MIDDLE EAST TECHNICAL UNIVERSITY

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

EE493: ENGINEERING DESIGN 1, DESIGN STUDIO 9

PROPOSAL REPORT

COMPANY: NATIONAL ELECTRONICS & SEMICONDUCTOR TECHNOLOGIES

PROJECT: GIMME FAST

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DATE OF SUBMISSION**:** 01 NOVEMBER 2019
STARTING DATE OF THE PROJECT**:** 02 OCTOBER 2019
ESTIMATED COMPLETION TIME OF THE PROJECT**:** 220 DAYS
THE COST OF THE PROJECT**:** 200 $

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Executive Summary

Background and Purpose

The purpose of this document is to explain how an Optical Wireless Communication (OWC) device is designed to meet the project requirements. An in depth search for needed outputs for the given requirements has been provided to accomplish customer needs. OWC is an important technology for remote area communication access with reliable, high speed data transfer. For this reason, NESET is dedicated to prove the advantages of OWC by delivering a ready to install OWC device package as well as a complete demonstration setup for full customer satisfaction and inspection. NESET Company consists of a highly motivated engineering team with comprehensive work background presented in Team Organization.

Results and Analysis

According to the outcomes of the requirement analysis for Gimme Fast project, a detailed solution procedure is provided with possible product outcomes to give rough cost and time estimates. One important observation of the analysis is that the main limitation for OWC is the data transmitting medium. For this purpose, several tests have been conducted with OWC prototype board and all software and hardware calculations are made to match with the maximum media capability. Resources provided(200$) for the project are considered sufficient to acquire the necessary computer hardware, microcontrollers, sensors and building material. Provided with the skill diversity in our team, time resource allocation for the completion of the project is provided with a Gantt Chart given in Appendix A.

Conclusions

It is possible to build an OWC device with its implementation on a terminal-to-terminal communication demonstration via a helper robot by utilizing the allowed financial source and time. The end product of this product not only offers a fully operational test setup but also portable OWC modules that can be installed in other computer hardware with standard serial communication capability. NESET Company also offers installation guidance and product warranty up to 2 years. It is also possible to contribute the research academia by publishing academic research outcomes of this project.

Appendices

Appendix A shows the Gantt Chart time table until the completion of this project.

Appendix B provides the comparison metrics for the project evaluation.

Appendix C shows the Objective Tree for Gimme Fast project.

Appendix D demonstrates the Product Tree for the project.

Appendix E OWC prototype tests.

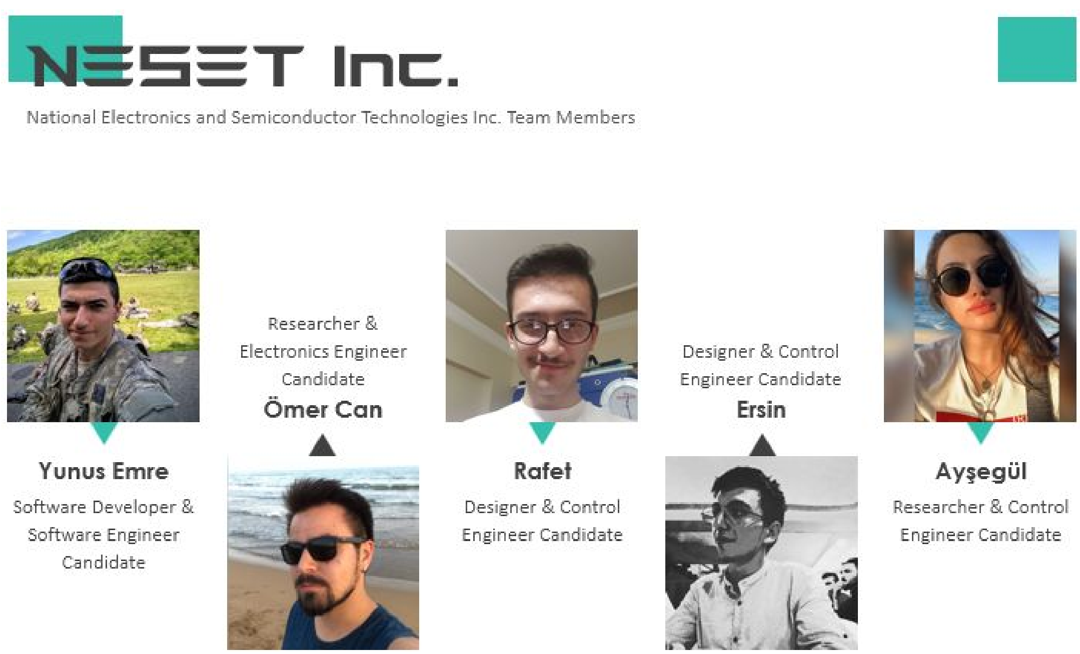
Introduction

Having originated from beacon fires and carrier pigeons of ancient times, wireless communication has evolved into a high-capacity complementary technology to provide links between people. As witnessed in the last two decades, the demand for wireless data networks has increased exponentially with the increasing popularity of private computers and smartphones.

The primary basis of network relies on RF communication today as it possesses high agility and vast range. However, its networking capabilities are becoming to fall short day by day with the increasing demand for data. By 2015, it was expected that the total wireless data traffic would reach 6 exabytes per month, creating a potentially %97 gap between the demand and the available data in mobile networks. Consequently, complementary wireless transmission techniques were to be explored. One such alternative is Optical Wireless Communication (OWC). As a product, Project “Gimme Fast” sets the groundwork for the possible utilization of OWC using visible light as a communication medium. The project also provides a powerful demonstration of data transfer via OWC between remote sites to deny the argument that OWC is not possible over long distances. In this project, it is aimed to have a broad understanding of this emerging alternative wireless communication and provide solid know-how for future product applications.

