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Developing ball controlling motions to make MiRo robot plays football

COM3610

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Declaration

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Abstract

Since the development of the many types of robots, human beings tried to find many ways about how to use them to in the way it is beneficial to us. Different robots have their own development purposes, some are for researching in various studies and some are for substitute of simple labour and some are for health caring. Nevertheless, sometimes they are being used for other purposes. Football is one of the most popular sports in the human world that played for centuries. The strategies and skills required are very complex and flexible in contrast to the easiness of the accessibility, rules and preparation materials. This is due to many studies to win the game are done to perform the best. Based on these studies, this dynamic sport is chosen as one of the methods to promote robotics and AI research as a form of an annual event called RoboCup since 1996.

The aim of this project is making the MiRo robot, the human interactive robot developed for multi-purposes, plays football. For now, it is not required to follow all the regulations and rules from the RoboCup since this project is very first starting point but the goal in the future is to make the robot capable to compete for one of RoboCup leagues. This project is the group project with every participant takes one task each and this paper is mainly focuses on the designing and implementation of the foundation of ball control, which are walking, dribbling, shooting and passing. The project also shows the experimental data that can be provided for future researches and succeeded to produce results of production and implementations of robust and reliable motions with identified ideal type of ball usage. By the project, it has shown high possibility and availability of MiRo robots are competable in robot football competition.

Acknowledgements

First of all, I would like to thank my supervisor, professor Tony J Prescott, for all the supports and provision of required materials for the project. Although he was really busy person and hard to contact, he provided good feedback and supervision to make this project success. Secondly of all, I would like to thank to my colleagues, He Yucheng and Yu Hok, for the collaboration of the project and working throughout the project with taking different tasks each. Finally, I would like to thanks to everybody who has supported me during the project, with advice and with inspiration. I almost forgot to mention our clever (sometimes stupid) MiRo robots, Jeff and Bobby,who cooperated to us to finish the project successfully without any trouble.

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Chapter 1

Introduction

1.0.1 Background

Robot football

Robots that made to play football are not entirely new in these days. At annual competition called RoboCup which started since 1997, many teams participates and show their development of football robot and sometimes the new technology or implementations are shown. Every team has its unique designs of robots with unique strategies involved. The idea of building such football playing robots was started even before holding those competitions[7] and since the first competition, the scale of the competition and also the researches related to AI grew up explosively.

MiRo robot

From all around the world, various robots are developed and used for certain unique purposes. MiRo robot is one of those unique robot. This biomimetic control architecture embedded mammal-like robot got appearance of dog[8] so that it can be get friendly to humans easily.

The Figure 1.1 and 1,2 show the technical specification of the MiRo robot. The program within the MiRo robot is runs by programming language called 'Python' and 'ROS'. It contains variety of sensors and features. From the Figure 1.1, the sensors that the MiRo robot got are ultra sound sensor, cliff sensor, light sensors, touch sensors, microphones and high resolution camera. Ultra sound sensor positioned in front of the head and measures the distance between itself and object by sending and receiving the reflected ultrasonic waves. The cliff sensor positioned at front-side of body and emits infrared (IR) to detect the cliff and prevents the fall off. Light sensors positioned at both front and back of body and detects the different level of brightness of the environment. Touch sensors positioned at whole upper part of body and head and determines if anything(usually human) touches the robot or not. Microphone positioned at each ear and hear the surrounding sounds. Finally, the high

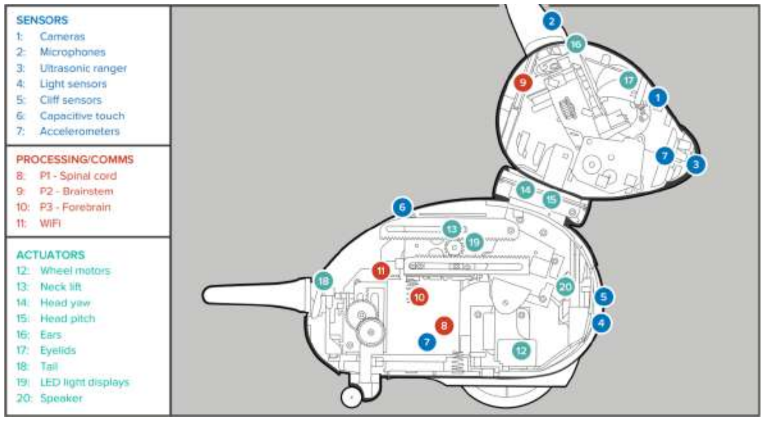


Figure 1.1: Mechanical features of MiRo robot. Reproduced from [1]

