DEBSA Limited Şirketi
Project Final Report

**Doğa Veske, Baran Bodur, Serhan Yılmaz,
Arda Efe Okay, Alper Özkan**

Customer: Assist. Prof. Elif Vural

Project Name: Robot taking part in a Pistol Duel

Electrical and Electronics Engineering Department
Room C-208
Middle East Technical University
Ankara, Turkey
March, 2016

Contents

1 Executive Summary

This report documents the 2016 Electrical and Electronics Engineering Senior Year Design Project made by the student-formed company DEBSA. The students forming the company are Doğa Veske, Arda Efe Okay, Baran Bodur, Serhan Yılmaz and Alper Özkan. The project was to design and implement an autonomous robot that will participate in a pistol duel with a similar robot. This means taking turns shooting at eachother and attempting to evade the opposing robots shot while staying in their own fields.

Our robot was designed with efficiency, effectiveness and independency in mind. This means our robot will operate at a level where it is efficient and effective while not relying on user input from the outside. It's decision algorithm is designed to be independent from the user save from a single function.

The robot was realized after a 9 month period starting at September. This period includes declaration of the available projects, DEBSA group choosing and proposing for a project, an initial design process, finalization of the design and implementation. During these times our process was documented with weekly reports and several big reports such as a Conceptual Design Report and Critical Design Review Report.

At the end of this design and implementation timeline, the final product, named ARMUT, can fully satisfy the requirements for the project. ARMUT can search for an opponent. After the opponent is found, it can aim at the opponent and shoot. ARMUT can take user input to switch between offensive and defensive modes. At its defensive mode, ARMUT can move in a random unpredictable manner to evade enemy fire.

This report will give information about the 9 month period concerning the design and implementation process of ARMUT. The report will also include information about ARMUT's final state, its deliverables and product content.

2 Introduction

The process for this project has several stages. First step is forming a mock-company composed of students. Each company is made up of 5 students who will work together for the entirety of the project. After the companies are formed, the companies will choose one of the available projects, writing a proposal report explaining why that project is the best fit for them. When the projects are assigned to the companies and they fully understand its requirements, members from the companies form a "Standard Committee" which will set up standards to ensure that the realization and the design process is fair to every group. The companies will perform the design and the implementation of their project satisfying both the project requirements and the standards. During this process the companies are also required to keep budgetary information and document their process with reports. This report will provide information on the 9 month period from the company forming to complete realization of the project.

3 Company Structure

As this is a group project, it is important that our company is a well functioning group both to avoid unnecessary conflicts and increase our working efficiency. It is particularly advantageous to form a company with a group of people that know each other well as they will know each others strengths and weaknesses allowing them to work better together, increasing synergy while each member is able to work on the section they are better at. Keeping this in mind, our company is composed of five students that know each other for an extended amount of time while also working together on other projects. This way they know how the others work. Our company is named after the five students forming it.

- **Doğa Veske** is specializing in the Microwaves and Antenna track at this department and a double major student at the Physics department. He also had experience in a complex engineering project, namely CANSAT.
- **Arda Efe Okay** is on the Computer track in this department and also a Double Major student at the Computer Engineering department. He also has experience with image processing.

- **Baran Bodur** is specializing in the Telecommunication track of this department and also a double major student at the Physics department. He also entered CANSAT project with Doğa.
- **Serhan Yılmaz** is specializing in the Computer track of this department and also a Minor student of the Computer Engineering department. He is an experienced programmer thanks to his interest in game design.
- **Alper Özkan** is specializing in the Computer track of this department and is a well rounded student involved in different projects and event organizations.

As it can be seen here, our group is heavily geared towards software development while also having experience with complete engineering projects. This experience helps greatly with scheduling and realization of our project. While our group seems to be one sided, one of the things we value most in our composition is versatility. We are quick to learn and adapt to subjects out of our field, we see it as an opportunity for growth. After forming the company and settling in, we were given 5 projects to choose from and we chose the one that felt like the best fit, the pistol duel project.

4 Project Requirements

Every project comes with certain requirements. The final product of the project must satisfy both the requirements set for the Project and also the Standards set by the Standard Committee. The project consists of two opposing robots taking turns shooting at each other. The robots will have to detect the opposing robot and shoot at it autonomously. During the defensive turn, the robot should try to evade the enemy fire either randomly or detecting the shot and moving accordingly. During these stages, user input is forbidden except for passing the turn when a shot occurs.

The standards also set several constraints on the robot. Documentation of the standards is in Appendix A.

- Standard 4.2.1 limits a robots turn to 40 seconds. If no shot happens in this time, the shooting robot concedes its turn.
- Standards 4.3.1 and 4.3.2 specify the bullet dimensions and colors, these must satisfy a certain conditions, effectively limiting the freedom on the gun barrel too.
- Standards 4.6.4 states that robot is still in the game while a reload is in progress which means the reloading process should be quick or non-essential.

The reason we chose this particular project was that it had more room for creative solutions, while some other projects seemed to have less possible solutions. While it required finer engineering as it had more room for error, we had confidence in our abilities.

As with every engineering project, each project presents its own set of problems. The engineer should provide solutions to the problem and design a system which will combine these solutions. Our design overview will be provided in the following section.

5 Design Overview

Every engineering project introduces a set of problem that must be solved. The engineer devises solutions to these problems and designs a system that is the combined product of these solutions. The problems introduced by this project is basically the tasks our robots must perform in the contest.

These tasks are

- Recognize Offensive or Defensive turn
- Load a bullet to the gun

- During Offensive turn, detect the opponent
- If an opponent is detected during the offensive turn, shoot at the opponent
- During Defensive turn, avoid being shot by the enemy.

We have devised several subsystems to act as solutions to these singular problems. All these subsystems are controlled by a singular decision module. These subsystems are

- Decision Subsystem
- Evasion Subsystem
- Detection Subsystem
- Shooting Subsystem
- Reloading Subsystem

All of these subsystem perform their own tasks and can work independently. But they are all connected to the Decision Subsystem with Data and Control connections. Their interfacing can be seen in the following figure.

