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# Executive Summary

This report presents details of the project for a teleoperated robot trying to score in opponent’s goal and defend its own meanwhile. Remotely controlled robots are widely used in many aspects of our life. Main idea behind this project reflects a real-world problem in occasions where the user has no view of the robot. Therefore, a two-way communication with the robot and user’s computer should be established. Reliability and efficiency of this communication is vital since intervening a distant robot which can be unreachable at that instant, by the user can be challenging.

This design will be accomplished by building an efficient communication, a robust mechanical design and reliable electronic system. We aim to achieve satisfactory performance in speed and accuracy. Our final product is to detect the ball on the field, shoot the ball towards the opponent’s goal, defend its goal and stay in its half field doing so. Several solution methods are sufficiently described in the following sections of this report.

Our company is composed of five shareholders with different specialization fields and backgrounds. Therefore, each team member came up with a solution from a different point of view. We merged these perspectives in order to construct solution approaches at this point of our design process.

Even though our base knowledge is similar, each team member chose to study in different fields. Therefore, at certain levels of the design process and solution offering, each member has a different idea and experience. Ms. Arabacı is more experienced in controller design and system modelling which will help her to guide and inform the team, Ms. Coşkun and Mr. Göksu will lead the team with their mechanic & analog design and integration skills. Mr. Beyenir’s skills & background in image processing will help us in programming stage and last but not least Mr. Elik will take an active role in building a durable and stable communication system.

Final product will be delivered in best way with a cost of 200$, at the end of 7 months by PITECH engineers. Once the customer purchases the final product, they will own the final action robot consisting of mechanical subsystems, camera, sensors and drivers. In addition to these, a user manual, a warranty document, required software tools, four batteries, two battery chargers, three game field walls, two balls (one is extra) and a dummy robot are also provided.

# Introduction

In the last few decades, robots are gaining more complex abilities, thanks to improvements of technology, that they substitute for humans in many fields of industry. This progress enables us to handle things easier and, in more time, efficient way since their performance is better than ours in many aspects of our daily life such as personal, professional life etc.

Being a newly founded company with five highly motivated, young engineers from different specialization fields such as electronics, control, computer and telecommunications; our aim is to develop a teleoperated robot that can play hockey which includes trying to score in opponent’s goal and also defend its own goal. Apart from the specifications defined above we intend to come up with the best featured robot possible.

In this project, our main purpose is to build a robot that we can control from a specified distance with a remote controller. In order to fulfill this requirement, we found an efficient way to transfer data from our robot to the main computer so that we can improve our chance to score a goal and win the round. This is a two-way communication since we will send directions to the robot so that it can move with respect to these commands. In addition, the mechanical structure of the robot should also be robust so that it can endure possible encounters with the ball. While developing the design, it should be noted that both mechanical and electrical solutions support each other. To sum up, this project and its solutions may contribute to the areas where teleoperated robots are used for many different purposes.

In this report, a detailed analysis of this project is presented. Detailed problem statements are defined, solution approaches for each subsystem is discussed, team organization, tentative cost-budget analysis and time plan of the project is introduced.

# Description of Individual Subsystems

* **Power Supply Subsystem:** This subsystem is for distribute power towards other subsystems at required voltage level and with specified current limitations.
* **Communication and Telecontroller Subsystem:** This subsystem provides communication between the robot and controller subsystem. This system is used for sending commands and sending the data received by robot and detection subsystem.
* **Motion Subsystem:** This subsystem consists of wheels and motors driving these wheels by which we provide capability of motion to our robot in the game field.
* **Detection Subsystem:** This subsystem detects the boundaries of the field, the position of the opponent robot & the ball. This subsystem also locates itself in the field.
* **Main Processor Subsystem:** This subsystem is the main robot computer onboard which controls other subsystem with respect to feedbacks sent from these subsystems.
* **Shooting Subsystem:** This subsystem is responsible for sending the ball to the opponent’s goal with high precision to score a goal.