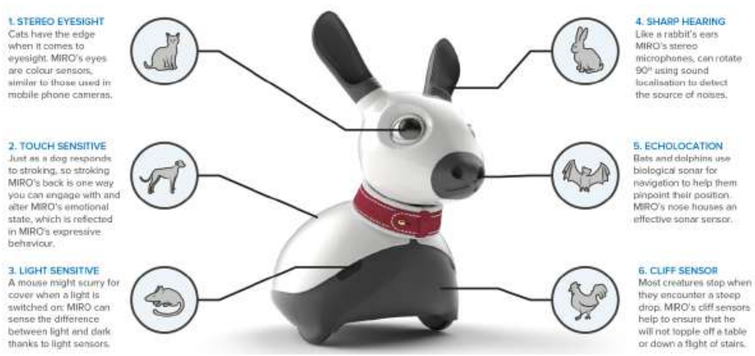


Figure 1.2: The sensors attached to MiRo robot. Reproduced from [1]

resolution cameras positions at eyes and make the robot able to see the world with sensor the colours. From the Figure 1.2, it shows the exact locations of the sensors and actuators. The features of the MiRo robot got are head, body, nose, tail and ears.

1.0.2 Aims and objectives

To make clear, this robot is not developed only to play football, from this how different will the MiRo robot be compared to other football play-purposed robot if we make it play football? This project has started by such idea. The main objective of this project is to make the MiRo robot plays football. There are three main tasks to be solved; The specific tasks are following: The first task is the scene perception. In simple word, how do we make MiRo robot see the world and knows what they are. The football field will be filled with not only the other MiRo robots, but also different types of objectives such as ball, opponent team and goal post. From this restricted area with obstacles, MiRo should make clarify which ones are which. The second task is choice of strategies and plans that MiRo can decide in certain condition or state of environment. Physical aspects are not only required skill to play football, but also strategy is critical as long as the football is a team game. The last task is how we make it controls the ball. With the sensors, MiRO collects data from the environment and the program decides how to behave the motions when certain conditions are met. The suitable usages of actuators in different motions are essential to control ball. This paper will focuses on the ball controlling task, mainly the methods of how the essential motions to play football such as walking, dribbling, kicking and passing are chosen. All the motions are tested with appropriate experiments each to figure out the suitability and finally, they will be applied to resolve some challenges similar to situations that can happen during real football game to judge the outcomes.

1.0.3 Overview

The structure of the report

This report is divided into several chapters. Chapter 2 presents the literature survey, reviewing the researches of relevant knowledge and techniques related to the project. Chapter 3 presents the requirements of the project with different priority and their implications. Chapter 4 contains the final designs for each chosen methods and why they are same or different to initial design with detailed explanations. Chapter 5 shows the actual implementations of those designs and testing their suitability of performances. Chapter 6 evaluates the results from testing and discussion about possible further researches. Finally, Chapter 7 states the conclusion of this paper.

Discussion

This project is very closely related to development project of actual field. It requires understanding of the robotics and AI and problem-solving ability about tasks for each participant and good communication and teamwork to solve the challenge at the end by combining all the participants solutions at the end as a team. This project taught me how to do the risk managing and long term team working very well. The possible challenges will be the technical issue followed by using the robots that are not developed by ourselves.

Chapter 2

Literature survey

When study about the robot football topic, many pieces of research were focused on humanoids or wheeled robot that specifically built and designed to perform robot football. The most famaliar robot get was make the AIBO robot, another dog appearance robot made by SONY that developed until 2006, play football, however, does not have exact same features as MiRo. The MiRo is originally built with the purpose of a composition of an animal-behaving robot at a cheaper cost, which means making it play football was not one of the considerations. However, from reviewing some of the works of literature related to robot football, we could still find some useful approaches. Those approaches were including both what could be done and what should not be done when developing the MiRo to play football.