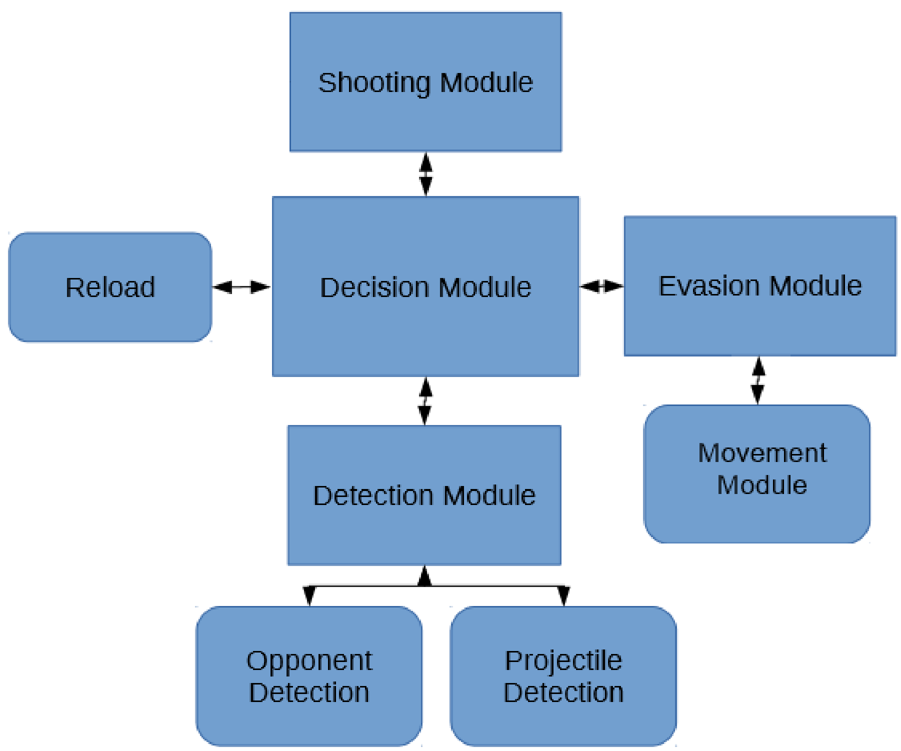

Figure 1: Detection of different objects with different speeds.

These subsystems were individually designed to satisfy the minimum requirements we set using the project requirements and the operating conditions as guidelines. These requirement and the designs satisfying them will be mentioned in this section, Technical Overview section will provide more in-depth information about these systems.

5.1 Decision Subsystem

The requirements our Decision Subsystem must satisfy are

- Must be able to determine Offensive or Defensive turn with user input
- Must be able to receive incoming data signals from the sensors
- Must be able to send appropriate control signals to the subsystems.
- Must be able to carry out the necessary algorithms for the duel

To satisfy these conditions we considered many different microcontroller units. Important criteria were amount of pins, processing speed and operating voltage. We decided to use an Arduino MEGA unit as it was the best choice on a cost/effectiveness basis. The microcontroller was also equipped with a bluetooth communication unit to satisfy the first bullet point.

5.2 Detection Subsystem

Our Detection Subsystem is required to satisfy these conditions

- Must be able to detect an enemy robot up to 2 meters away
- Must be able to detect outer walls so the robot does not hit the boundaries
- Must be able to provide information to Decision Subsystem which can be used for error detection(rooting out false positives)
- Should be completely on-board

As image processing is a resource-intensive process, we felt we could use a more efficient method to detect outer walls and enemy robots. For this we used Ultrasonic Distance Sensors. To detect the enemy, we utilized an array attached to the gun barrel while the outer walls are detected by sensors mounted on the sides of the robot.

5.3 Shooting Subsystem

Our shooting system governs ARMUT's offensive capabilities. For a good performance, it must satisfy these conditions

- Should have a high projectile speed to reduce chances of evasion
- Must be able to shoot accurately to at least 2 meter distance
- Should be small and easily mounted on the robot
- Must be controlled fully electronically

Considering these requirements and several options, we decided to build a single phase coil gun. When used with high voltages, this coil gun can shoot projectiles at high speeds. However this method requires ferromagnetic projectiles. For this purpose, we built 3D printed bullets with iron cores inside them. This way we have lightweight and low damage bullets that can be launched at high speeds. We also designed a charging circuit that charges 4 capacitors to about 80 Volts to provide a high enough current to the coil. The reason we are not charging a singular capacitor to 320 V is that this process is a lot slower than charging four capacitors due to the charging behaviour of capacitors.

5.4 Reloading Subsystem

In order for the robot to be autonomous, it must be able to feed the shooting subsystem with the bullets it requires. For this reason we need to design a reloading subsystem. This system has several requirements.

- Must be able to load a singular bullet to the gun barrel
- Should have little to no critical errors such as jamming
- Should have little variation in the bullet position.

In order to make a working reloading system, we designed a magazine to hold all the bullets, and then implemented a one bullet chamber, with two gates controlled by a servo motor. The motor will load a single bullet to this chamber, and then drop that bullet from the chamber to the gun barrel. More information can be found in the technical overview section.

5.5 Evasion and Movement Subsystem

In order to have a good defense system and a good offense system, we need to design a good movement system. This system will allow us to evade the opponent shots and also get in position for a better shot. The requirements for a good system is as follows.

- Must be able to move to any position on the field.
- Must be able to move randomly on the X axis.
- Should have large acceleration
- Should consider incoming projectiles

Considering these requirements we used two motor driven wheels and two caster balls, as our main movement is on a single axis, we can use two motors. These motors have high-torque and therefore are able to provide high acceleration. We used a random movement axis on the robot that utilized the detection system to avoid hitting the walls. This random movement is also aided with two Doppler sensors that can detect incoming projectiles increasing ARMUT's chances of evasion even further.

5.6 Structural Design

Even though we designed these subsystems accordingly, we must not forget that these systems must be realized for an end-product. These systems should be integrated on a working model. We need to efficiently place all these systems on a robot as we need to use as little space as possible. For this, we designed our robot structure with three floors.

- **Ground Floor** has the motors and the wheels underneath it. This floor also houses the wall-detecting sensors, shooting module, opponent detection system and the reloading system
- **First Floor** contains the Power Supply and the Microcontroller for ARMUT. It also houses the switchboard used for power control, the magazine for reloading and the doppler sensors for the Evasion Subsystem
- **Second Floor** is the top floor of ARMUT. This floor contains the charging circuit and the capacitors for the Shooting Subsystem. Top floor also has the opening of the reloading subsystem where the user can reload the magazine.

Below is a picture of the floor structure of ARMUT. It can be seen that the structure favours height over width to easily evade enemy fire. This however requires us to be more careful with our movement as the robot must not tip over.