This report presents the project requirements and solution approaches in a logical structure. Details on the team organization, requirement analysis, solution procedure, and deliverables can provide a detailed explanation of each submodule of the final product.

Team Organization



National Electronic & Semiconductor Technologies (NESET) Company was founded by highly motivated Electrical & Electronics Engineering students to provide our nation with the cutting edge technologies. We aim to bring out next-generation systems and applications to shape the future of human-machine interaction. Our team consists of people from various fields and work experiences to provide a diverse thinking and problem-solving environment. We are capable of solving engineering problems with given specifications and constraints. Also see *Table 1* for respective workload of the team members.

- Y. Emre İKİZ is a very experienced engineer candidate in terms of software skills. He has worked for several companies as a part-time engineer in the field of embedded software development for avionics and software development on 2D navigation. He was also the chairperson of the Robotics & Automation Society in METU, and he is still very active and developing several projects with his teammates. Therefore, he wants to take place microcontroller coding and data transfer protocols of the project.
- Ö. Can KARAMAN is an undergraduate researcher at BioMEMS Research Group for five months, and he has gained a lot of research skills. He also loves analog & digital electronics courses very much, and he is willing to take place on the analog part of the project.
- Rafet KAVAK is a control engineer candidate who wants to take place Raspberry Pi parts of the project because of his curiosity on smart systems like Raspberry Pi intelligent mirror etc.
- Ersin KESKİN is a very experienced control engineer candidate in terms of mechanical design. These mechanical skills date from his internship, which was performed in FNSS. He has done very precise soldering and assembly during his internship. He is also a very enthusiastic student, and he has a finger in every pie, i.e., during his undergraduate years, he developed several games in Unity, wrote many hobby codes for daily life and so on.
- Ayşegül KILIÇ is an undergraduate researcher at CEMMETU since November 2018, and she is the most experienced student in terms of researching in the team. She was also performed her summer practice in Silicon Valley, USA, and gained software skills in the control area. She will work on Raspberry Pi coding in this project too.

	Market Search	Mechanical Design	Raspberry Pi Coding	Microcontroller Coding	Analog Design	Handshake Protocols	Image Char. Decision	Image Binary Conversion	Power Analysis
Y. Emre İKİZ	✓			✓		✓	✓		
Ö. Can KARAMAN		✓			✓	✓			✓
Rafet KAVAK	✓	✓	✓					✓	
Ersin KESKİN		✓		✓			✓	✓	
Ayşegül KILIÇ			✓			✓		✓	✓

Table 1: Respective workload of team members

Requirement Analysis

Project Objectives

The current project of NESET Inc. is a design of a data transfer system with two complementing technologies of transportation and communication that includes a vehicle and two end terminals. The system has the capability of visible light communication, as mentioned briefly in the introduction. In this part of the report, the objectives of the project will be briefly mentioned.

The goals of the project can be summarized as follows;

- Taking a picture and dividing that picture into several data packets
- Data transfer via visible light from a free space distance of ≅ 5 cm at source and destination terminal
- Having a vehicle that can store, transport and transfer data
- Reconstructing the data and displaying the transmitted image
- Being able to do all these operations under 2 minutes, at least five full rounds

Project Requirements

To establish the scope and boundaries of the project, the following requirements should be provided

1. The taken photograph should be compressed and modified to a simpler version.
2. In the case of missing bits, the system should provide a recognizable image.
3. Resolution and color depth of the image can be adjustable according to changing on the LEDs performance due to environmental conditions.
4. Transform the image into transmittable data packages (5 packages at least).
5. Maximum allowed packages size will be 10kB
6. Provide a communication protocol for data transmission/reception
7. Using packet ordering protocols correctly
8. Using the handshake protocol correctly
9. Transferring the data with minimum loss at a distance of 5 cm
10. Operate at a frequency that allows the task completion in time at a rate of at least 1000Bits/sec
11. Loading a data packet to a mobile vehicle via visible light communication and storing it on the vehicle.
12. Transporting data from one terminal to the other on a physically guided track.
13. Conveying the data stored in the vehicle to the Receiver Terminal.
14. The minimum speed of the vehicle should be 0.4m / s.
15. Receiving, reconstructing and displaying the image at the destination terminal
16. Being resistant to different external lighting conditions

Project Constraints

The project is limited under Optical Wireless Communication (OWC) range and easily affected by lighting conditions. Limitations can be considered as

- Successful data transfer over OWC at high frequencies is only possible within a distance boundary. The distance can not exceed i.e., 5-10 cm.
- A complete data transportation from one terminal to the other is highly dependent on the success in the execution of handshake protocol between shuttle and terminals.
- Image displayed in the secondary terminal may not be recognizable if there is an overlap in the received data packets.
- The shuttle shall travel with a speed of faster than 0.4m/s so that there is enough time left for analog data transfer.
- Maximum amount of data transferable is limited by transmission time per bit. Thus, the maximum amount of data that can be delivered within 2 minutes is not greater than 50KBytes.

Solutions Procedure

Possible Solutions

Additional details such as example solutions and their alternatives regarding the products given in the product tree in *Figure 1* are presented in this subsection.