# Restatement of the Problem and Requirement Analysis

The goal of this project is to design and construct a teleoperated robot (controlled from a distance up to at least 30 meters) which can compete with a similar robot in shooting and scoring to opponent’s goal. This part is restatement of the problem and requirement analysis. We already state the problem for proposal report. This is the updated version of the previous statement and requirement analysis. Functional, physical and performance requirements of the project are as follows:

## Functional requirements:

* Detect the start signal
* Monitor the surrounding
* Process the monitored data
* Encode the processed data for communication
* Transfer the encoded data to the teleoperator

*If the ball is at players half-field and far away from the robot:*

* Transfer the movement direction command given by the teleoperator, to move toward the ball
* Perform the move operation respect to the command transferred from teleoperator
* Move robot to the ball until ball is in the shooting range
* Transfer the hit the ball command given by the teleoperator
* Perform the hit the ball operation given by teleoperator

*If the ball is at opponent’s half-field:*

* Transfer the movement direction command given by the teleoperator, to cover the goal, given by the teleoperator
* Perform the move operation respect to the command transferred from teleoperator
* Move robot to the own goal to protect it from the incoming shoot
* Protect the goal respect to the commands from teleoperator

## Physical requirements:

* Goals must be at least twice as wide as their defenders’ lateral dimensions.
* Robots can hit, push or otherwise drive the ball but not grasp, scoop or otherwise carry it. So, robot cannot have a grasping or scooping part.
* The playfield also has some physical requirements:
* The playfield should be regular hexagon on a bare floor, with center-line and goal lines marked by “masking tape”.
* The playfield constructed from 6 sidewalls of 70-75 cm length each and two goals snugly fit at the opposite corners, while preserving symmetry.
* The robot should fit in a cylinder to measure the maximum dimension.
* In order to move fast enough our motors should carry the weight of the remaining parts.
* Weight should be aligned in center for steady and controllable movement.

## Performance requirements:

* Ball should be transferred to opponent’s half-field in no more than 20 seconds from the project description. For our team for successful operation it should be less than 15 in order not to have any unforeseen violations. So, consistency of operation in this case is important. It should transfer the ball to the opponent field less than 15 seconds at least 55% of the time and other times it should be less than 20 seconds because of project description.
* The operator remotely controls the robot from a distance up to at least 30 meters.
* The transmission between the robot and receiver should be less than 1 second for successful operation. So, less than 4 points for transmission delay objective is unacceptable.
* In order to have successful operation aiming precision of the robot should not be less than 45%. So, less than 4 points for precision objective is unacceptable for our company.
* The robot’s throwing mechanism should be strong enough to throw the ball to opposing goal.
* The robot’s structure should not be affected by hitting the ball fast to the robot, so, durability of the robot cannot take less than 4 points.

**Constraints:**

* The robot is not allowed to cross the center-line
* The ball must be transferred to the opponents half field no more than 20 seconds
* The communication between robot and teleoperator must happen from a distance at least 30 meters
* Carrying, grasping and scooping the ball is not allowed. Robot can only hit or push the ball.

Objectives, metrics and related objective trees are given in the next section of this report.

## Metrics

**Budget:** Money which is considered to be spent in order to develop and produce the final project.

In metrics, 10 points will be given for budget considered to be less than 200$, 8 points will be given for budget considered to be between 200$-250$, and 6 points for the budget between 250$-300$, 4 points for 300$-350$, 2 points for 350$-400$ and no points for budget 400$+.

**Fun:** Measure of how much each shareholder enjoyed from performing tasks required to complete the project.

In metrics, 2 points will be given for each shareholder who would enjoy.

**Performance:** Parameters which are considered as important. These can be investigated in three sub-categories:

**Durability:** Robots ability to preserve its structure and function against external impacts and wear down.

In metrics, 10 points for preserving its structure against the effects caused by collision to wall with a speed of 1m/s and no points for not preserving its structure against the effects of collision to the wall with a speed under 0.1m/s. The points between is distributed linearly with respect to speed.