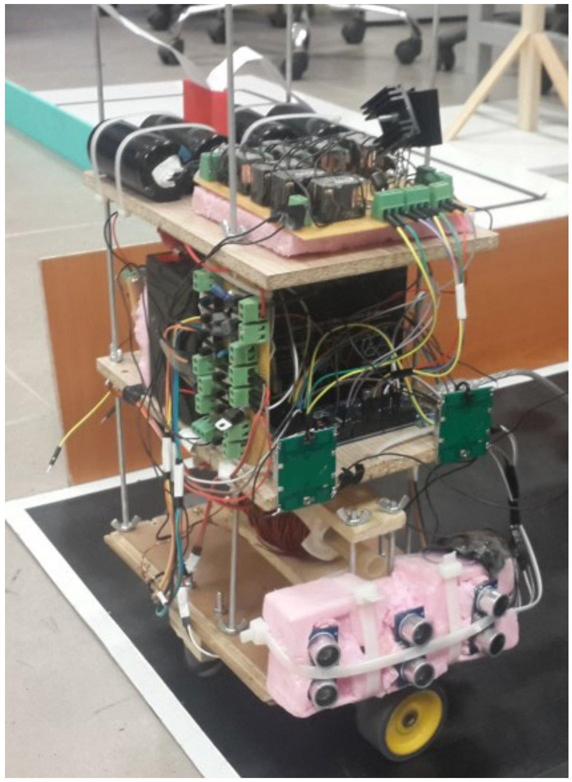

Figure 2: Isometric Photograph of ARMUT

6 Technical Overview

While the design can be summarized by the section above, there are far more details to building ARMUT than that. The measurements and the technical information can be read from this section for each subsystem. This section also contains test results for every other subsystem.

6.1 Decision Subsystem

The decision system is basically the system that governs the other ones. It collects raw data from the other subsystems such as the Detection Subsystem and the related sensors from the Evasion Subsystem, then it determines the right course of action and sends the related subsystems such as the Shooting Subsystem the appropriate signal(Such as detecting an opponent with the Detection Subsystem and Shooting them with the Shooting Subsystem). The decision subsystem acts as a hub for all the signals within the system. The diagram below shows the signal flow going in and out of the decision subsystem and within the entire system. The subsystems do not interact with another subsystem other than the decision subsystem. This adds scalability to our system as introducing new systems to our robot is much simpler.

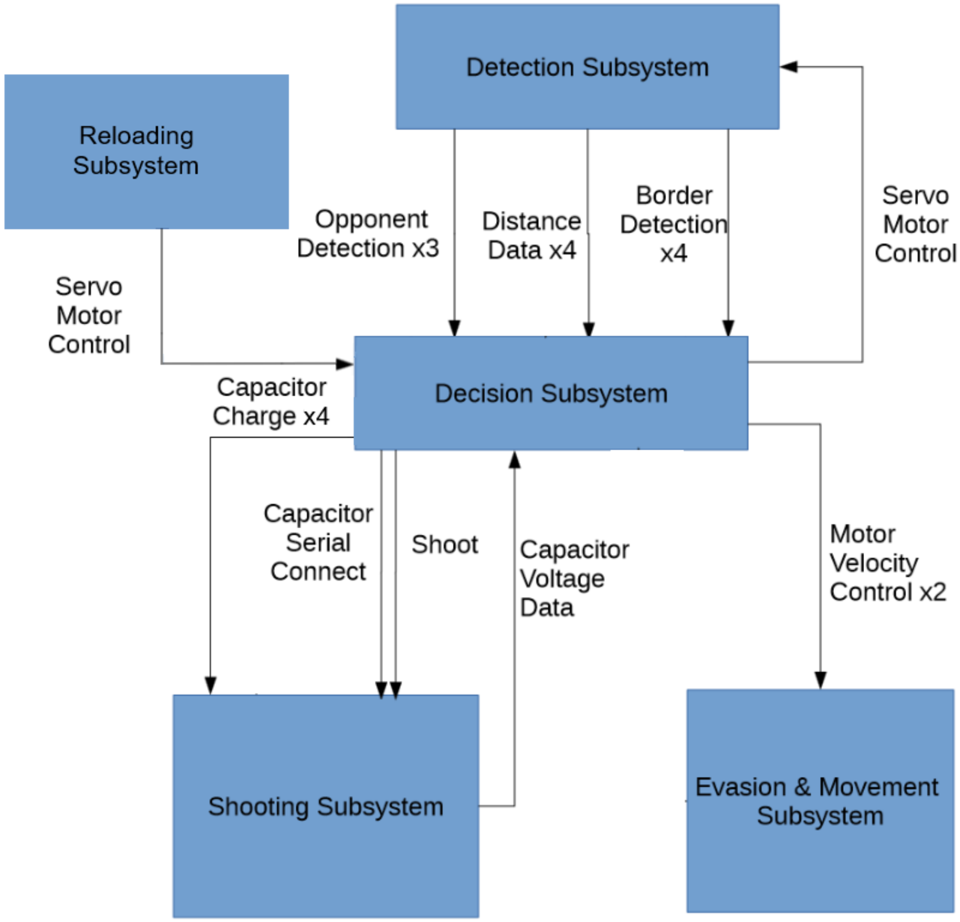

Figure 3: Signal Flow Diagram showing Decision Subsystem Functions

The decision subsystem also includes a HC-05 bluetooth module which can communicate with a smartphone for turn-passing signals and also data transmission. We have developed an app for these purposes which has more detailed information in the user manual.

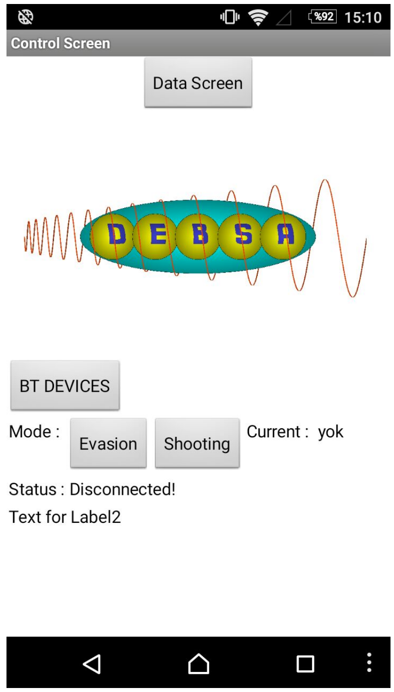

Figure 4: DEBSA Smartphone App

6.2 Decision Subsystem Testing Process and Results

The main microcontroller has been utilized in the testing process so its capabilities are well known to us and it did not go through a testing period like the rest of the subsystems. However, the bluetooth interface with the user was tested to see its capabilities. ARMUT can receive turn passing information. Moreover, it can send sensor data to us. While this is an important function, it is a resource intensive process should be used carefully.