1. **Transmitter Terminal Primary Approach**

The image will be taken with Raspberry Pi Camera Board v1.3, and by using Python, the resolution of the images can be changed between 2592×1944 and 64x64. According to the visible light communication restrictions, the resolution of the images will be adjusted. Then the image will be converted to a suitable binary format for the transmission. Data transmission will be carried out from the Universal Asynchronous Receiver/Transmitter (UART) pins of the Raspberry Pi 3.

Considered alternatives:

a. Main Computer: A standard low power microcomputer such as Raspberry Pi or Nvidia Jetson Nano. Approximate budget:≅$40
b. Camera: An RGB camera up to 5MP resolution. Raspberry Pi's own camera or an alternative basic camera. Approximate budget:≅$10-$15
c. Transmitting Beacon: An analog circuit wholly designed and assembled by our team. Approximate budget:≅$10
d. Battery: A battery with proper power modulation for the main computer and the transmitting beacon, such as a simple power source made up of 18650 Li-On cells. Approximate budget:≅$5

2. **Transmitting and Receiving Data Primary Approach**

In this part of the project, digital data taken from the microprocessors will need to be transferred to analog media, and this analog signal will be transmitted and received by using visible light.

- To emit light, NESET Inc. will use the low-cost LEDs and Photodiodes, which are available in any electronic market. Transresistance amplifier will be used to drive the LEDs, and the transconductance amplifier will be used to drive Photodiodes.
- The effect of the ambient light on data transfer is a problem that we will face during the implementation phase of the project. To cope with this problem, the frequency we will work with must be determined in advance. This frequency should be in an area where the noise emitted by the ambient light is the least.
- At the same time, this frequency will be compatible with the operating speed of the microcontroller in the system.
- The quality of the signal will be improved by analog filters and amplifiers designed for this specific frequency.
- As a company, we have developed design solutions in addition to analog solutions to solve the ambiance noise problem. To get rid of the adverse effects of this noise, our design will have waveguide, which reduces the transmission of ambient light to Photodiodes.
- Since LM385p has two outputs on a single chip and has a high slew rate, our company chose it as Op-Amp to use in analog system design. And also, UA741 was determined as an alternative to LM385p.
- After the design of the analog parts of the system is finished, the whole circuit will be transferred to the Printed Circuit Board.
  - *Note: All cost approximations for this part is included in both terminals and the shuttle.*

3. **Data Carrier Primary Approach**

Data transportation from Transmitter Terminal to Receiver Terminal will be done with a shuttle. The main services of this shuttle is to load a data packet originated from the first terminal, and carry it to the second terminal on a physically guided track. The data load will be done by detecting the visible light emitted from the LEDs on the Transmitter Terminal. The specifications on the emission and the detection of the visible light are discussed in “Transmitting and Receiving Data primary approach”; however, a crude black box representation of the light detection block is displayed in *Figure 1* as Photo Receiver Module for convenience. The corresponding data packet is sent to a controller and stored there. An Arduino Nano is chosen as

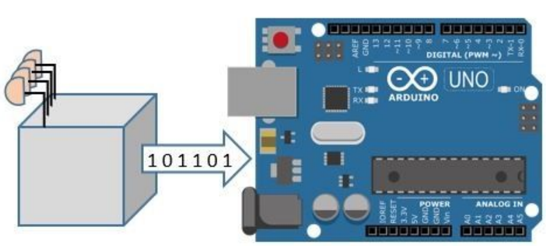


Figure 1: Photo Receiver

a microcontroller for this step as it is easy to use and cost-efficient. TM4C123 is the other emerging alternative here; however, its price is relatively high for this specific task. Refer to *Table 2* for a briefer comparison.

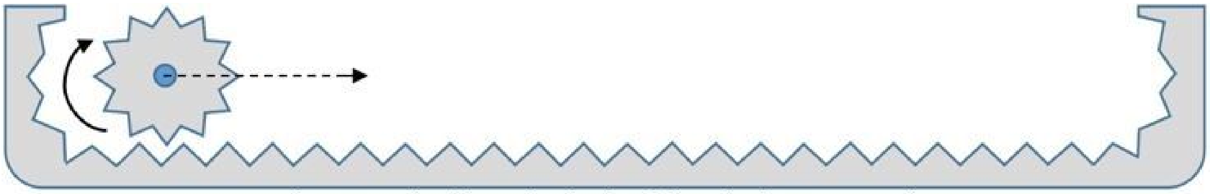


Figure 2: The first physical guide solution approach

Having stored the received data, the vehicle shall go towards the secondary terminal. The movement control of the vehicle can be done again with an Arduino and a supplementary Motor Driver Shield. The vehicle is to travel on a physically guided track. One possible solution is to install a gear track and control the position of the shuttle with the help of rotation controlled servo motor, as illustrated in *Figure 2*.

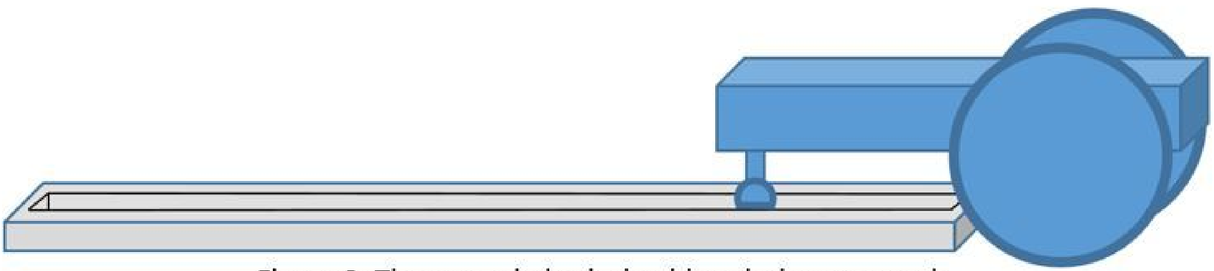


Figure 3: The second physical guide solution approach

This is a precise method for which the shuttle travels and stops very accurately as it is guided throughout the travel; however, the frictional loss has a considerable effect on power consumption. To decrease the impact of friction, a more loose guide shall be installed. As demonstrated in *Figure 3*, the track is now only there only to affect the direction of the movement rather than the action itself.