2.1 Existing types of football robots

Since the start of development of the football robot, a variety of designs and features are developed. According to the RoboCup, they separated the league into 4 categories (four with physical robot football league and one with simulation league). They have set size and mass limits of the robots for each league. This means there exist different challenges depends on categories and therefore the solutions or approaches are different. Humanoid and standard platform categories was especially had a close look at. Any literature related to RoboCup simulation leagues were excluded in our literature review since simulation is non-physical area whereas this report mainly covers the physical control systems.

2.1.1 Control system

Control system is the control loops that regulate other devices or systems behaviours and able to take over their characteristics and /or behaviours. It is divided in into two major categories; the open-loop control systems and the closed-loop control systems. The major difference is the output of the open-loop control system does not affect on actual conditions encountered since the control action is independent of system output, whereas the output of the closed-loop control system will be actually measured and compared with input over the loop and it gets feedback until it reaches close to the desired response. [2]

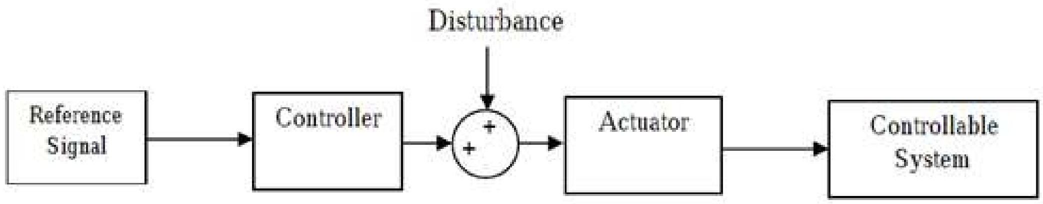


Figure 2.1: Open loop control system[2]

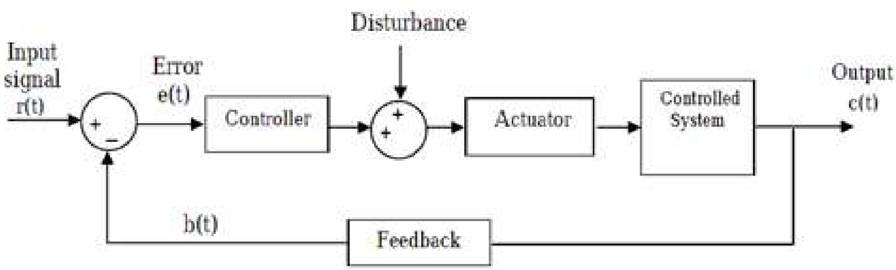


Figure 2.2: Open loop control system[2]

Most of the robot control systems chose the robust closed-loop control system. The researchers get the inputs from the environment by the sensors and improve the output with the feedbacks over the loops of error corrections until the loop outputs satisfactory result. This is because although the open-loop system is an easy and inexpensive system, it is unstable due to the lack of reducing instability. The robot controls have to be very accurate and precise and need to be improved over the actions, so the open-loop control system is not a suitable system to meet their objectives. The challenge of using the closed-loop control system is how to not make the system unstable caused by its high complexity.

2.1.2 Humanoid

The history of development of humanoid is very long. The early design of humanoid was out from middle age by Leonardo da Vinci and modern typed humanoid, which digitally controlled, is built in 1970 at Waseda University [9].

Figure 2.3: Different design of humanoid robots. Reproduced from https://www.robocuphumanoid.org/league/history/.[3]

The humanoid league in RoboCup was first started since 2002, the youngest league within RoboCup. For those time due to lack of processing power, they only had to demonstrate few demonstrations such as balancing on one leg, penalty kick and freestyled. The actual soccer game was available since 2005 with improved robustness and walking performances and better team plays and strategies were built since 2008[3]. The main challenges of controlling issue for humanoids in the early stage were the balancing and coordination of the robot during any kinds of action performance and to solve them, different types of control algorithms are built.

Kinetic control

Kinetic chain is the chain that represents the combination of arranged joints forming the complex motor unit as tree structure[10]. From the base, usually the hip or the torso in skeletal structure, the linking joints to each body parts are seen and able to calculate the location, rotation and direction of those body parts. Combining kinetic chain and the joint parameter, the vector value of all joint angle ignoring the angular velocity, the forward kinematics, which to calculate the kinematic configuration of the robot can be produced [11]. However, to control the robot, the inverse kinematics is required to find the corresponding joint parameters, which can be many while forward kinematic is unique. Many solutions have appeared to solve this problem and the most popular one is called Jacobian-based Approaches. Even the Jacobian based approach contains several problems, the research is still ongoing by many researchers.

