Concept Generation and Selection Document

ECEN 490 Robot Soccer

Team Botnet

Yazan Halawa
Adam Hastings
Brian Russell
Josh Powell

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Introduction

The goal of the Robot Soccer team project is to develop two autonomous robots that will play as a team in a robot soccer competition. This document describes the design process used by team Botnet. It will address several key design decisions and the key considerations involved in each area. It will also detail chosen design solutions.

Process Description

For each critical design area, we used our functional specifications and customer needs documentation to establish a set of criteria. We then used these criteria to evaluate various possible design specifications. By applying our criteria to each proposed design, we were able to score options and determine which would best address our needs.

Using this data, we generated a scoring matrix. By applying the matrix to a decision table, we were able to visually show which criteria should be used, what baseline it satisfies, and the pros and cons of each alternative. Using this methodology, we were able to effectively select and defend our reasons for each decision. Specific decisions and the reasons for them are detailed below.

Body of Facts

Overview of Facts and Assumptions of Competition

- Build a pair of competitive autonomous robots
- State of play will be determined by video processing from overhead camera
- Controls will run in real-time using PID loop
- Robots will not communicate directly with one another

- Soccer Field will be 10’ x 15’, with a smooth, non obstructive surface
- Robot dimensions less than 8" diameter x 10" height
- Goals 2ft wide
- Field layout similar to that of actual soccer field

- Robots will be allowed to kick the ball so that it becomes airborne.
- Control the ball without glue, tape or other adhesives.
- No human interaction is allowed after the initial setup.

- The ODROID-U3 will be able to run Linux and ROS effectively.
- All provided hardware will function according to specs
- The $50 of funding we have for the robot will be sufficient to fund the project fully.
- The power provided by the batteries is enough to run all peripheral components as well as the ODROID for the duration of an active game.

Rules:

1. Robot must fit in an 8 inch diameter can.
2. Robot must not trap the ball. Ball must be approx. 70% visible from all angles.
3. Robots may not be remote controlled.
4. Robots may not hit into or damage other robots.
5. Basic soccer gameplay will be followed

Materials (per robot):

1. 2x Nickel Cadmium Batteries 7.2V
2. 2x Roboclaw to drive the motors 5A
3. 5V voltage regulator
4. 12V voltage limiter
5. 3x motors

6. ODroid U3 Board – Ubuntu 14.04
7. 3x wheels
8. Wireless Transmitter

Basic Form:

1. 3 Wheels
2. Body of Aluminum, Plexiglass, or 3D printed
3. Must wear “jersey” for purposes of Image Processing

Movement:

1. Controlled by powerful overhead computer with low latency web cam. Image delay approx. 15ms. Position determined by overhead camera – Error introduced by angle.
2. Each wheel will have 1 motor. Two of the wheels will be controlled by the same “roboclaw”, the other wheel will have a dedicated roboclaw.
3. Use PID controller to control robot movements.
4. Using equally spaced and angled wheels robot should move in any direction .
5. Unequally spaced wheel design could make a robot move faster in one direction, but turn slower. This would lead to the robot having a front.
6. Need for a calibration script to correct for physical differences

Strategy:

1. Basic Plays – Blocking, Rushing, Matching
2. Positions – Offense / Defense

Tools:

1. Simulink – Simulator

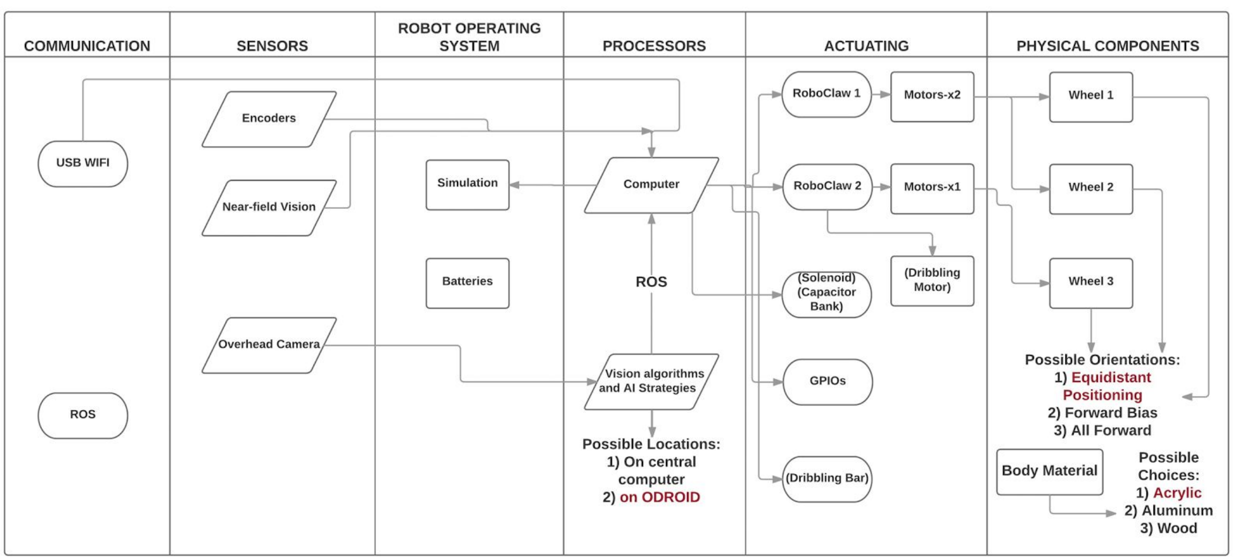
2. OpenCV
3. ROS – Robot Operating System