6.3 Detection Subsystem

In the project we are designing an autonomous robot which interacts with another robot inside an arena. Therefore perceiving the environment is crucial in the design of our robot. There are two main parts of this perception, one is to detect the location of the robot inside the arena, the other is detecting the opposing robot. For the detection of the opponent robot we are using an ultrasonic sensor array, for locating ourselves we decided to use 3 ultrasonic sensors. Since these sensors cannot operate at the same time, in order to increase the sampling speed, sensors for opponent detection and navigation are not used simultaneously.

6.3.1 Auto-navigation

We need to know our orientation and position to position ourselves ready for shooting and to run during our opponents turn. For this purpose placing 2 walls to the 2 neighbour sides of the arena and 3 ultrasonic sensors to the 2 neighbour sides of our robot. With this configuration we can position ourselves by measuring the distance between us and the walls. Furthermore we can find our orientation angle by comparing the outputs from the sensors which are on the same side.

These data will be utilized by the Evasion and Movement Subsystem, with the assistance of Decision Subsystem.

6.3.2 Opponent detection

Opponent detection is an essential subsystem due to the purpose of the project. We are using 3 ultrasonic sensors placed side by side for this purpose. We installed a platform where the coilgun and these sensors will be mounted vertically. The platform will be rotated by a servo motor according to the algorithm and the received signals from the sensors. The system will work as follows, the servo motor will start to rotate the motor from one side to another and during this process we will look to the differences between the distance signals from the sensors. A significant amount of distance, such as 10 cm and the minimum distance reading is coming from the middle sensor, if both conditions are satisfied, this will mean the robot detected the enemy robot and will shoot without the need of tracking.

We will perform the same operation in several other spots with the help of Evasion and Movement subsystem, to increase our chances of detecting the opponent. This is necessary to obtain better and more accurate angles of attack.

6.4 Detection Subsystem Testing Process and Results

6.4.1 Opponent detection

The ultrasonic sensor array has been mounted on the gun barrel and connected to the servo motor. The testing shows us due to the widening of the beam angle of the sensors, at larger distances the sensors are less reliable. In order to reduce this angle, we rotated left and right sensors outward, giving the array an arc shape. So we use the intersection of the left and right sensors' field of vision to see if we detected a target. In the latest tests ARMUT was able to acquire targets up to 2 meters away which is more than enough for our project.

6.4.2 Auto-navigation

We implemented the ultrasonic sensors to our robot . We successfully acquired the distance and orientation information while moving. We also utilized these values as feedback to the Evasion and Movement Subsystem. The robot is fully capable of navigating in the battlefield.

6.5 Shooting Subsystem

The shooting subsystem utilizes a single phase coil-gun structure to accelerate the projectile in order to hit the opponent. The coil-gun accelerates ferromagnetic metals by applying strong magnetic field which can basically be obtained by providing high currents (several Amps) to an inductor for a short amount of time. The major problem with this structure is that providing high currents with low voltage being a near impossible task as each component has a small but non-zero resistance. In order to overcome this problem, the basic structure is modified such that voltage source is replaced by a initially charged capacitor. In order to charge the capacitor, a DC-DC boost converter circuitry is used. However, as charging a single capacitor to high voltages (300-350V) is a slow process, the design is modified further to use 4 capacitors which are charged separately to a lower voltage (80-90 V) and then are serially connected with the use of relays to provide the high voltage requirement. This is illustrated in figure 4.

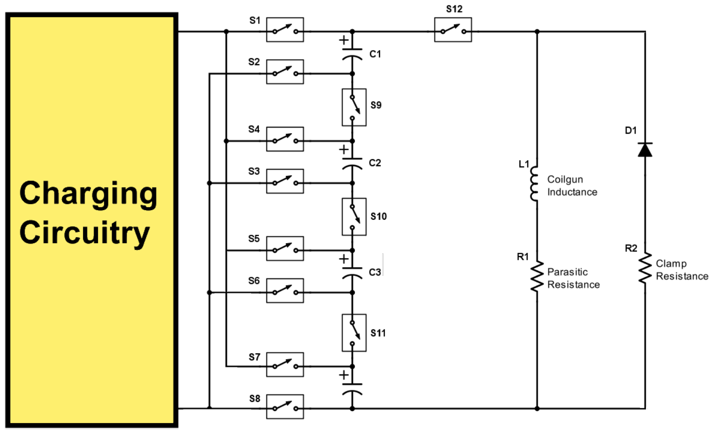

Figure 5: Schematic of the Capacitor Switching Circuit

In order to protect the circuitry from very high voltage spikes due to inductive behavior, the inductors are wrapped with reverse clamping diodes to provide a discharge path. The charging circuitry which is shown in figure 5, requires a high inductance for fast charging. In order to provide the high current and high inductance requirements, a home-made 3 mH inductor is made from 300-turns 5cm long 3cm radius solenoid shaped 1mm diameter copper wire with iron core. The transistor used is a high power IGBT with 600 V, 50 A, 480 W ratings which are more than enough for the system requirements.