2.1.3 Standard Platform

In the standard platform league, it is been ruled that all the teams use identical robots. This allowed teams to focus on the software side, rather than hardware side since the robots are already operating fully autonomously[12]. For the first time AIBO robot, developed by Japanese cooperation SONY in 1999, was chosen as the standard four-legged robot to play football. AIBO robot has been used until 2008 and the league changed the standard robot to NAO robot, a humanoid robot developed by French robotics company Aldebaran Robotics, due to SONY stopped further development of AIBO.

Figure 2.4: The AIBO Robot.

As mentioned above, most of the researches that participants were interested at were more focused on software development. They did not have to worry about hardware development as they are released with full operations ready. However, it does not mean that it's unable to find any information about their trials of different implementation of different techniques for the hardware.

AIBO

One of the researches about AIBO robot movement was making gait generation algorithm and implement it to the AIBO robot so the robot can travel with trajectory wheel-like motion. From their definitions, some of matters are need to be considered, such as while the legs are not in moving phase, it needs to be prevented from performing any other movement phase. There must be the condition to tell end of the movement phase and the angular velocity of supporting legs while in motion of leaving or landing. These condition has to be constant for robustness and reliability[13].

NAO

After the standard robot model for the standard platform league in RoboCup changed from AIBO to NAO, many participants had a lot of interest in using this NAO robot because

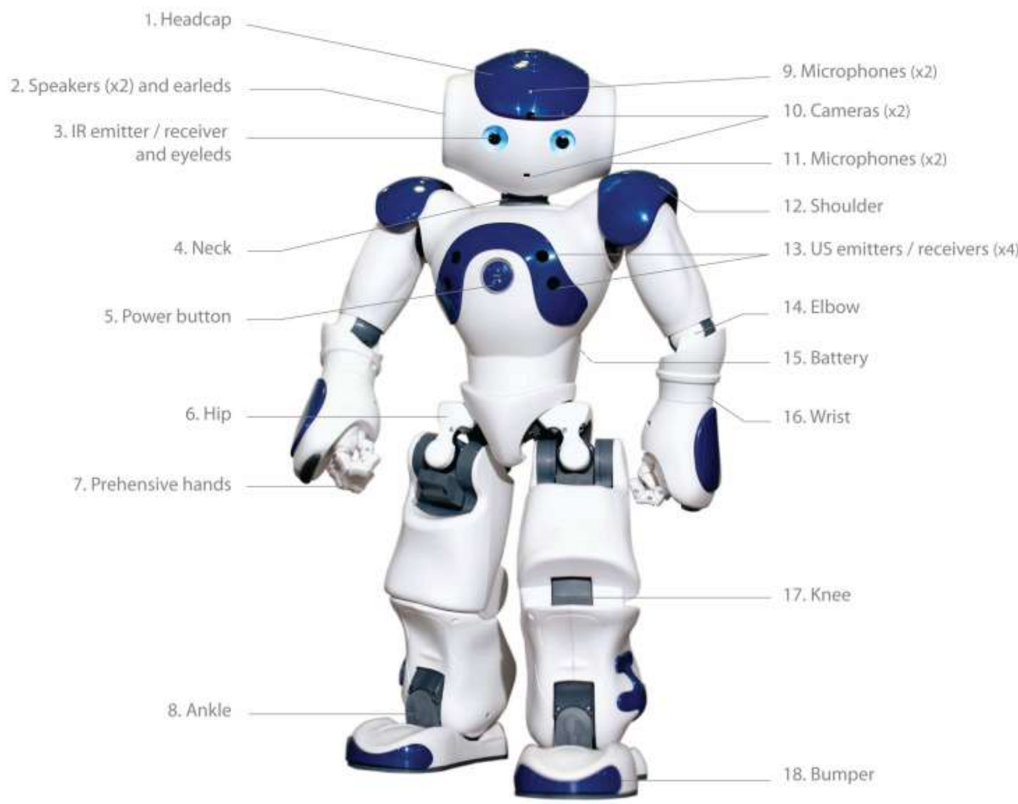


Figure 2.5: The NAO Robot. Reproduced from http://doc.aldebaran.com/2-1/home_nao.html[4]

development of humanoid was a matter of great interest in that period[14], the more they research about it, the higher probability that those researches can be implemented or based for future work. As it's mentioned previously, most of the robot controls use the closed-loop control system and NAO is also one of them.