Necessary Assumptions to Evaluate:

Within the project requirements there are several different design implementations that must be evaluated and chosen. These elements of design will be key factors in differentiating team BotNet from other robot soccer teams. Key areas that our design will address are the following:

1. Vision Algorithm and AI Strategies Placement
2. Wheel Positioning and Alignment
3. Body Design and Material

Proposed Solutions



This block Diagram shows the various components in our system and how they interact with each other. Furthermore, it shows the various alternatives considered for the code placement, wheel orientation, and body material choice. The alternatives colored in red are the choices we settled on for our design. The analysis of those alternatives and the reasons we picked those choices is elaborated in the Critical Design Areas Section of this document.

Critical Design Areas

Vision Algorithm and AI Strategies Placement

In order to have a competitive robot, we need to have the best code organization and placement that maximizes efficiency and reduces delay.

We considered two locations where our code can be placed. Each one presents unique advantages and disadvantages:

1. We can have the code be placed on the central computer.
    - All the processing and heavy work is done on the central computer.
    - The final low level commands to the motors are communicated to the ODROID using ROS.
2. We can have the code be placed on the ODROID.
    - All the analysis and heavy work is done on the ODROID
    - The only thing that needs to be communicated from the central computer to the ODROID is the data acquired from the camera.

These are the criteria we used to judge each option:

1. Latency:
    - This is the delay from the moment the camera captures the frame till the robot reacts to the current situation.
    - It is weighted at 50% because this is crucial for our robot to respond to its environment and play adequately.

2. Reliability:
    - This is a measure of how our robot can handle unexpected events like the wifi signal dropping.
    - It is weighted at 30% because if such an event happens our robot has to be able to recover and not crash.
3. Organization
    - This is a measure of how efficient our code organization. The code has to be modularized with minimum number of dependencies.
    - It is weighted at 20% because while it is important for efficiency, it not as crucial to the operation of the robot as the other factors are.

Concept Scoring	Weighted Value	ODROID		Central Computer	
		Score	WT	Score	WT
Latency	50	7	350	7	350
Reliability	30	8	240	5	150
Organization	20	6	120	8	160
Total	100	710		660	

First, we scored the ODROID choice. Starting with latency, we realize there is a delay between the time the camera grabs the frame and the time we send it to the ODROID on ROS. This depends on the speed on the wifi signal and how fast we are grabbing frames from the camera. Once that is done the analysis happens really fast on the ODROID chip and that delay is basically negligible. So we scored it at a 7. Next, we scored reliability at an 8. This is one of the huge advantages of having the analysis happen on the ODROID. If the wifi signal drops, that won't affect the robot as all the code to figure out the motor controls is on the chip itself. However, it might affect how well the robot responds to changes in its environment. Either way, it won't act unpredictably. Finally for organization, we scored it at a 6. Since the code for analysing the data from the camera and the AI algorithms are in one place, the code is not as modularized as it can be. Multiplying the scores by the individual weights and summing them up the ODROID option scored a total of 710 points.

Second, we scored the central computer choice. For latency, we scored it at a 7 as well since there is going to be delay associated with sending the data over the wifi and the speed at which the analysis happens on the computer is similar to the speed with which it would happen had it been on the ODROID, we figured they score similarly. The difference came in reliability, as we scored it at a 5. This is because we figured if all the AI strategies and analysis code happens on the central computer, then the ODROID will be blind if its connection to the computer was severed. For example, if the wifi signal falls then the ODROID has no way of recovering and it will behave unpredictably. This is why this is a bad choice in this regard. Finally, for organization, we scored it at an 8. We figured since the vision code and the AI strategies are on the computer while the motor control is on the ODROID, the code would be better modularized and the organization would be more efficient. This option scored a total of 660 points.

Finally, we compared the totals for both choices and found that the ODROID choice scored higher. The different is mostly due to the area of reliability, which is why we preferred the code be mostly done on the ODROID. We believe functionality is most important in robots and their ability to recover from failures is very crucial in a constant game of soccer. This is why we chose to go with placing the code on the ODROID.