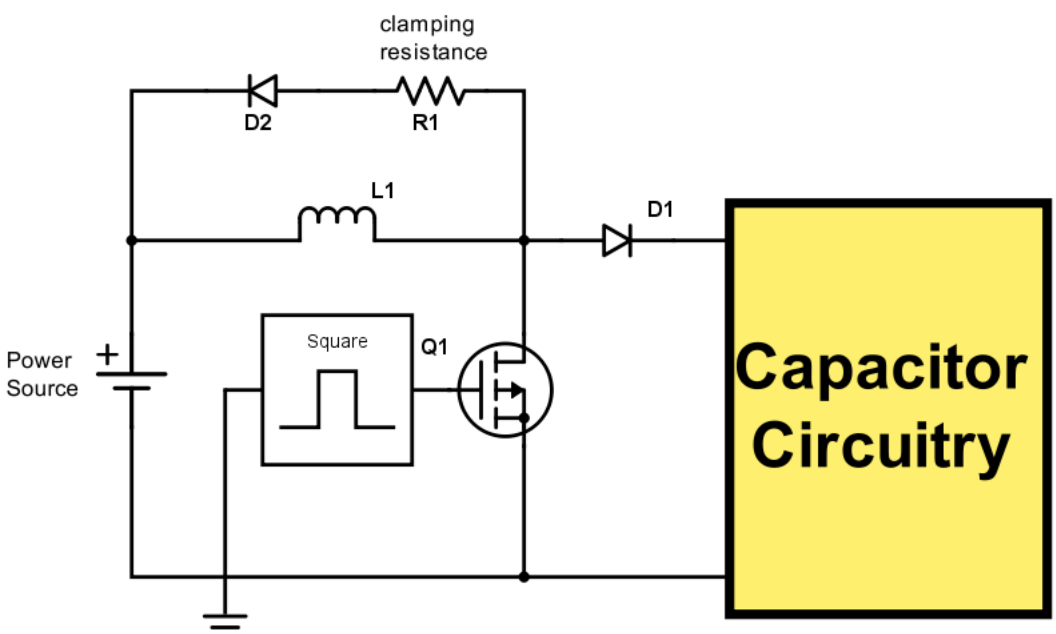

Figure 6: Schematic of the Charging Circuit

For reaching high magnetic force hence high projectile velocity, the radius of the solenoid which creates the magnetic field (evidently the projectile radius as well) should be as small as possible. For this reason, the projectile is designed in such a way that its perpendicular area to its moving direction is $1.2cm^2$ which is the minimum amount in accordance with the standards. The minimum volume regulation is hence fulfilled by making the remaining dimension of the projectile 4 cm long.

6.6 Shooting Subsystem Testing Process and Results

The following tests for the Shooting Subsystem were performed with

- 12 V Accumulator
- 6800 uF capacitor x4
- 3 mH charging inductor
- 0.8 mH coil-gun inductor
- 20 ms response time high current mechanical relays.

6.6.1 Results for Charging

We have set up testing for the charging operation with a 12 V accumulator. Due to the standards ruling, we need to charge the capacitors to a satisfactory voltage under 40 seconds. The circuit managed to charge the capacitors up to 85 V each(Totalling to 330 V) in 15 seconds, which means we have a very effective charging circuit. The charging was performed several times in a row to see if this charging speed was indeed sustainable, the results showed no dangerous overheating from the circuit elements and successful charging.

6.6.2 Results for Shooting

The projectile velocity is obtained by measuring the vertical slip due to gravity for a constant distance to a target with horizontal aiming.

- For total 180 V $\longrightarrow$ 25 A maximum inductor current for 10 ms, 5 m/s projectile velocity
- For total 225 V $\longrightarrow$ 35 A maximum inductor current for 10 ms, 8 m/s projectile velocity
- For total 285 V $\longrightarrow$ 45 A maximum inductor current for 10 ms, 13.5 m/s projectile velocity

A 285 V velocity for the projectile is sufficient to hit a target robot at about 1.5 meters without having to lead the target as the time it takes to reach the target is too small for the target to evade our shot. ARMUT utilizes 320 V shots in its operation and managed to shoot its targets successfully utilizing the Detection Subsystem.

6.7 Reloading System

For this project, the robot will have an internal magazine for reloading. Our robot can carry up to 15 projectiles at the same time. It will reload the projectile from magazine when attack turn starts. There will be a magazine above the shooting module. Using a servo motor system, the robot will reload a bullet from magazine. Also, there will be a magazine-pipe on the reload unit. The bullets will placed as horizontally in a vertical pipe. With gravity and a servo-reload design, the next projectile will flow into loading chamber. This chamber has 2 gates. One takes projectile from pipe and the other send the projectile to the shooting module.

The position of the bullet after successfully being dropped on the barrel is random. This causes randomness in our shooting performance. In order to eliminate this randomness, we first move the projectile to the back of the barrel by rotating the gun barrel, using centrifugal force. Then the bullet will be moved to the correct position using minimal magnetic force with the gun coil. As the position and the force is constant, the bullet will end up in the same position every time.

6.8 Reloading Subsystem Testing Process and Results

The reloading system has been tested accordingly. The system adapts well to high speed reloading. The reloading system does not jam without user error. These errors happen when the user loads the bullets to the magazine perpendicularly. To avoid this, we have designed a reloading apparatus for the magazine. A simple strip of paper is laid into the magazine before loading of the magazine and it is removed after the magazine is loaded fully. This apparatus ensures that the magazine is correctly loaded and no error occurs.

6.9 Evasion and Movement Subsystem

6.9.1 Evasion Subsystem

ARMUT is equipped with two HB100 doppler sensors, which can detect the speed of incoming (or outgoing) objects via doppler effect. By using two of these sensors, ARMUT can also determine approximate direction of the projectile, and perform an evasive maneuver to the opposite side.