**Consistency:** Robot’s ability to execute the same performance under different conditions (starting position, ambient lighting, ambient temperature) using the same line of commands.

In metrics, 10 points for similarity of behavior over 95%, 8 points for similarity of behavior between 85%-95%, 6 points for similarity of behavior between 75%-85%, 4 points for similarity of behavior between 65%-75%, 2 points for similarity of behavior between 55%-65% and no points for similarity of behavior under 55%.

**Power Consumption**: How long the robot would last on same battery capacity of 1750mAh.

In metrics, 10 points for operation over 2 hours, no points for operation under 20 minutes. The points between will be distributed linearly.

**Transmission Delay:** Measure of how many second delay of the transmission will the solution have.

In metrics, 10 points for operation less than 100ms delay, 8 points for 400ms delay, 6 points for 700ms delay, 4 points for 1s delay, and more than that will be failure.

**Creativity**: Measure of how many different solution approaches can be proposed.

In metrics, 2 points will be given for each proposed solution and 1 point will be given for each proposed sub-solution.

**Precision**: Measure of how accurate robot will aim the opponent’s goal.

In metrics, 10 points for more than 90% precision, 8 points for precision rate between 90%-75%, 6 points for precision rate between 75%-60%, 4 points for precision rate between 60%-45%, the other points will be given accordingly. Less than 4 points is a failure because of our performance requirement.

Table 1: Pairwise comparison chart for top objectives

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Budget** | **Performance** | **Fun** | **Creativity** | **Precision** | **Total** | **Weighted** |
| **Budget** | - | 0 | 0 | 1/2 | 0 | 0,5 | 0,05 |
| **Performance** | 1 | - | 1/2 | 1 | 1 | 3,5 | 0,35 |
| **Fun** | 1 | 1/2 | - | 1 | 1/2 | 3,0 | 0,30 |
| **Creativity** | 1/2 | 0 | 0 | - | 0 | 0,5 | 0,05 |
| **Precision** | 1 | 0 | 1/2 | 1 | - | 2,5 | 0,25 |

Table 2: Pairwise comparison chart for performance objective

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Durability** | **Consistency** | **Power Consumption** | **Transmission**  **Delay** | Total | Add 1 | Weigthed |
| **Durability** | - | 1/2 | 1 | 0 | 1,5 | 2,5 | 0,25 |
| **Consistency** | 1/2 | - | 1 | 1/2 | 2,0 | 3,0 | 0,30 |
| **Power Consumption** | 0 | 0 | - | 0 | 0 | 1 | 0,10 |
| **Transmission**  **Delay** | 1 | 1/2 | 1 | - | 2,5 | 3,5 | 0,35 |



Figure 1: Weighted objective tree for device trying to score in each other's goal

# Solution for Subsystems

## Power Supply Subsystem

The one thing to remember about battery selection is that there is no such thing as a perfect battery that works for every application. Selecting the right battery for our application is about identifying the most important battery metrics and trading these off against others.

For this selection, we use the comparisons in Figure x.



Figure 1:Quick Guide for Common Battery Chemistries [1]

Lithium is the lightest metal in the periodic table and has a specific capacity of 3860 mAh/g. Lithium also has an electrochemical reduction potential of 3.045 V against 1.22 V for NiMH (i.e a lithium-based battery provides a battery voltage of 3 V or greater). Some of them can be seen in Figure x+1. The combination of these two properties results in very high energy densities for lithium-based batteries. [4]



Figure 2: Graph of one cell voltage capacity [2]

Li-Po batteries are lightweight, can be produced in desired size, have high capacity and power, also have fast charging and discharging features provides us to choose the Li-po battery.

We decided to use Li-Po to drive motor, but we decided to use powerbank for controllers (arduino, raspberry). Because they have to drive with 5V. For this reason, we can also use a voltage regulator with a Li-Po battery for controllers as a backup plan.