Zero Moment Point based

ZMP is one of the popular approaches for stable gait generation and great for analysing dynamic balancing. Many RoboCup participants used this approach, but some teams had found the problems within it. Valerio and Sander stated in their paper that although the ZMP approach produces stable dynamic walking, it lacks another important factor, which is speed[15]. Czarnetzki et al[16] showed their use of ZMP based control in RoboCup 2009 with faster gait generation. Their improved approach made successful fast enough gait generation with reaching the speed of NAO robot walking to 20 cm/s, but there was a lack of robustness i.e., robot fell down to the ground often[5].

Center of Mass based

Colin Graf, Alexander Hartl, Thomas Rofer et al[5] stated in their research that they could get better robust control than using ZMP based control. They first solved the inverse kinetic problem and then showed their Center of Mass based closed-loop control systemic approach to active balancing. Although the inverse kinetic problem of NAO robot is complex due to its physical nature[6], their straightforward solution for this problem using transformation matrices by 2 circumstances for NAO robot they stated; the axes of hip yaw joints are rotated by 45 degrees and the joints are also mechanically connected among both legs. These circumstances can be checked from the below figure.

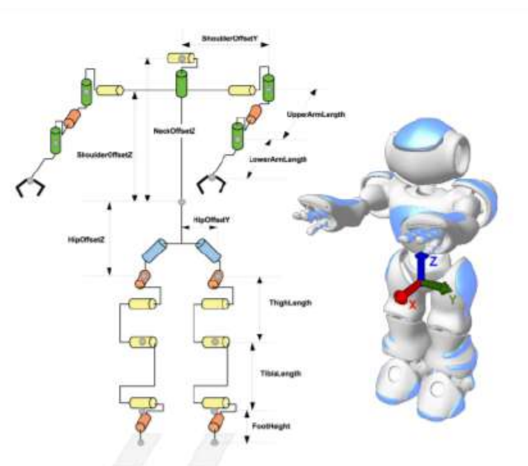


Figure 2.6: The joints of Nao robot and the coordinate system. Reproduced from [5]

For the balancing, they used 4 different methods; CoM balancing, Rotation balancing, Phase balancing and Step-size balancing. Each of them calculates the errors from actual outputs and desired outputs and these errors are used as one of the necessary components for the closed-loop control system. In the end, their team made the most robust and fastest gait generation within all participants in RoboCup 2009.

Chapter 3

Requirements and Analysis

The aim of this project is to not make MiRo robot join the RoboCup football competition and compete with other football robots. This project has motivation about finding possible MiRo robot usages not just for therapy or educational purpose by interacting with a human, but also finding potentials usage of MiRo robot outside from its original development intention, supervised by Prof. Tony Prescott, who is one of the developers of MiRo robot. Thus, the aim of this project is research which are required tasks for robot play football, set them as the goal and accomplish the tasks. Further researches based on the research made in this paper are expected. This paper mainly focuses on the ball controls, with setting below tasks as the goals to be achieved.

- Dribble the ball
- Kick the ball
- Pass the ball
- Do the goal keeping (Challenge)
- Do the penalty kicks (Challenge)
- Do the corner kicks (Challenge)

The idea of these tasks is based on how the demonstrations were in the very first humanoid league in RoboCup. Each of the tasks will be analysed in this chapter, with showing what skills, development or researches are necessary. Testing and evaluations are essential for the successful finish of development and proving achievements of the tasks, so they will be done at the end stage. Other studies such as tactics or scene perception of MiRo robot to play football will not be covered from this report due to the separation of work.

3.1 MiRo robots features

The first approach is the design of the components of the robot. Most the robots are designed to perform single behaviour actions only, beside, required actions to play robot football are pushing, dribbling, rolling, juggling and hitting. This means the design of the robot must be either let each component must perform for single behaviour only or build multi-purposed components[17]. These components should be decided carefully in the development stage because of the numbers of wheels of the robot even matters to the performance of robot[17]. Our MiRo robot has three degrees of freedom and many others such as ear rotation, head movement and tail wagging and so on. Assigning each DOFs performs any behaviours that required in playing football are expected.