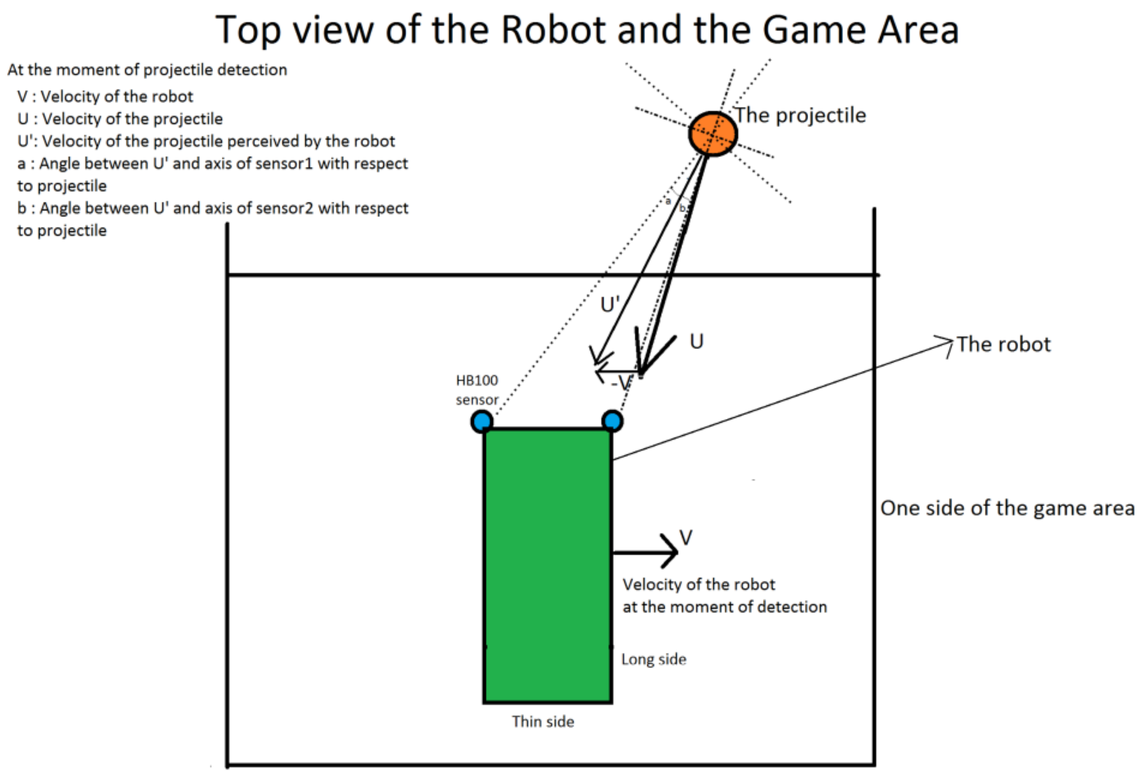

Figure 7: Diagram showing the Doppler-Guided Evasion

The use of two Doppler sensors can be seen in the previous figure. The doppler sensors will detect frequency shifts caused by the projection of relative velocity (u') on the axis between sensor itself and the projectile. Therefore if the projection of u' on the second sensor axis is larger (angle b is greater), it will detect a greater frequency shift when compared to the first one.

In order to make such decisions, we need to know

These HB100 sensors will give the frequency of the doppler shift (not the shifted frequency but how much shifted it is), however there are multiple ways to process these signals. Before sampling the signal with ADC, it is first amplified, shifted by 2.5 V (to make it compatible with 0-5 scale), and filtered by a low pass filter (to prevent aliasing and reducing noise).

Then the signal is processed digitally, with the aim is to find the dominant frequency of the spectrum. The most powerful way is to use Fourier Transform in the form of STFT. The maximum binsize of FFT in Arduino is 256, which will result in very low resolution over our 5 kHz band. To further enhance this resolution, a digital low pass filter was used so that same bins will be shared over 1.25 kHz, which means ARMUT can detect projectiles up to 17 m/s speed, with a velocity resolution of 0.14 . Since Arduino samples 9615 times per second and needs 1024 (256 * 4) to obtain an FFT and decide on action, our time resolution is 9 Hz (we look for incoming projectiles 9 times per second).

Currently, we suffer from some errorous FFT results at high frequency bins, possibly due to some computational glitch or spectral leakage of the default window type. These errorous bins and its values are generally constant, therefore it is possible to ignore them. If they cause more problems, there are always time domain frequency detection methods such as zero crossing detection or autocorrelation, that are better suited for microprocessor implementations but gives us less information.

6.9.2 Movement System

This subsystem moves our robot to the designated location provided by the Decision Subsystem by using the data from the Detection Subsystem. Movement subsystem is essential to realize the action needed by the Evasion and Movement Subsystem.

First of all, we control our robot using two different PWM. One of them aligns the robot according to the side wall. While the other is used to control the robot movement in the X axis. In order to change the position in the Y axis, we impose this condition to our alignment control PWM. With this configuration ARMUT can easily move to any location in the X axis, but moving in the Y axis requires careful manoeuvring.

After deciding PWM's for orientation and X-position seperately, we combined them with a coefficient which satisfies the normalization condition. Each of these PWM's depending on their error are of PID controller design. At higher orientations, above 12.5 degrees, maintaining control of the robot becomes exceedingly difficult. Due to this, we utilize the ultrasonic sensors to make sure we never lose control.

6.10 Evasion and Movement Subsystem Testing Process and Results

Data is obtained from two ADC channels without any problem, with a sampling frequency of 9.6 kHz. Since it is very critical in our operations, we tested this even with a stopwatch.

FFT of current and previous data can be stored using 3 kB of RAM. Fortunately, we have chosen our Arduino board carefully as Arduino Mega which has 8 kB of RAM, so that these kind of operations can be done.

Speed of larger(hand sized) objects can be determined from the peaks at the FFT bins.

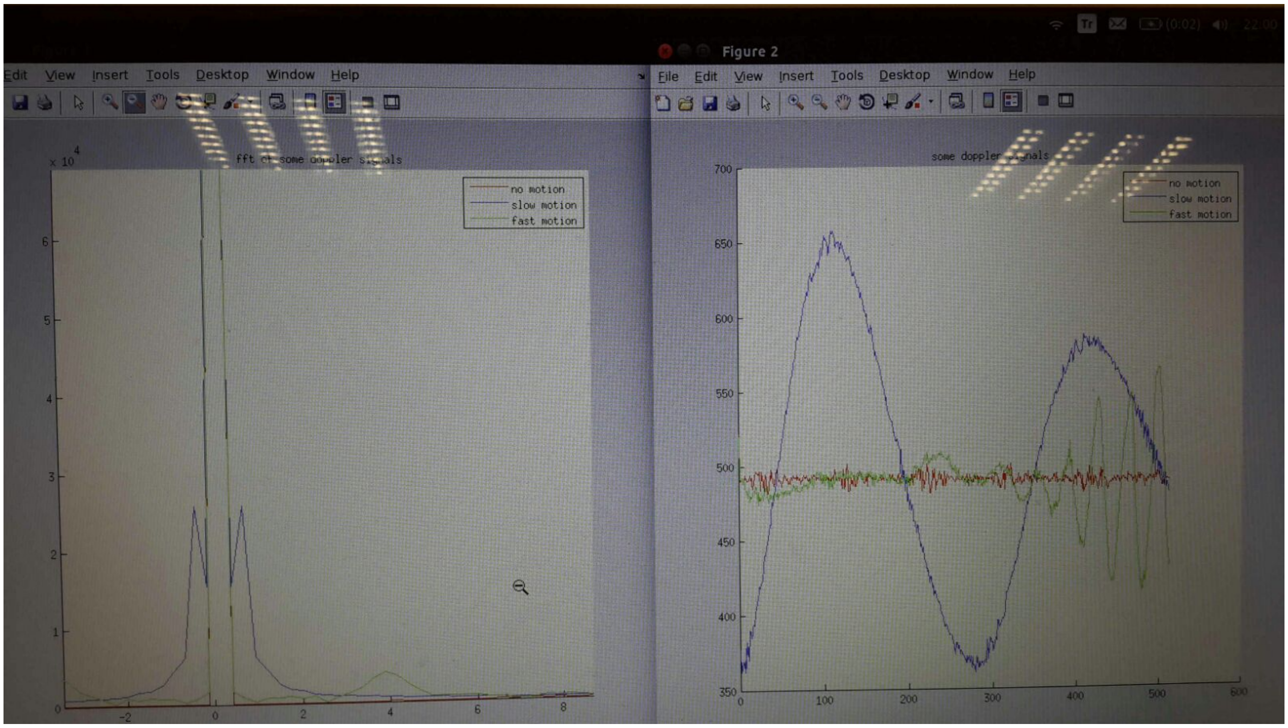

Figure 8: Detection of different objects with different speeds.

$$\Delta f = 2vf/c$$

Movement of smaller objects from half a meter can be detected, but we did not attempt to extract velocity data of these objects. Their movement can be found by subtracting current and previous FFT data.