After deciding to use Li-Po, the next step was to choose which type of Li-Po should be used. Since we need 12V, we decided to use "3S" (3 \* 3.7V = 11.1V. In Figure x, the one Li-Po cell can be seen.



Figure 3: Example of 3 cells Li-Po Pack [3]

The power sources that we should use in the project can be seen below.

**Robot Part:**  Drone Transmitter LiPo – 12V

2 DC motors for movement LiPo – 12V

1 DC motor for shooting LiPo – 12V

Arduino Mega Powerbank – 5V

Radio Li-ion (inside itself)

**Controller Part:** Drone Receiver LiPo – 12V

Raspberry Pi 3 Powerbank – 5V

### Level Risks Assessment

There are few risks of using the above-mentioned processors.

* The first risk is these systems heats a lot which can create a risk for other parts of the system.
* Power supplies are one of the heaviest part of our whole system, so they can create alignment problems and cause immobilize.

### Error Sources

Some internal and external sources can cause an error at this subsystem. The possible error sources are as follows:

* Environmental temperature conditions can be a source of error. To eliminate this effect fan can be used or power is drawing can be reduced.

## Main Processor Subsystem

Processor subsystem consists all the processors in different subsystem.

### Solution and Relevant Algorithms:

A processor is needed to identify the command and give an output respectively. We have already tried different processors for this task. At first, we tried TIVA Board for identifying the frequency. It worked but with TIVA board we needed another module of PWM converter. So, we search for different and easier ways to identify a signal. For the demonstration we used Arduino MEGA. For a cheaper option we also tried Arduino UNO but for demonstration it failed to give enough current for our system.

#### Plan A

Our main plan for main processor subsystem is to use Arduino Mega. Figure 1-2 below shows an Arduino Mega and its specifications.



Figure 1: Arduino Mega [5]



Figure 2: Arduino Mega specifications [5]

Our main plan is to use Arduino Mega for main processor subsystem it is chosen because it has better DC current than UNO. Also, Arduino has a variety of online sources that are easily reachable which makes it easier to use from alternatives like TIVA. The Figure below shows the code for code for receiving sine input and identify the frequency, then output from different GPIO pins.





Figure 3: Code for GPIO control of Arduino

From the Figure 3 above it can be seen that it is easy to program Arduino. This code both reads the input and give output from different ports. Output of this system will be connected to the motors of motion subsystem.

#### Plan B

Our plan B for this subsystem is to use another processor for example TIVA board, Arduino Uno or Raspberry Pi can be used for this purpose. All of these have different advantages and disadvantages. These are going to be covered in 3.4 Comparative Analysis section. TIVA board has already been tried for frequency control and outputting. Arduino UNO works with the same principle as Arduino Mega there is no need to change the code above in Figure 3. In addition to that Raspberry Pi also has GPIO ports that can be used for this purpose but it is not as efficient as Arduino Mega.

### Level Risks Assessment

There are few risks of using the above-mentioned processors.

* The first risk is these systems heats a lot which can create a risk for other parts of the system.
* Processors are one of the heaviest part of our whole system, so they can create alignment problems.
* Processors have their built-in fault algorithms which causes them to shut down at unforeseen situations.

### Error Sources

Some internal and external sources can cause an error at this subsystem. The possible error sources are as follows:

* Environmental temperature conditions can be a source of error. To eliminate this effect heat sink or fan can be used.
* Overflow can be an error caused by increasing the current coming to the system. To eliminate this a voltage comparator can be used so that we should be sure that we are not feeding the systems a voltage higher than 3.3V.
* For higher frequencies sampling rate can cause discrepancies. To eliminate this kind of error we are going to work on comparatively lower frequencies.

### Test Results

We conducted a test to find error rate of the Arduino Mega frequency counter. We experimented the frequencies between 0-20kHz. The results in Figure below showed approximately 2% error for these frequencies which is acceptable in many cases.