Body Material

A critical design decision was the body material of the robot. We considered several materials for the body of the robot, including acrylic plastic, aluminum, and wood.

1. Acrylic Plastic
    - a plastic material that is reasonably strong, lightweight, and reasonably durable. Can be cut with a laser cutter
2. Aluminum
    - a metal that can be purchased in sheets. Very strong and durable. Can be cut with a metal bandsaw
3. Wood
    - Any wood-fiber based product, including hardwoods and composites. Can be cut with most saws. Lightweight and durable.

We used a concept scoring and screening matrix to determine which material to use for the body of the robot. These are the following criteria we used to evaluate the different options:

1. Strength
    - This category accounts for how well the material will hold up to the wear and tear of playing soccer.
    - It is weighted at 30% because we don’t have the time or resources to constantly be repairing our robot.
2. Weight
    - This category describes the weight of the material. How much will the body shell weigh down the robot?
    - It is weighted at 40%, because the lightness will help determine the agility of our robot.
3. Workability
    - How easy is it to work with the material? Can it be cut and shaped with standard tools? How easy is it to make changes to it?
    - It is weighted at 20%, because the workability of the material will can help cut time spent constructing the body, and time is a precious resource.

4. Cost
    - How much will this material cost us?
    - It is weighted at 5%, because we have a generous but finite budget to work with.
5. Aesthetics
    - Will this material make our robot look cool? We want our robot to be visually impressive in addition to functionally impressive.
    - It is weighted at 5%, because aesthetics can improve the perception of our robot, but are also not our top priority.

Once we had identified the options and judging criteria, we created a scoring matrix:

Concept Scoring	Weighted Value	Acrylic		Aluminum		Wood	
		Score	WT	Score	WT	WT	WT
Strength	30	7	210	10	300	5	150
Weight	40	8	320	5	200	9	360
Workability	20	9	180	4	80	10	200
Cost	5	7	35	6	30	7	35
Aesthetics	5	8	40	7	35	5	25
Total	100	785		645		770	

We first scored the acrylic. Acrylic is a fairly durable plastic, so we scored its strength a 7. It is also a lightweight material, so we scored its weight an 8. Furthermore, acrylic is very easy to cut, drill, bend, and shape, and can also be laser cut. This gives it great workability, so we scored it at 9. It is cheap (~$5/sq ft), so its cost is a 7. Lastly, acrylic comes in many different colors, so its aesthetics was scored an 8. This gave acrylic a total score of 785.

Secondly we scored aluminum. Aluminum is a strong and durable metal, and will not break if stepped on, unlike acrylic or wood. We therefore determined that it was the strongest material available in our price range, so we scored it a 10. However, as a metal, it is dense and heavy (although lighter than other metals), so we scored it a 5. Furthermore, aluminum must be cut using a metal bandsaw, and can only be drilled with special drill bits, making workability low - because of this we scored it a 4. However, it is generally pretty cheap (~$3.50/sq ft) so we gave its cost a 6. Lastly, metal has an industrial aesthetics, so we scored it a 7. These scores for aluminum summed up to a final score of 645

The last material we considered was wood. Wood is fairly durable, but can degrade over time, so we scored its strength a 5. However, it is very lightweight, so its weight was given a 9. Wood is also very easy to saw, drill, and sand down, and so its workability was given the highest possible score of 10. It is fairly cheap, so its cost was given a 7. Lastly, wooden materials don't seem to fit with the futuristic aesthetic of robotics, so its score was given a 5. This led to a combined score of 770.

The highlighted orange column identifies acrylic plastic as having the highest score, and this is the material we have chosen to construct our robot with. It is interesting to note that acrylic did not score highest for any of the most significant categories (weight > 5). In fact,The only category that acrylic won was aesthetics. Further analysis reveals that acrylic plastic scored the highest because it was the most consistent - while it didn't win any significant field, it also didn't have any major drawbacks. These factors led us to use acrylic for the body of our robot.

Wheel Positioning

We considered three different wheel placements for our robot. trade offs of the different arrangements included ability to move in any direction, max speed in a single direction, ability to spin, and compliance with pre-existing resources.

1. Equidistant positioning
   - All three wheels are equal distances from each other. This positioning allows the most even speed in all direction, and has best spin capabilities.
2. All forward
   - All wheels are parallel to the forward direction. Allowing for the fastest speed in any single direction, but also only has the one direction of travel. Has worst spin.
3. Forward Bias
   - The wheels form an isosceles triangle shape, and the two forward wheels are closer but not yet parallel to the forward direction. This is a hybrid of the other two options.

