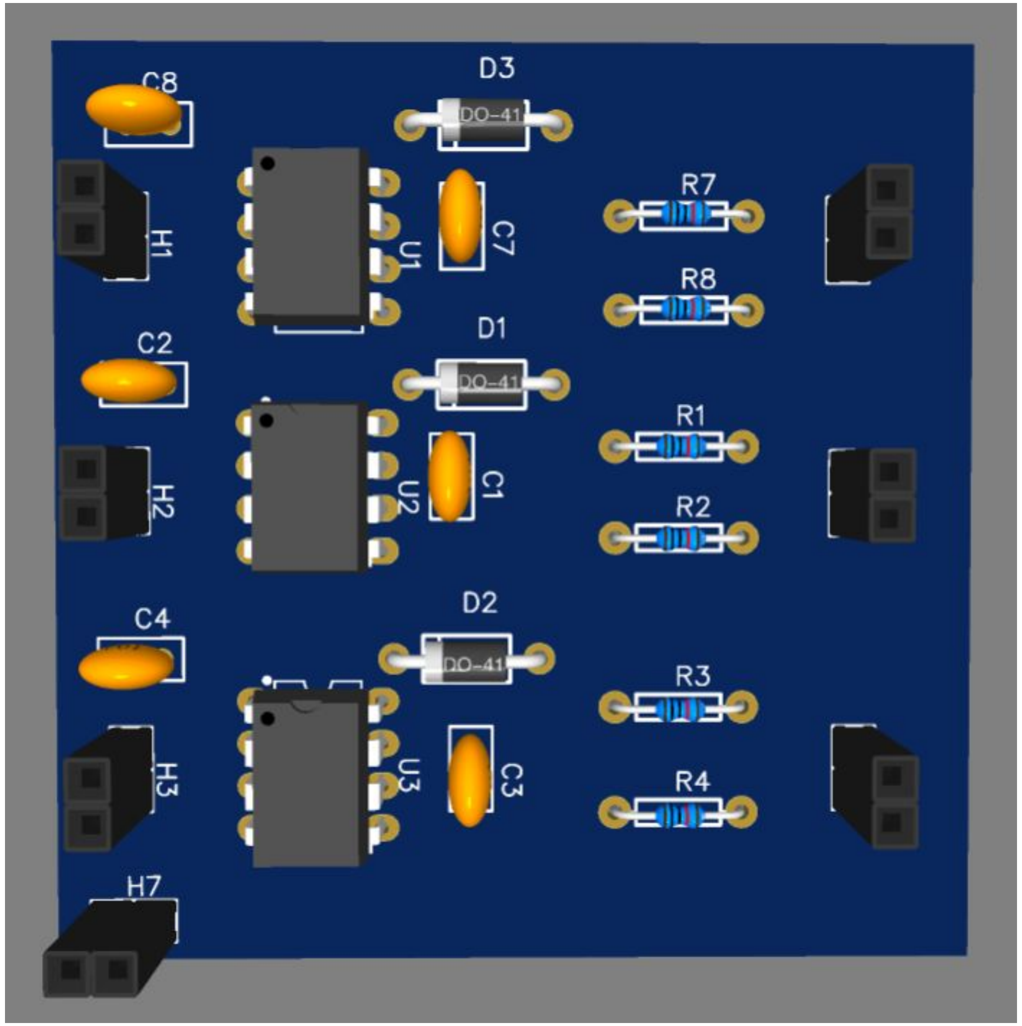

Fig. 5 PCB Design of Gate Driver for ESC

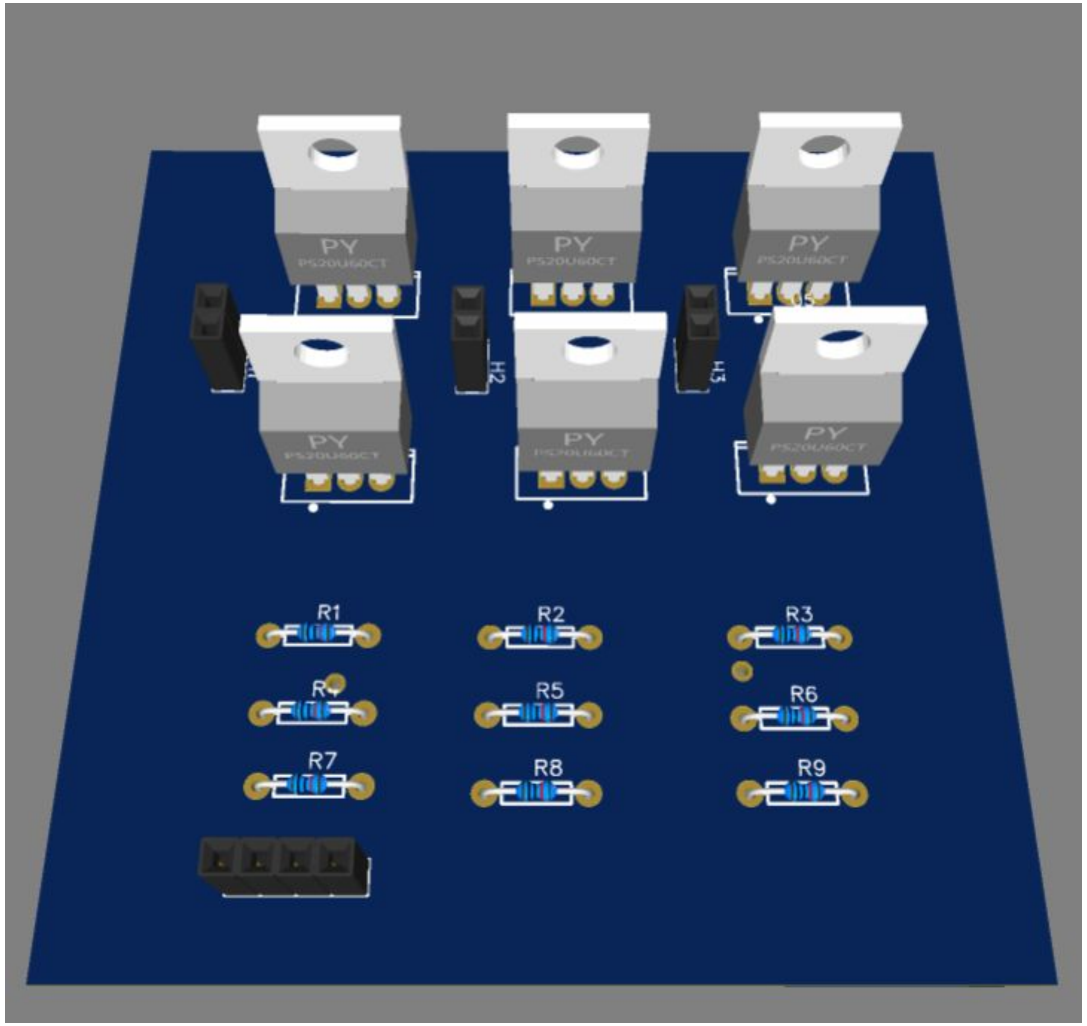

Fig. 6 PCB Design of MOSFET Driver for ESC

Conclusion

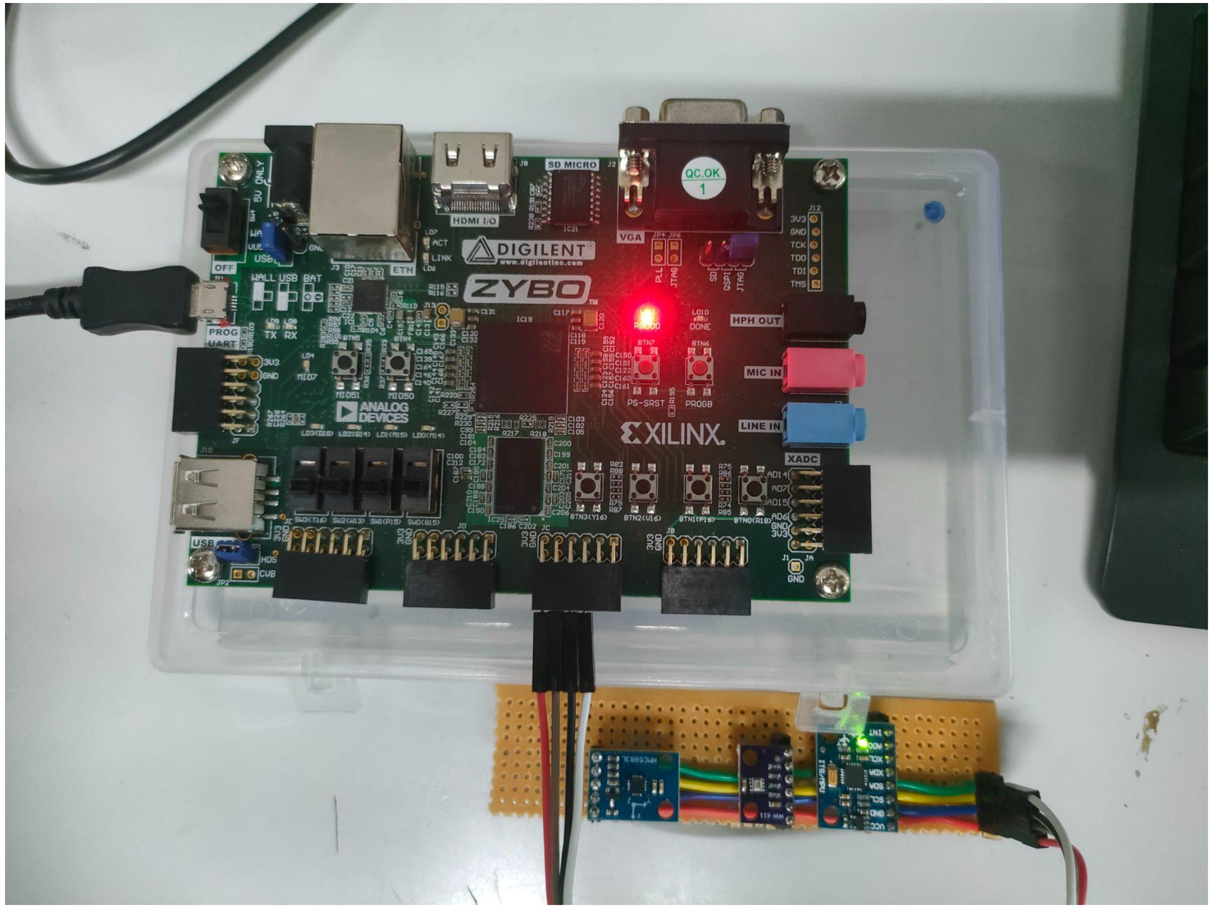