After the travel to the secondary terminal is completed, the data should be dispatched by light emission, which is done in the Beacon module. Please refer to the *Transmitting and Receiving Data Approach* for further details on the functions and the specifications of this module.

Approximate Budget (for tracks, motor and motor driver): ≅$8-$10

Considered alternatives:

a. The Carriage: Two possible candidates for microcontroller device:

Arduino Mega 2560: ● 4 UART ● Digital/Analog I/O ● PWM for motor control ● 7-12V barrel connector power input	Texas Instruments TM4C123: ● 8 UART ● Digital/Analog I/O ● PWM for motor control ● Micro-USB power input

● 8KB SRAM ● 256KB Flash Memory ● 8-bit 16MHz Controller chip ● Approximate budget:≅$40	● 32KB SRAM ● 256KB Flash Memory ● 32-bit 80MHz Arm Cortex M4 Controller chip ● Approximate budget:≅$25

Table 2: Arduino Mega 2560 vs. Texas Instruments TM4C123

b. Signal Receptor: An analog device very similar to the Transmitting Beacon. Approximate budget:≅$5
c. Transmitting Beacon: An analog circuit completely designed and assembled by our team. Approximate budget:≅$5
d. Battery: A Li-Po battery to provide a high current source for the motor alongside a regulated lower voltage output for the microcontroller power inlet. Approximate budget:≅$5

4. Receiver Terminal Primary Approach

In the destination terminal, the data that the shuttle carries will be collected first by an analog circuitry dual to the one in the source terminal and will be converted into logical binary values that can be handled by the main computer. Process time will be approximately equal to the process in the source terminal. In this terminal, likewise, to the source terminal, for our system to understand the signal transfer started, handshake protocol between shuttle and terminal should be made. Another possible solution can be using a preamble signal for the same purpose. For every round, the transferred data will be recorded to the main computer. If whole packets of the image are not transferred, this terminal needs to give the required “go for another round” signal to the shuttle. The recorded image can be shown on the monitor as a pairwise or whole when the overall process is done.

Considered alternatives:

a. Main Computer: A common low power microcomputer such as Raspberry Pi or Nvidia Jetson Nano with HDMI or VGA output capability. Approximate budget: $40
b. Signal Receptor: An analog device very similar to the Transmitting Beacon. Approximate budget:≅$10
c. Battery: A battery with proper power modulation for the main computer and the signal receptor, such as a simple power source made up of 18650 Li-On cells. Approximate budget:≅$5

Deliverables

The users are going to get the following items from the product's box:

- **Transmitter and Receiver Terminals:** Transmitter and Receiver Terminals are the parts that make up the non-moving parts of the system.
- **Shuttle:** Shuttle is the moving part of the project
- **Physically guided track:** The physically guided track indicates the system required for the vehicle to move.
- **Batteries:** The user will get three batteries to run the robot.
- **User Manual:** The user will get a user manual that contains information about the system, its components, and software.
- **Warranty:** Warranty is an official document showing that the system is guaranteed against errors that occur beyond the control of the user.

Conclusion

NESET Incorporation is capable of solving visible light communication problems with its diverse and young engineer candidates. Having interest areas in image processing, embedded software and hardware development, control theory, and integrated circuits, our company can provide solutions for the core problems of robotics and automation.