Figure 4: Frequency vs Error Rate for Arduino Mega frequency counter

### Comparative Analysis

In order to choose our main solution, we compared possible solutions. Comparative analysis can be seen in Table 1 below.

Table 1: Comparative analysis for main processor

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Arduino Mega | TIVA Board | Arduino Uno | Raspberry Pi |
| Price ($) | 38.5 | 14 | 20 | 5-35 |
| Analog compatibility | Yes | No | Yes | No |
| Max DC current(mA) | 50 | 40 | 40 | 40 |
| Weight(g) | 37 | 20 | 25 | 23 |

Even though, Arduino Mega has the worst values for price and weight it can has higher maximum DC current rate and analog compatibility. Analog compatibility and DC current are the most important specifications for selection, so we selected Arduino Mega even though it is the heaviest and priciest option.

## SHOOTING SUBSYSTEM

There are two issues that stand out in this part of the project. The first one is to determine the mechanical design of the shooting part and the other to choose the motor to be used for this shooting. When determining the mechanical design for the shooting system, it was necessary to select the one that would provide the best shooting experience. For this reason, we tried to develop different solutions by making some 3D drawings. The program which is called “Rhinoceros” is used for 3d modeling of the shooting subsystem and “Keyshot” is used to get the end product image of the system.

For shooting mechanical design part, our main solution axonometric perspective can be seen in Figure X.



Figure 1: First shooting subsystem Design Axonometric View

According to our experiences, there should be two angular sticks that are parallel to ground for holding the ball closer to rotational shooting part.

However, the size of the goal in our project will be determined by the size of the widest part of the robot, the decision to use these sticks will be made after the demo matches. Therefore, it was decided not to use the sticks in backup design while keeping the sticks in the main solution.

In the Figure X, the orange ones are representing these sticks. The radius of the ball is 4 cm and it gives reference for the rest of the model. The length of the sticks are 6 cm and the radius of larger cylindrical part is around 20 cm. The yellow parts represent the rotational shooting system.

For better understanding, this design can be examined in two different aspects in Figure X + 1 and Figure X + 2.



Figure 2: First shooting subsystem design front view



Figure 3: First shooting subsystem design side view

For shooting mechanical design part, our backup solution axonometric perspective can be seen in Figure X+3.



Figure 4: Second shooting subsystem design axonometric view

In this design, the part indicated by the blue part comes out of the robot and hits the ball. It is compressed by the spring system inside and then it is released so that the ball is hit.

For this application, it was decided to construct a spring actuated shooting device.

To wind the spring up, a spindle with nut is used. The nut presses against the spring which is thereby compressed. A lock and release mechanism hold the plunger in place and releases it when needed.

The time needed for the winding of the spring is the most important problem for this design. Therefore, the determination of the spring type and maximum force of the motor will be the most important stages.

For better understanding, this design can be examined in two different aspects in Figure X + 4 and Figure X + 5.



Figure 5: Second shooting subsystem design side view



Figure 6: Second shooting subsystem design top view

For choosing the motor of shooting system is the second topic for shooting system. There can be 3 motor types to use in shooting part and main solution is usage of DC motors for that.

DC motors are the most widely used engines in robotics. Also, the DC motors have magnets instead of the coils in the stepper motors. The DC motors are available in a variety of versions with or without gearbox, which have different operating voltages and rpm values. Speed control of DC motors can be done with pwm. DC motors are cheap, small and effective. Also, the wide variety of sizes, shapes and power is another reason for the frequent use of DC motors. For these reasons, they are ideal motors for using as a shooting part motor.

Also, the usage of Step Motor is our second solution. Stepper motors are electric motors which are surrounded by a magnet or a metal rotor and a coil that creates an inductance of voltage by creating an electromagnetic field effect. They are also suitable for sensitive applications such as robot arm applications and laboratory robots. However, areas of use are narrowed due to the heavy weigh, high current draws, low torque and difficulty in assembling in robotics. Hence, this type of motor will remain as our backup plan.