Fig. 7 Hardware Implementation of IMU

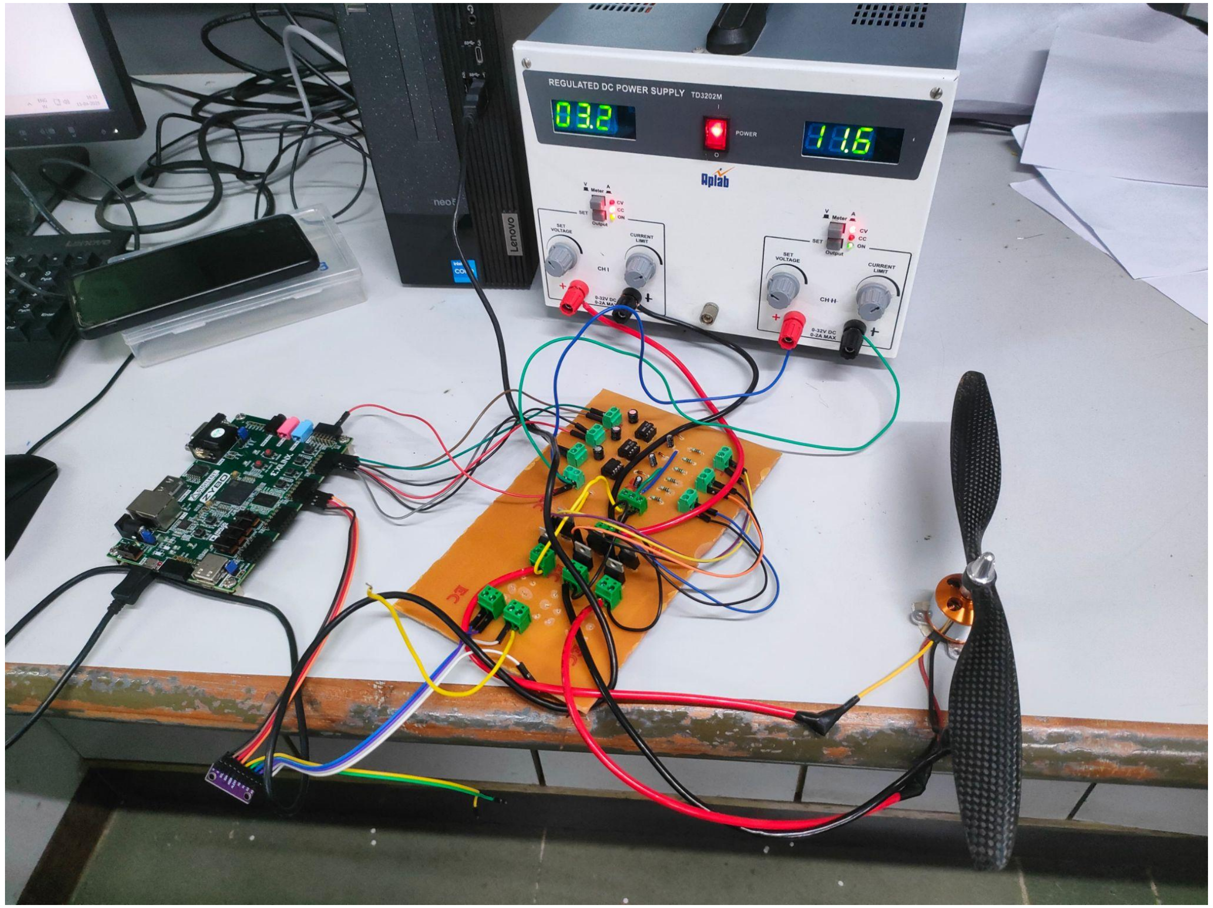

Fig. 8 Hardware Implementation of ESC

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[1] Ł. Przeniosło and M. Hołub, "Efficient electronic speed controller algorithm for multirotor flying vehicles," *2018 Innovative Materials and Technologies in Electrical Engineering (i-MITEL)*, Sulecin, Poland, 2018.

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Thank You