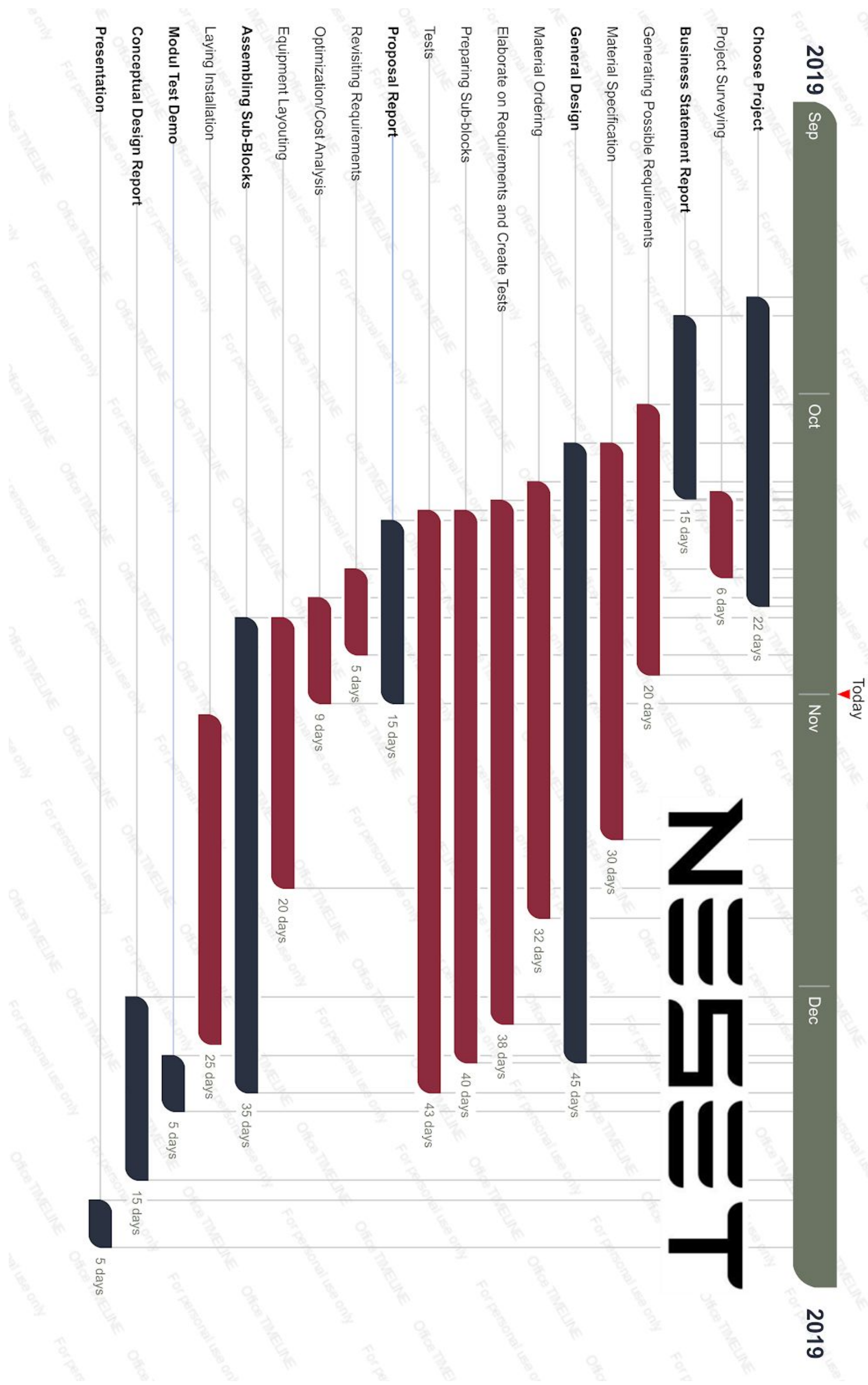
Approximate cost analysis shows us that the whole project will not be more than $145 which is not even close to our cost constraint of $200.

References

- Getting started with the Camera Module. Retrieved from https://projects.raspberrypi.org/en/projects/getting-started-with-picamera/8
- "Visible Light Communication (VLC) - A Potential Solution to the Global Wireless Spectrum Shortage," GBI Research, Tech. Report, 2011, http://www.gbiresearch.com/