3.2 Walking

Currently, MiRo robot is designed with two balanced wheels, therefore it will not face any balancing issue like humanoids, however, it can be considered how to make it not fall down or lose balance while it drifts or stop suddenly. Furthermore, one of the benefits of using more than 2 wheels is making the robot omnidirectional movement by each wheel can move at any point any moment in a dynamic moving field. During sample activation of MiRo robot, one of MiRo robots limitations is found, which is it cannot move dynamically. The speed of moving straight was satisfying but a sudden transition of direction required more time when compared to other wheeled football robots regard to its size and weight, thus, further necessity of more experiments and calculation will be demanded.

3.3 Dribbling

Unlike humanoid robots use their feet to control the ball, most of the wheeled robot use its body to move the ball. According to RoboCup final match in 2005 using AIBO robot[18], they also use their own body to perform dribbling. MiRo has more options, either use own body or use its nose when the neck is towards down. However, the more suitable approach will be using its own body. If the neck is facing towards down, the vision sensors will also go down, which MiRo will become impossible to sense the environment using visual sensors.

Another consideration is the precise calculation of the velocity of MiROs movement to keep dribbling the ball. The aim of dribbling is to move the ball from its position to target place under control, so the ball should not off the track while dribbling, no matter the MiRO is moving forward or turning. The vision sensor or the ultrasound sensor will be used to know the ball position, so the MiRO can know whether the ball is under control or is not. If yes, continue until the next action is decided, if not, find the ball to get it.

3.4 Kicking/Passing

To send the ball to target place there are two ways, either taking up the ball to the target place or kick the ball to send it to the place[19]. The first approach is more definite to send the ball and the second approach requires fewer actions and ball controls. The strength of each first and second approaches are the first approach guarantees better ball control and the second approach only needs to calculate whether it is possible to kick the ball, the path where to shoot the ball and how much power it needs. Many other football robots decided to use a physical kicking device or features even though there are possibilities of sending the ball to opponent/other teammates and interruption during ball moves toward the goal line (such as goalkeeper or other factors). The second approach is more realistic as well as a real-world human does in football playing and also has a higher chance to achieve the goal. Meanwhile, for the first approach, it takes more time to achieve the purpose due to the programming installed in the robots make them put the ball directly into the place, even though whenever it has the chance to make a goal or pass by shooting the ball. This drags more time, which means the possibility of losing ball or opponent blocks the way increases at the same time.

With these reasons, MiRo will also need to able to kick the ball using the kicking device or physical body. Possible features could be an act of MiRo head down and up to roll the ball or acceleration of the body to hit the ball. The corner kick is an extension of both passing and kicking, where it requires a long distanced pass to the team with kicking motion. The other grafting studies for corner kick is to distinguish the team and the obstacle, which is the scene perception but this will not be covered in this report.

3.5 Others

3.5.1 Ball stopping

Stopping ball is also a one of good ball controlling and it is used in RoboCup especially for goalkeeping. Goalkeeper stops the ball to make sure the ball does not move in its hand. By this, the possibilities of losing the ball control become extremely lowered and prevents own goal from the keeper. NAO robot is one of the robots that able to do this motion using its feet.

Figure 3.1: Nao robot stops the ball motion. Reproduced from [6]

As it is able to see from the Figure 3.1, humanoid type robots like NAO can do ball stop motion by holding their feet on top of the ball and push the feet slightly to the downward. It requires accurate calculation of motor power, coordination, angle of ball, angle of feet and balancing robot.

For the case of the wheeled robot, some teams performed the concept of stopping the ball movements by using grabbers, which is also can be used as dribbler with wheels contained within. They chose this mechanism because it was the easiest but the most efficient way of holding the ball. The mechanism did not make the robot actually grip the ball, in fact, they solved the issue by giving more force towards the body from rotating wheel action to the ball[20].

For the MiRo, both methods of the humanoid and wheeled robot can be applied. For instance, if MiRo chose humanoid's method, it can use its head act like the humanoids feet, push the ball down, so any parts of the head such as nose or chin can hold the ball on the ground. The state whether the ball Is successfully stopped or not can be found by ultrasound sensor placed at the nose. If MiRo chose wheeled robot's method, while the size of the ball is big enough, the body and chin MiRo can take roles of each arm of the grabber and so the ball is grasped by those two parts of MiRo.