The usage of Servo Motor is our third solution for shooting system. Servo motors are very used in robot operations, especially since they are very easy to control and do not require any control circuitry. Although servo motors have advantageous features such as easy control and installation, compatibility with robot projects and having their own gearbox; they are not as popular as dc motors due to their costly, low torque and ineffective speed controls.

### Level Risks Assessment

There are few risks of the shooting system.

* This subsystem heats a lot which can create a risk for other parts of the system.
* The command to be given from the controller can be corrupted.

### Error Sources

Some internal and external sources can cause an error at this subsystem. The possible error sources are as follows:

* Environmental temperature conditions can be a source of error. To eliminate this effect heat sink or fan can be used.
* Overflow can be an error caused by increasing the current coming to the system. To eliminate this a voltage comparator can be used so that we should be sure that we are not feeding the systems a voltage higher than 12V.
* Wrong command can be the problem for shooting system. To eliminate this, we can use more accurate signals.

# Total Power Consumption

In the development of battery powered projects, development of the robot part in our case, power analysis is one of the crucial step. Since the batteries are the only power source robot has, to ensure proper operation of robot for a predetermined time the power analysis must be done carefully.

In the total power consumption calculation of the system, we considered the worst-case scenario of each design element separately. Despite, this analysis method overestimates the power consumption, it creates a safety margin for us. In the case all the systems are active and at their full power, our system is going to be still fully functional. The power analysis of robot and telecontroller can be observed respectively in TABLE 1 and TABLE 2.

Table 1: Power analysis of Robot

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Device | Quantity | Maximum Values per Device | | | Total Device Power |
| Current | Voltage | Power |
| DC Motor | 2 | 300 mA | 12 V | 3.6 W | 7.2 W |
| Drone Transmitter | 1 | 100 mA | 12 V | 1.2 W | 1.2 W |
| Shooting DC Motor | 1 | 200 mA | 12 V | 2.4 W | 2.4 W |
| IR Proximity Sensors | 1 | 45 mA | 5 V | 225 mW | 0.225 W |
| Arduino Mega | 1 | 100 mA | 5 V | 500 mW | 0.5 W |
| Total Power |  | | | | **11.5 Watt** |

Table 2: Power analysis of Telecontroller

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Device | Quantity | Maximum Values per Device | | | Total Device Power |
| Current | Voltage | Power |
| Drone Receiver | 1 |  | 12 V |  |  |
| Screen | 1 |  | 12 V |  |  |
| Antenna Driver | 1 | 50 mA | 12 V | 600 mW | 0.6 W |
| Raspberry Pi zero | 1 | 200 mA | 5 V | 1 W | 1 W |
| Total Power |  | | | | **13 Watt** |

# Test Procedure

Test procedure mentioned below consists all the subsystems rather than the ones in demonstration. It can be seen as a User Manual for end user. Test procedure is as follows:

1. All switched should be in off position.
2. Li-po connections for data receiver and robot should be made.
3. Powerbanks should be connected.
4. All switches and powerbanks should be on for now on.
5. At this part we should observe some fan actions on the robot and receiver which are located for cooling purposes.
6. Moreover, video or image data transmission should be visible at this stage if not check the previous steps.
7. From now on robot should be controllable by telecontroller.
8. Start the test procedure when robot and telecontroller at the same place. (Approximately 0 m distance)
9. The buttons on telecontroller should create forward, backward, left and right movements. Also, not decided yet if any, shoot button controls the shooting subsystem.
10. Different combination of pushes will be tried during the process.
11. The steps 9 and 10 will be tried for different distances until the data transmission and command transmission both end.
12. At the end of the process it is necessary to wait at least 30 seconds without pushing any button in order to be sure that all motor activity ended.
13. The robot lifted up and switches should be off from now on.
14. Li-po batteries will be disconnected from the system for safety.

# Plans Management

This section of the conceptual design report consists the plans, breakdowns, foreseeable difficulties and Gantt chart.

## Planned Work

Detailed planned work can be seen in Table x below.