6.11 Implementation Difficulties

During the implementation process, we encountered some difficulties due several component errors. To overcome these difficulties we implemented solutions, or in some cases adapted our systems to it.

Coil Gun: One of the difficulties with implementing the coil gun was that it obviously showed non-uniform behaviour. This was expected, even utilized by us as we wanted to control the point of force by controlling the density of the coil. As we are humans, the coil we manufactured did not match the design perfectly. While this proved to be a difficulty, it did not require an intricate solution as we adapted our system to work with its current behaviour.

Movement Motors: The movement motors we used were the same models from the same manufacturer. However, these motors were not identical to each other. This discrepancy did not allow the robot to go a straight path, even rotated it by a significant angle when motion started. This was solved by using separate PWM controls for each robot, controlling them to act identical.

Detection System: A problem with the ultrasonic distance sensors was that its field of view was not a straight line, rather a cone. This caused us to get false readings

7 Safety Analysis

Safety is a critical issue and it should be well-defined especially in a project involving shooting. We understand, its importance and we will arrange mechanical properties of the robot accordingly. All moving parts and electrical contacts (especially the ones carrying high voltage) will be sealed.

Our product will be completely safe for the user, as long as he/she operates the product within the limits and follows the instructions which will be specified in the user manual.

Possible safety issues and their respective solutions include:

Projectile shooting: User should initialize the robot according to the defined conditions in the user manual. Prior to the initialization, the robot should be on the test field and only moving object in front of it within a radius of 1.5 meter should be the target robot. If these conditions are satisfied the robot will never shoot to a human being. However, just in case our iron projectiles will be covered with cotton/styrofoam type of shell, and will be lighter than a table tennis ball. It is tested that, such a projectile will not cause any significant damage to the defined styrofoam by the standards committee. However, we cannot guarantee this safety if the user exceeds maximum voltages defined in the user manual.

High voltage: Our design depends on generating high voltages (up to 1 kV), and instantaneous high currents generated by these voltages. User access to these areas will be prevented, by sealing these high voltage areas with insulator materials.

Impact: According to our design there should not be any objects within its operation area of 1x1 m. If such objects are present, robot will ignore them and cause harm to these objects. The user should respect instructions in the field and prevent any such situation.

8 Environmental Impact Analysis

ARMUT only uses eletrical energy, stored in the form of chemical energy in our accumulator battery. It can be recharged easily by a simple adaptor connected to a regular AC plug. Since it is reusable, it will not cause any environmental damage. However, when the accumulators safe operation time ends it should be replaced, and the accumulator should not be thrown away to a regular trash bin. In order to simply this process and prevent environmental harm our company will replace the accumulator after its life time, only with the expense of the accumulator.

ARMUT's bullets will be reusable, therefore if the user does not leave them on the ground they will not cause environmental damage.

9 Comparison with the Critical Design Review Report

The final product is not too different from the design reviewed at the Critical Design Review Report.

There has been several minor component changes such as a new power source, an additional capacitor to the charging circuitry and decreasing a sensor from the wall detection. While these changes are small, they still alter the test results. ARMUT's performance has improved drastically thanks to these updates.

Another change regarding the system structure is the reloading system. While it was planned to be connected to the Shooting Subsystem and located outside the robot, in the final product we managed to mount the magazine and the reloading system on the robot. We also implemented it as a seperate subsystem communicating with the Decision Subsystem directly.

Finally, we did not utilize the bluetooth to its full potential until now. Other than sending turn passing signals, we can also receive data from it. This way we can immediately see the status of our robot at any time.

10 Deliverables

The end product of this project is a fully-automated robot that shoots to enemies as well as dodges enemy missiles. However, as the end product of a well-scheduled project, the robot is not the only deliverable. First of all a maintenance instruction and operations manual booklet which explains the corrective maintenance operations and user instructions will be provided. This booklet is included in Appendix B for further inspection. The deliverables also include a Companion App to control the robot mode of operation and even receive diagnostic data. The robot represents a minimal version of a prospected automated military/security application. Such a product should not have one time usage.

Life cycle of the product is being planned carefully to optimize the cost effective support for projected demand. Secondly a technical training for operator and maintainer of the robot will be given for proper operation and support. Even though operation may seem trivial, knowing how robot operates is important for proper usage. Besides these, spare parts, maintenance equipment and software support will be supplied.

Last but not least, obsolescence management of the product will be done and "form-fit-function " interchangeable parts will be supplied throughout the life cycle. This issue is very important especially in areas like electronics where the technology develops rapidly; i.e. nowadays it is very hard to find 64MB RAM for an old motherboard. In addition, on-call and field support will be served.

11 Power and Fiscal Budget

11.1 Cost Budget

Our additions to the Conceptual Design did not change our budget much, the most significant addition was to the Detection System which resulted in us adding more ultrasonic sensors. The updated budget is as follows

- Arduino Mega Microcontroller Board : 7 $
- 1 kg Enamelled Copper Wire: 10 $
- High Voltage ($\approx$ 100V) Capacitors: 4x5 $
- Relays/Power Transistors: 5 $
- Power Supply: 10 $
- High Torque DC Motors: 2x10 $
- Motor Driver Circuitry: 5 $
- Wheels: 2x5 $
- Gun Barrel: 1 $
- Ultrasonic Sensors: 6x3 $
- Iron Cores: 2 $
- Servo Motors: 2x2 $
- 3D Printing Costs: 6 $
- Mechanical Parts: 15 $
- Grand Total: 138 $ $\pm$ 14

11.2 Power Budget

Our current state of the project is not too different from the conceptual design but since we still made some changes, we need to revise the power budget to account for these changes.

Power Supply Capacity: $7A * 12V = 84W$

Arduino Mega: $100mA * 12V = 1.2W$

Servo Motor: $200mA * 6V * 2 = 2.4W$

Ultrasonic Sensors: $6 * 15mA * 5V = 450mW$

Movement Motors: $3A * 12V = 36W$

Charging Circuit: $3A * 12V = 36W$

Our power supply can supply ARMUT with 84 W while ARMUT can drain 77 W at maximum load. This leaves us with a 7 W gap we can use to implement new systems without changing the power supply or just use as safety margin. The power supply can supply 84Wh energy. This gives us a minimum of 84/77=1.1 hours of operation. This estimation is considering maximum load at all times. ARMUT can last much longer than this as all systems will not be at full load simultaneously.