3.5.2 Behaviors Confliction

The actions will be activated according to the current state of the sensors sensing the current environment. All the actions will be weighted and will be calculated internally to avoid the conflictions of actuators caused by multiple behaviours try to manipulate the same actuator, kicking and passing at the same time as an example. By calculating the value of each action in that situation is more valuable, the actuator can decide which actions need to be performed.

3.5.3 Vision based

In most of the researches, they emphasized the importance of the role of vision system[21][22][23]. The higher performance of the visual sensors, minimize the challenges associated with the speed of motion and latency impact on control[24]. Regarding these, MiRo robot is expected to get upgraded version high-resolution camera, expecting to help to solve some challenges of quality of sensing, motion detecting, capturing pictures and calculation of robots current position[22].

3.6 Programming and Simulating

Simulation is a good way to calculate the changes in real time since it contained some physics rule and model of the robot. It's also able to make the robots interact to any events and find what results happen. But the research warns to consider the dynamic change in actual field[25]. It is important to not trust with certainty about the simulation in case of difference between the reality, just the brief overview of the set situation of the robot and its following behaviour according to programme code. Both actual robot and the simulator was coded using ROS, which is the python based programming language, which got a huge collection of libraries as one of the strengths. This means we may find any useful libraries, especially about the sensors and movement related.

3.7 Requirements

Category	Number	Description	Priority
General	1	The robot learn from the previous trials and produce better results next time it performs in same or similar situation	Desired
	2	The behaviors must receive the information/inputs from various sensors	Mandatory
Walking/Dribbling	1	The robot must run the fastest it can with good balance and stability	Mandatory
	2	The robot must use its own feature to control the ball	Mandatory
	3	The robot try not to lose the ball	Desired
	4	The robot stop the ball when it needs to perform different behaviors	Desired
	5	The robot must perform omni-directional walking/dribbling regardless of condition of surface	Mandatory
Kicking	1	The robot must perform the kicking motion as fast as it can	Mandatory
	2	The robot must kick strong enough so it is distinguishable from dribbling/passing	Mandatory
	3	The robot can choose which feature to use to score the goal	Desired
	4	The robot must kick to score the goal whenever it gets chance	Mandatory
Passing	1	The robot pass to same team accurately	Desired
	2	The pass must be performed quickly before any kinds of the interruptions	Mandatory
Ball stopping	1	The robot fix the ball's position	Mandatory
	2	The robot stops the moving ball	Desired

Table 3.1: Functional requirements for development.

Category	Number	Description	Priority
	1	All the behaviors must be decided in real time and reliably	Mandatory
	2	The motion modules must be coded straight forward, easy to maintenance and with least complexity	Mandatory
	3	The system should run by robots internal CPU with the least interactions from outside	Desired

Table 3.2: Non-functional requirements for development.

Chapter 4

Design

After the literature survey part, the new version MiRo robot has been arrived and I finally could start development. During the development of making the MiRo robot play football, there were many considerations about the methods of ball controlling that I could not find out during the literature survey. Most of the difficulties to proceed the initial ideas of ball controlling came from the difference between the expected spec from the simulation and actual spec of real MiRo robot. This is because during the literature survey part, I had no chance to actually run the MiRo robot. By those differences, some methods are changed to adapt new MiRo robots spec, however, some methods are still remained same.

4.0.1 Field and objects

For the equivalent conditions for development and experiments of the robot, the testing ground is set. The green mat is covered on the floor for flat and even ground, surrounded by desks covered with dark clothes to block additional colours interruptions and the goal post at the corner to save the space.

4.0.2 General Structure

The Figure 4.1 shows the general structure of making the MiRo robot playing football. This report mainly focuses on the Ball control part, where Scene Perception and Strategy is discussed in other paper in more detail. Briefly, the 'Scene Perception' gets the images from the cameras, convert the colour based from the RGB value to HSV value, do the colour segmentation and finally uses contour around the objects and draw a box on it for identification. For example, when the MiRo robot sees the white colour, it will detect it as the 'MiRo' as the colour of the MiRo robot is mostly white. When the orange ball is used, MiRo robot will detect any objects with orange as the 'ball'. If the green objects are continued and stops at some point, that is the boundary of the field. Image stitching is simply stitching the two images from each camera into one, as each cameras' viewing angle are different, the objects which cameras' detecting are different as well. This is required to make the MiRo robot not confused to follow which images from the cameras. 'Strategy' is the part where

Figure 4.1: The view of the set field where all the development, experiments and challenges are carried out. The length of one side of field is 3.07 m.