While discussing the needs of our robot and assigning corresponding metrics, we discovered many of our top needs were directly influenced by the wheel positioning. Such needs included ability to efficiently react to the environment, prevent ball from entering goal, move quickly in a single direction, as well as in many directions. These needs were linked to metrics such as time for robot to move from one side of goal to the other and top speed. This lead to us creating a scoring and screening matrix to decide on the best positioning of our wheels.

Our matrix utilized 4 different scoring criteria. they included:

1. Maneuverability
   - The ability to move in any direction while facing any desired object.

- We weighed it at 40%, because we determined this to be the most important criteria.

2. Max Speed
   - The fastest the robot can go in any single direction
   - It is weighed at 30%, because speed is a major factor in the game of soccer
3. Space and Mass
   - The placement of the wheels directly influences the shape and size of our robot as a whole which have their our repercussions
   - This was given 20% weight, because it is important but less important that the other categories
   - This is important but less important than other categories, so weight = 20
4. Aesthetics
   - Does our wheel positioning make our bot look sharp?
   - It is weighted at 10%, because it is the least important criteria.

Concept Scoring	Weighted Value	Equidistant Positioning		Forward Bias		All Forward	
		Score	WT	Score	WT	Score	WT
Maneuver-ability	40	10	400	5	200	2	80
Max Speed	30	4	120	8	240	10	300
Space and mass	20	6	120	7	140	5	100
Aesthetics	10	7	70	6	60	5	50
Total	100	710		640		530	

In the above Matrix we had scoring concepts such as maneuverability, max speed, size implications, and aesthetics. We gave the higher values to the first two criteria.

First, we scored the equidistant positioning. We gave it a perfect 10, because it is very good at going quick in any direction. We gave it a 4 in max speed because it has the wheels spaced and angled evenly, which means for reasonable wheel posistioning it has the slowest maximum speed. It received a 6 in space because the distancing of the wheels allowed a significant amount of other components to be placed besides the wheels. Lastly we gave aesthetics a 7, because of its charming good looks. Bringing the total points to 710.

Second, we scored the forward bias positioning. We gave it a 5, because side movement and spinning slowed by close to 30% when biasing the wheels towards the forward speed positioning. We gave it a 8 in max speed because speed in the forward direction increased significantly with two wheels angled closer to being parallel with the forward direction. It received a 7 in space because the distancing of the wheels also allowed other components to be placed besides the wheels, and it gave us the option of reducing the width making it the weight less. Lastly we gave aesthetics a 6, because we liked how it would look. Bringing the total points to 640.

Third, we scored the all forward positioning. We gave it a 2, because side movement and spinning slowed by close to 45% from the equidistant positioning. We gave it a 10 in max speed because the wheels are positioned to all be parallel with the forward direction maximizing possible forward speed. It received a 5 in space because the distancing of the wheels didn’t allow components to be placed besides the wheels, but it gave us the option of reducing the width making it light. Lastly we gave aesthetics a 5, because it looked okay.Bringing the total points to 530.

After completing the matrix it was apparent that the equidistant approach was the best fit. It was by far the most Maneuverable. This was important not only because it permitted easy movement to any desired position but to do so while keeping the side of the Robot with the ball kicker pointed at a desired object simultaneously. It would also have decent max speed, along with providing good spacing opportunities for the robot design and a nice look.

Other Design Areas

Robot Layout

The only constraint that we need to meet is fitting in the specified robot dimensions. As long as this metric is met, the internal organization of the robot can vary.

The design of the robot will be a “sandwich”. That is, it will be partitioned into layers that house different parts. The bottom layer will contain the motors, wheels, roboclaws, ODroid, and kicker. The top layer will house the batteries, voltage regulator, and compressed air cartridge. The layouts for the robot will be designed in Adobe Illustrator, and manufactured using a laser cutter.

Kicker Design

We have decided to use pressurized air to move our kicker. We decided that this will give us the most force per kick, and will also not drain the battery. The compressed CO_2 cartridge will be on the top layer of the robot, which will allow easy access and easy replacement of air cartridges.

Programming Languages

In choosing programming languages we gave preference to choosing a language based on the resources we had available as examples. This meant a trade off in ease of communication between different software components, and speed of code execution.

As our motion control code was done in python, we had to write some of our ROS nodes in python to interface easily with the motor commands. However since our vision code was mostly done in c++, we also had to write the ROS nodes that deal with vision stuff in c++. We could have streamlined the whole code to be in one language, but that would have made it much harder to interface all the components. This is why we opted to use this hybrid model of various languages.

Conclusion

After having considered many aspects of the project , and what designs will best satisfy the customer needs, while remaining within our constraints of engineering and materials, we have made many decisions that will separate team BotNet from the competition. Our light but strong robot body, and efficient design will ensure our robots perform well under the expected play conditions. Our systematic approach to decisions regarding the design shows that we have studied the problems from many perspectives and used the gathered knowledge to create what we anticipate will be a reliable, and highly effective team of robots.