Table 2: Detailed breakdown of planned work

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Irem Coskun | Fatma Nur Arabaci | Aycan Beyenir | Berkay Goksu | Furkan Bahadır Elik |
| Telecontroller and communication subsystem integration |  |  |  |  | Onay işareti |
| Motion Subsystem integration | Onay işareti | Onay işareti |  |  |  |
| Processor and signal receiving module implementation | Onay işareti |  | Onay işareti |  |  |
| Detection algorithm verification and optimization |  |  | Onay işareti | Onay işareti |  |
| Power system implementation to other subsystems |  |  |  | Onay işareti | Onay işareti |
| Testing of individual subsystem integrated modules | Onay işareti | Onay işareti | Onay işareti | Onay işareti | Onay işareti |
| Bringing subsystems together |  | Onay işareti | Onay işareti |  |  |
| System Verification | Onay işareti |  |  | Onay işareti |  |
| Optimization for motion system |  | Onay işareti |  |  |  |
| Optimization for telecontroller |  |  |  |  | Onay işareti |
| Testing at different environment | Onay işareti | Onay işareti | Onay işareti | Onay işareti | Onay işareti |
| Final verification of systems | Onay işareti | Onay işareti | Onay işareti | Onay işareti | Onay işareti |

## Gantt Chart

+



Figure : Gantt Chart

## Foreseeable Problems and Solutions

In the implementation process of an engineering project, facing with problems and difficulties is something expected. The theoretical solutions not always work as expected in practical applications. As a newly formed company we are aware that, in order to develop a robust system, it is necessary for us to consider all the possible problems will harm the operation of system and come up with solutions to handle them. In this part we investigate foreseeable difficulties and problem sources we will face and propose their possible solutions. For the sake of clarity, we stated these possible problems and solutions in four subgroups.

### Communication problems

* There might be a high level of noise in the communication band, which will decrease the quality of transferred data.
* The range of the communication dependents on the environment condition, and the maximum range might vary under different environment.
* The communication band might be used by another robot or local user, which causes both signals to mix-up and makes it impossible to communicate with robot.

Our communication system is designed to work on different channels. In case of any unexpected intrude to our communication band, we can maintain our communication with robot by changing the band. To withstand various environmental conditions the power of communication system is adjusted to cope with worst scenario.

### Mechanical problems

* The movement of the robot might not be precision enough. This will make the control of the robot harder.
* The motors of the robot would not be fast enough and that will end up with time violation in attack and weakness in defense.
* If the force applied to the ball in the shooting is not well calibrated, it will decrease our control over the ball and decrease our chance to score.
* The weight of robot will deform the framing of the robot.
* If the sensitive parts and connections take hit from ball, they will be malfunction or lost connection.

To protect the robot from impacts, we add a protective shield covering the robot and all connections are going to be soldered. To increase precision of operation, feedback connections and algorithms will be integrated to system. The choice of motors and other mechanical parts will be done with additional safety margin.

### Field vision problems

* Due to the limitation of visual angle of sensors, all elements on the field will not be visible at the same time to the operator.
* Location of sensors will create some blind spots around the robot.

To extend the field coverage some sensors will be attached to moving parts. Some of proposed visual systems can be used together to benefit from strengths of each.

### Electrical problems

* Under continuous operation batteries, motors, development boards might overheat.
* Rapid changes in the current can cause voltage spikes, which will harm voltage sensitive elements such as ICs and sensors.

Heat sinks and fans are going to added to heat sources. Voltage protection circuits will be added in the supply of sensitive elements.

## Future Test Plans and Measure of Success for Subsystems

To verify the overall operation of the robot, the subsystems must be verified first. To measure the performance of subsystems, we prepared future test plans and measure of success for subsystems.