Appendices

Appendix A: Timetable

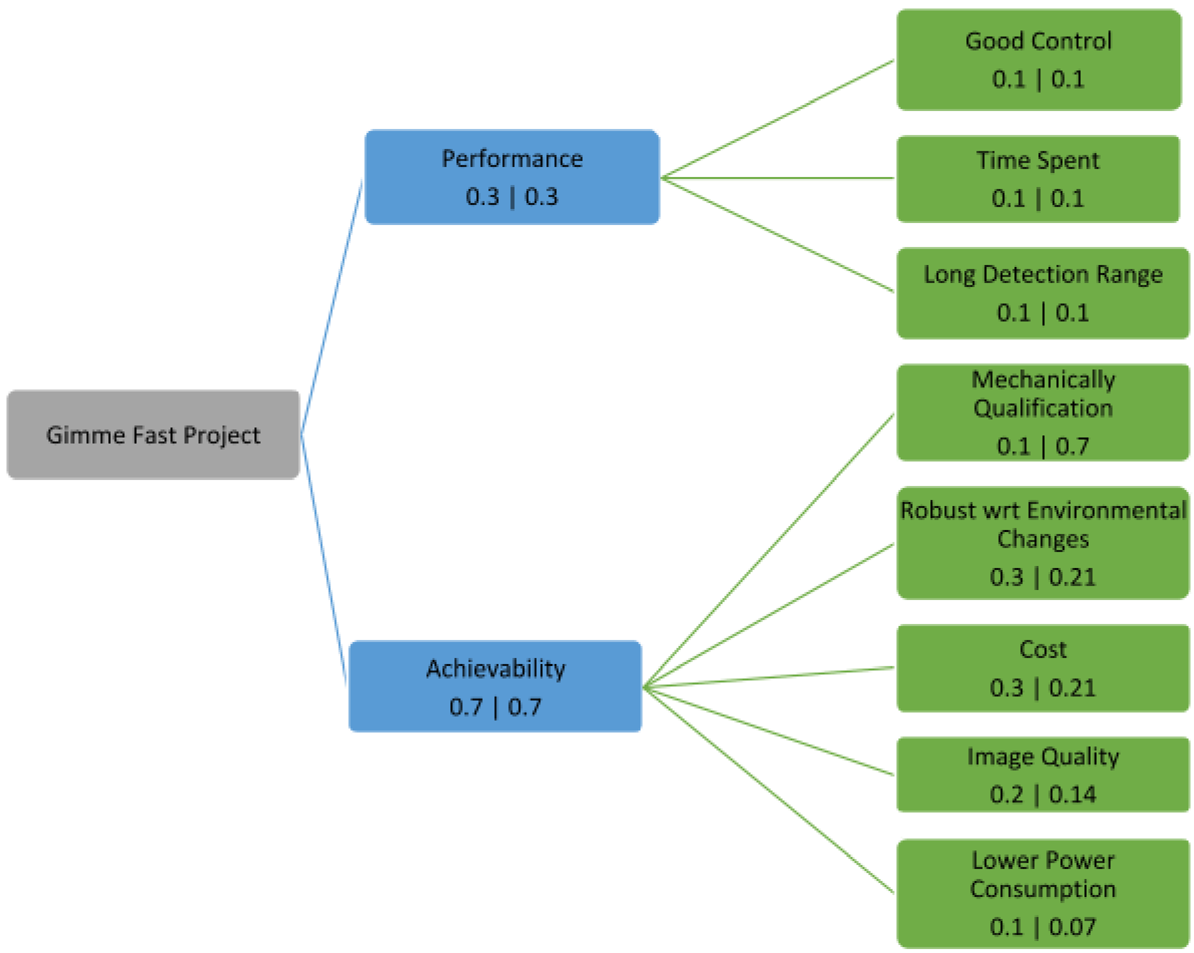


Appendix B: Objective Metrics

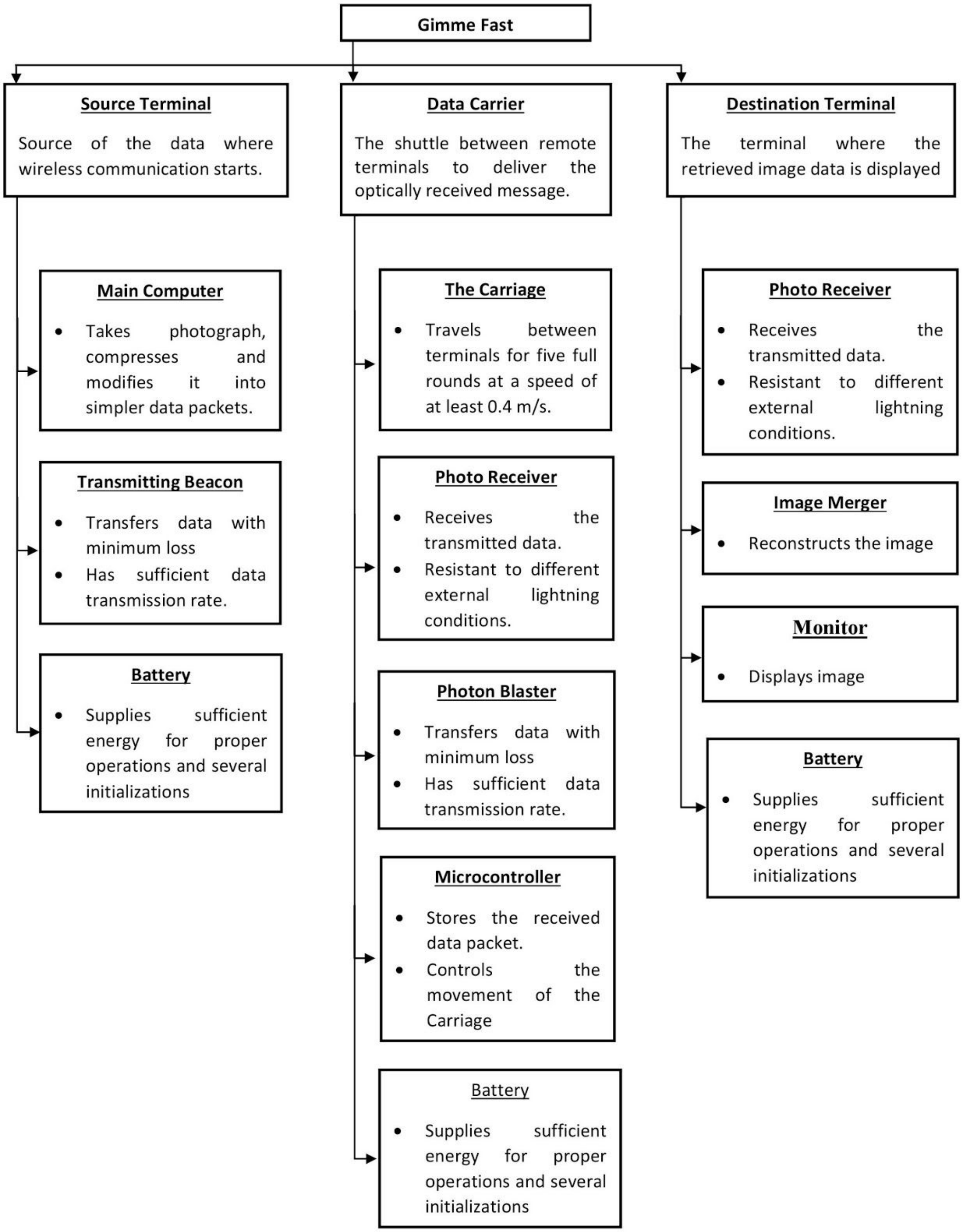
Objective Metrics

	Good Control	Time Spent	Long Detection Range	Mechanical Qualification	Robust wrt Environmental Conditions	Cost	Image quality	Lower Power Consumption
Excellent (10)	The system can be controlled easily.	0-2 min	2-4 m	Very easy to implement and quite durable	The system can work under any conditions that may occur in the environment.	<100 $	There is no difference between the captured image and the displayed image.	The system works very efficiently.
Good (8)	The system rarely gives some errors but not critical.	2-4 min	1-2 m	Slightly easy implement and sometimes vulnerable to sudden reactions.	The system can work under conditions that may occur in the laboratory environment.	<125 $	There is less difference between the captured image and the displayed image.	The system usually satisfies the restrictions.
Satisfactory (6)	The system gives some errors, but it can be correctable.	4-8 min	10-100 cm	Moderately difficult to implement and usually vulnerable to sudden reactions	The system can work above average ambient light and physical obstacles in a laboratory environment.	<150 $	There is an average difference between the captured image and the displayed image.	The system usually satisfies the restrictions, however, sometimes, it exceeds limits sometimes
Average (4)	The system rarely gives serious errors.	8-20 min	1-10 cm	Hard to implement and usually vulnerable to sudden reactions.	The system can work under-average ambient light and physical obstacles in a laboratory environment.	<175 $	There is much difference between the captured image and the displayed image.	The system sometimes satisfies the restrictions .
Unacceptable (2)	The system sometimes gives critical errors.	20-40 min	0-1 cm	Very hard to implement always vulnerable to sudden reactions	The system can operate when there are no environmental barriers.	~200$	The photo shown cannot be distinguished.	The system usually does not satisfy the restrictions.
Failure (0)	The system cannot be controlled autonomously or by hand.	+40 min	Even 0 cm	The project is inadequate mechanically.	The system cannot work in harmony.	+200 $	No photos are shown.	The system cannot satisfy the power restrictions.