12 Conclusion

This report explains in detail the design and the final product of DEBSA LTD "Robot Participating in Pistol Duel" project, ARMUT. After this 9 month period of designing and implementing a robot, our product is finally complete. While there is always room for improvement, we feel confident in our design and ARMUT's abilities.

This 9 month process has improved our technical abilities as engineers but also our teamwork and ability to work within a company. We feel that this project also increased our versatility as we had to adapt and learn about different subjects.

13 Appendix

13.1 Appendix A: Standards Directive

Standard Code	Content
4.1.1	Each group is responsible to construct their own half field
4.1.2	Each team can use any material to construct their own game field
4.1.3	Color of the platform must be opaque black
4.1.4	Color of the boundary of the game field must be white
4.1.5	Width of the boundary must be the same as width of the standard electrical tape(19-20 mm)
4.1.6	Height of the platform can be maximum 1.5 cm from ground
4.2.1	There will be a time-out period to fire. This period will start when the opponent robot fires. The duration of the time-out period is 40 seconds
4.2.2	If no fire occurs within the time-out period, the turn will pass to the opponent
4.2.3	Teams can send a simple signal to their robot to notify it of its turn. The signal can only be sent after the opponent projectile falls on the floor.
4.3.1	The bullet/projectile must be standard table tennis ball orange color.
4.3.2	The bullet/projectile dimension constraints are as follows -Minimum dimension: 1 cm -Maximum dimension: 4 cm -Minimum volume: 4 cm^3 -Maximum volume: Volume of the standard table tennis ball
4.4.1	Teams are responsible for the safety of the opponent and the spectators. The bullets should not cause any notable indentation on a standardized test material.
4.4.2	Sample pieces of the test material can be obtained from Bauhaus™
4.4.3	Test shoots should be made from 1 m distance.
4.5.1	Remote sensors can not send command data, they can only send ”measurements” (The data to be sent to the robot should not compromise the autonomous nature of the robot.)
4.5.2	External PC and connected devices can be used as a remote sensor.
4.6.1	During reload, a portion of the robot can go out of the game field excluding the opponent side.
4.6.2	Reload can be done any time during the competition.
4.6.3	No extra time will be given for the reload
4.6.4	During the reload operation, robots may be under attacked
4.7.1	At least 50% of the visible area(from every viewpoint) of the robot must be covered homogenously with a green material
4.7.2	The reference color is specified as Akcali spray paint no:314 (Light Green). Eylem Tokat is responsible to test this color
4.7.3	The material color should closely match the reference color
4.7.4	The material can not be sound and light absorbing
4.7.5	In order to use sensors there can be holes on this material.
4.8.1	The audience must be at least 50 cm outside the game field.
4.9.1	Stray bullets, if requested by the team who has the turn, will be removed from the game field manually by the referee.
4.9.2	The removal will be done by a non-intrusive ”Stick”.

Table 1: Standards Directives

13.2 Appendix B: User Manual

WARNING!

- This device operates in high voltages. Do not try to dismantle the cover or scratch the cables. In case of any scratches turn off the system and call the distributor/service.
- In case of contact with water turn off the system and call the distributor/service.
- During the operation don't stand in front of the robot.
- During recharge make sure the device is turned off.
- Keep out of children's reach.

OPERATION The operation for the ARMUT is simple.

- Set the robot down on a flat surface a target in front of it
- Provide the robot with a target for the Offensive operation and select Shooting from the Companion App
- Select Evasion from the Companion App if you want ARMUT to evade incoming shots.

TROUBLESHOOTING It is not advisable to perform troubleshooting by yourself if you are not experienced with electronic circuits.

Make sure the robot is powered off when performing troubleshooting.

In case of a malfunction, contact service for repairs. **SWITCH BOARD** ARMUT has a switchboard that can controls electrical power inside it. **DO NOT** tamper with switches other than the first one outside of troubleshooting The switch functions and ON/OFF orientations are as follows

- Main Power - **(ON/OFF)**
- External Power Source - **(ON/OFF)** DO NOT USE AN EXTERNAL SOURCE UNLESS YOU ARE EXPERIENCED WITH ELECTRICAL CIRCUITS
- Enemy Detection Sensors - **(OFF/ON)**
- Side Sensors - **(OFF/ON)**
- Reloading System - **(OFF/ON)**
- Doppler Evasion Sensors - **(OFF/ON)**
- Arduino Power - **(OFF/ON) DO NOT CONNECT A COMPUTER TO THE ARDUINO WHILE THIS SWITCH IS ON**
- Shooting and Charging - **(OFF/ON)**
- Movement Motors - **(OFF/ON)**
- Not Connected - **(OFF/ON)**

APPLICATION MANUAL

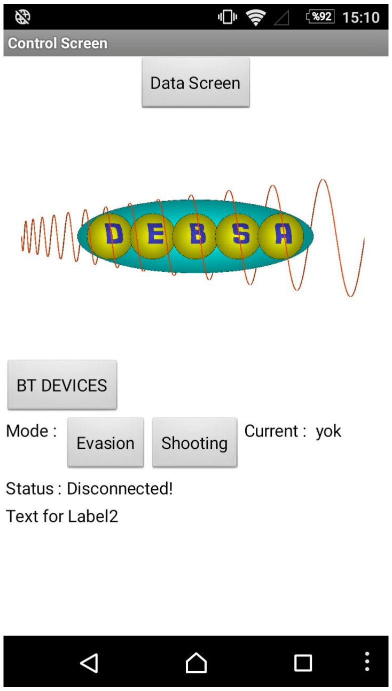

Figure 9: DEBSA Smartphone App

In order to use the application a device with a bluetooth connection and an Android opertion system is required. There are two main screen of the application

1. **Control Screen** In this screen the robot can be controlled. Status of the Bluetooth conection can also be seen at the bottom of screen.

   Buttons:
   - Data Screen: Brings up the data screen
   - BT DEVICES: Chooses the Bluetooth device to be connected from the previously paired Bluetooth devices.
   - Evasion: Switches the operation mode of robot to evasion
   - Shooting: Switches the operation mode of robot to shooting

2. **Data Screen** In this screen all the data coming from the robot can be monitored. These data include mode, sensor readings, capacitor voltages and operation stage. Status of the Bluetooth conection can also be seen at the top of screen.

   Buttons: Control Screen: Brings up the control screen