### Communication and Telecontroller Subsystem

* Robot to Telecontroller Range Test: The quality of sent data is measured for every 5 meters, starting from 10 meters. In indoor conditions if more than 60% of the visual data transferred to the telecontroller, then at this step the communication test is satisfied. The range more than 30 meter is satisfactory, and more than 40 meters is perfect score.
* Robot to Telecontroller Delay Test: At 30-meter indoor range the delay of the video input is measured. Between robot and telecontroller, delay less than 0.2 sec is satisfactory and less than 0.1 sec is perfect score.
* Robot to Telecontroller Data Quality Test: At 30-meter indoor range the quality of the video input is measured. Between robot and telecontroller, transfer of more than 60% of visual data is satisfactory and 80% is perfect score.
* Telecontroller to Robot Range Test: The quality of sent data is measured for every 5 meters, starting from 10 meters. In indoor conditions if more than 90% of the commands transferred to the robot, then at this step the communication test is satisfied. The range more than 30 meter is satisfactory, and more than 40 meters is perfect score.
* Telecontroller to Robot Delay Test: At 30-meter indoor range the delay of the commands is measured. Between robot and telecontroller, delay less than 0.2 sec is satisfactory and less than 0.1 sec is perfect score.
* Telecontroller to Robot Data Quality Test: At 30-meter indoor range the quality of the commands is measured. Between robot and telecontroller, transfer of more than 80% of commands is satisfactory and 90% is perfect score.

### Motion Subsystem

All the motion subsystem tests are done with a fixed environment. For the test the telecontroller is located 2 meters across the robot since performance of communication module is not our concern in this test.

* Straight movement precision test: Under forward and backward movement instructions the distances robot traveled are measured and these measurements are compared with expected values. The 20% or less error is satisfactory and less than %5 error is perfect score.
* Straight movement speed test: For the forward and backward direction movement, speed of the robot is measured, and these measurements are compared with expected values. The 30% or less error is satisfactory and less than %15 error is perfect score.
* Fixed center rotation test: The robots ability to fixed center rotation is measured. For a 180° turn the robot expected to preserve its center at same spot. Dislocation less than 5cm is satisfactory and 1 cm is perfect score.
* Rotation precision test: Under fixed center clockwise and counterclockwise rotation instructions the rotation angle of robot is measured, and these measurements are compared with expected values. The 20% or less error is satisfactory and less than %5 error is perfect score.
* Rotation speed test: For the fixed center clockwise and counterclockwise rotation, angular speed of the robot is measured, and these measurements are compared with expected values. The 30% or less error is satisfactory and less than %15 error is perfect score.

### Shooting subsystem

All the shooting subsystem tests are done with a fixed environment. For the test the telecontroller is located 2 meters across the robot since performance of communication module is not our concern in this test. The ball is located 1cm front of the shooting subsystem with 60° - 90° - 120° angle with central plane of robot.

* Shooting direction test: For 10 successive tests, number of shots going in opponent’s goal is counted. More than 7 successful shot is satisfactory and more than 9 successful shot is perfect score.
* Shooting force precision test: For 10 successive tests, the distance ball travels is measured. The measurement and expected data is compared. Error less than 40% is satisfactory and less than 20% is perfect score.

### Detection Subsystem

All the detection subsystem tests are done with a fixed environment. For the test the telecontroller is located 5 meters across the robot since performance of communication module is not our concern in this test.

* Data quality: For 10 second of data transmission, the ratio of successful visual data transfer is measured. If all the important elements are visible, the test is successful.
* Data frame rate: For 20 seconds of data transmission, the frame rate is measured. Frame rate higher than 10fps is satisfactory and 20 fps is perfect score.

**Power Subsystem**

Power subsystem test are run separately on robot and telecontroller. For both the measure of success is same.

* No operation battery life test: When all units are on and under no operation condition the duration of batteries are measured. If the battery stays longer than 3 hour it is satisfactory, if stays longer than 5 hour it is perfect score.
* Active operation battery life test: When all units are on and under control of teleoperator the duration of batteries are measured. If the battery stays longer than 1 hour it is satisfactory, if stays longer than 1.5 hour it is perfect score.

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