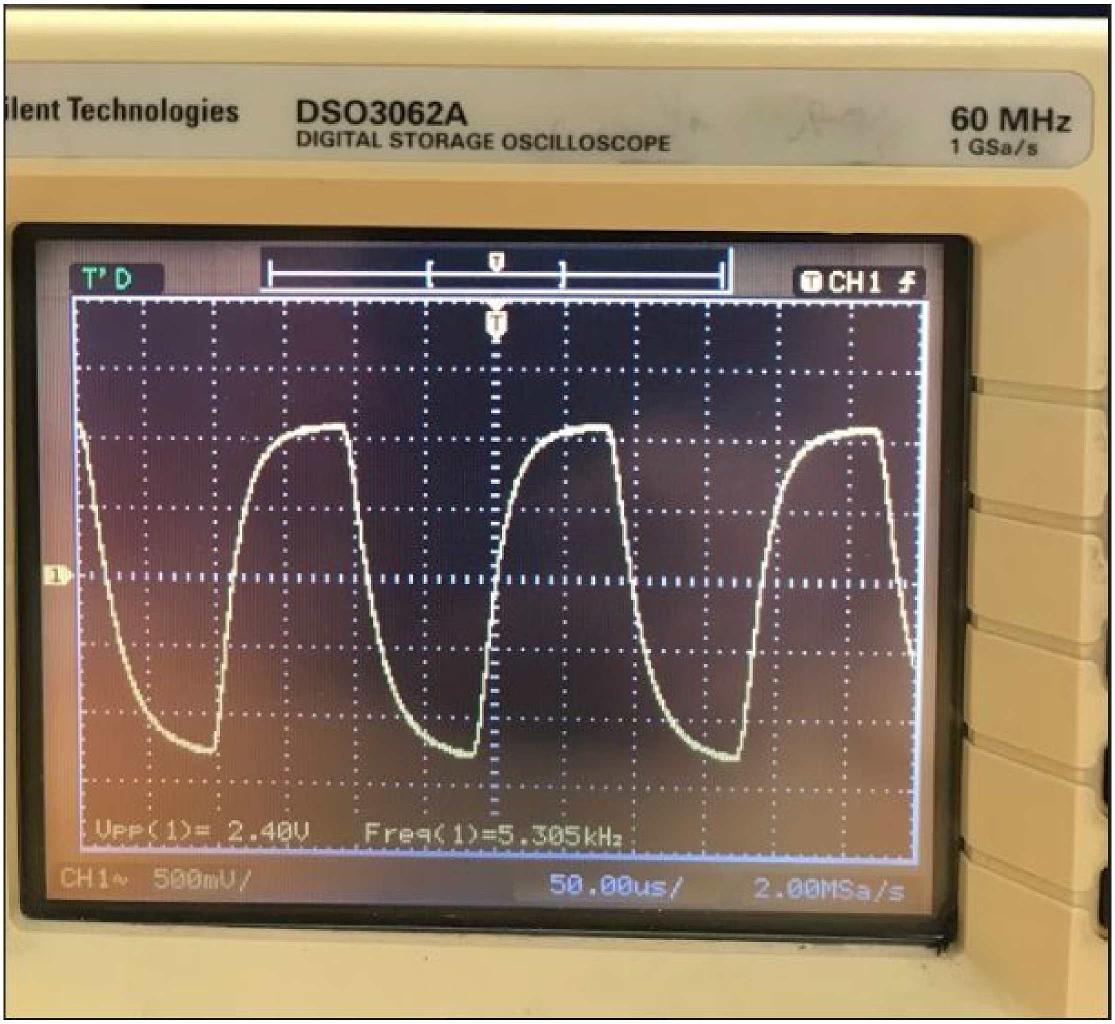
Appendix C: Objective Tree

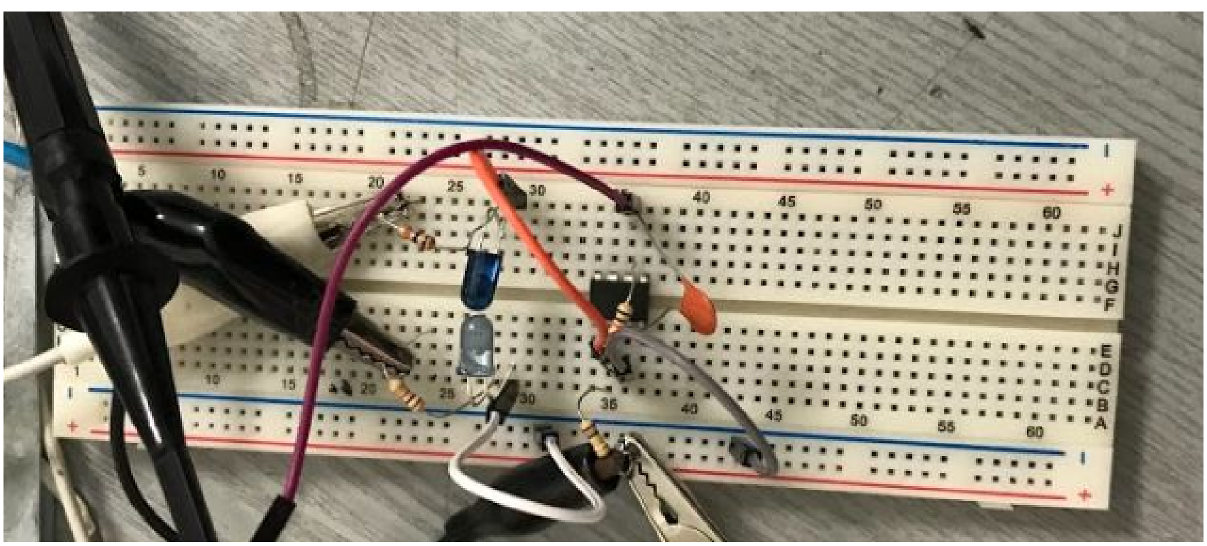


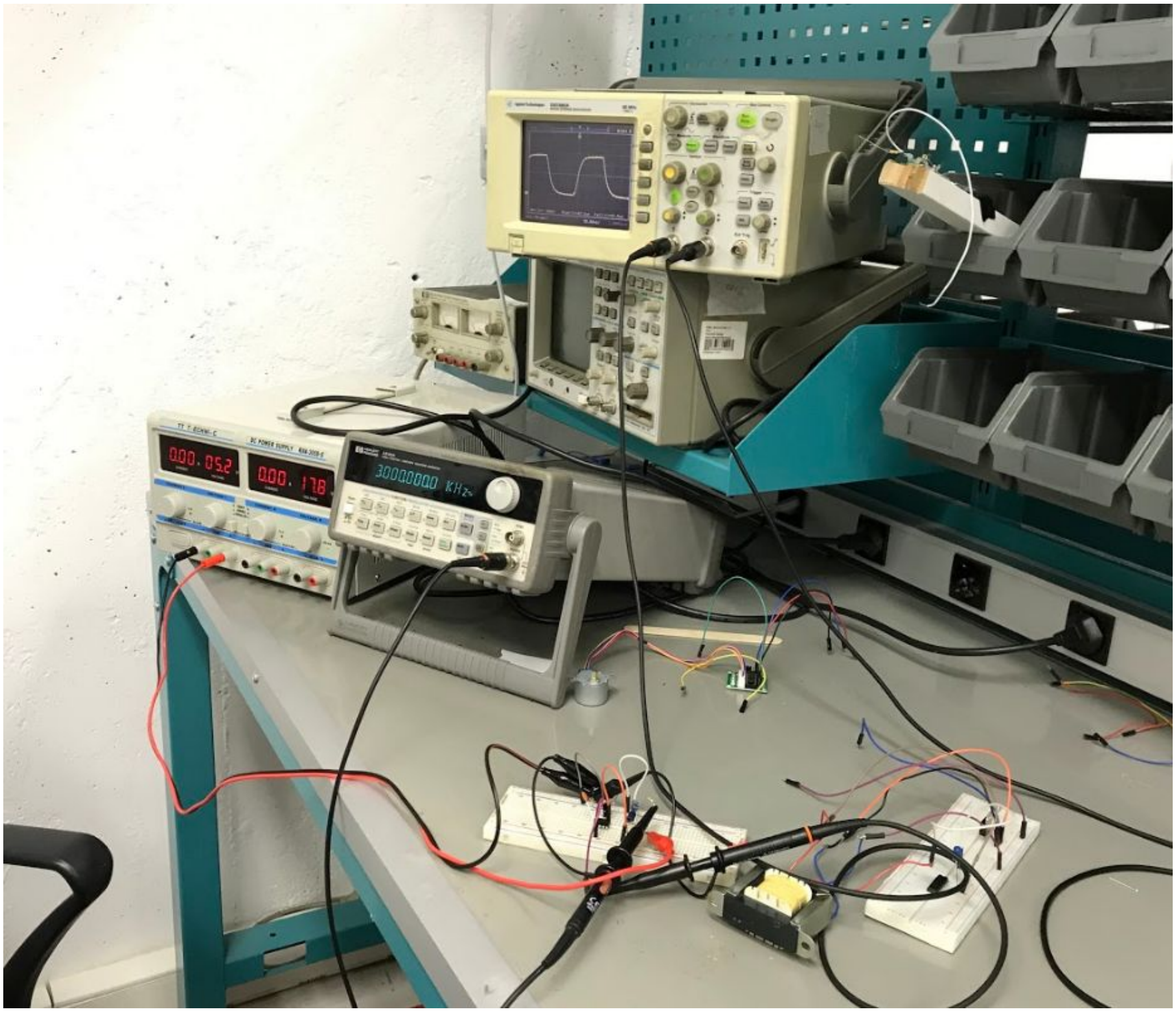
Appendix D: Product Tree



Appendix E: OWC Prototype Tests



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