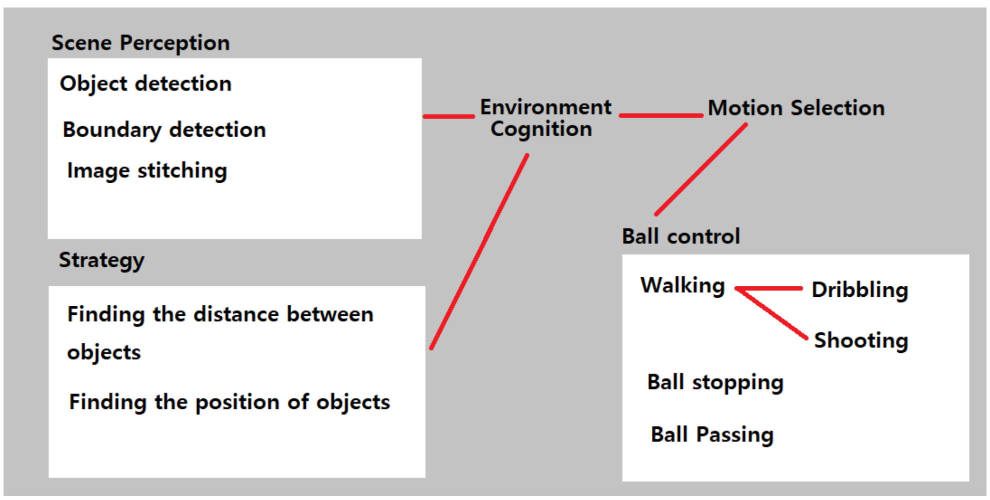


Figure 4.2: The general structure of the system.

finds the specific locations of the objects and the related parameters. It finds the centre and bottom of the objects able to measures the distances between the MiRo robot and them. All motions are independent of each other and these independent motions are chosen to be executed by the Motion Selection. To execute the motions, they require different conditions and the fulfilment of these conditions are decided by given data from Environment Cognition observes the surrounding environment of the MiRo robot using the Scene Perception and the Strategy.

4.0.3 Simulation

Due to the development of upgraded robot, it was impossible to use the robot for periods of time for this project. Instead, we could use the simulation that has same logic work with

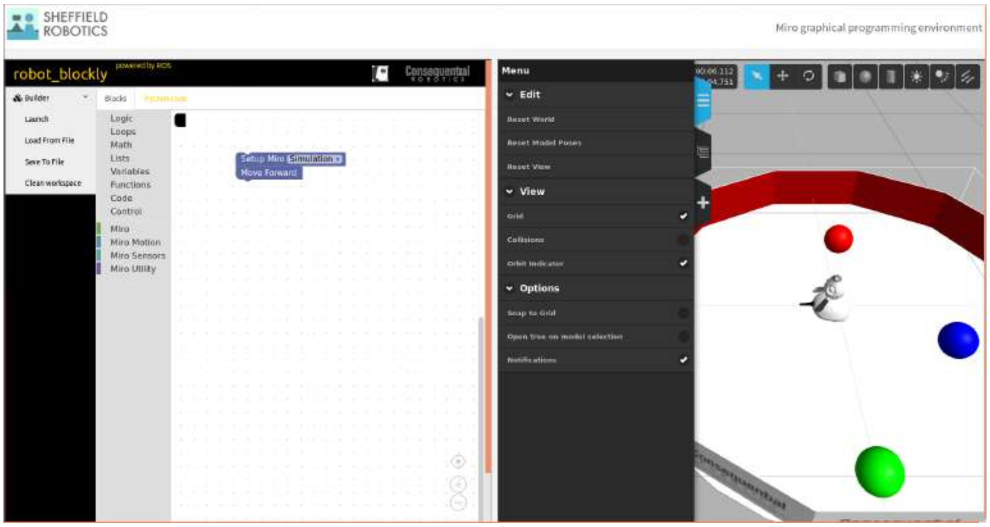


Figure 4.3: The simulator of the MiRo robot powered by ROS. The code is written and executed on the left side by putting and arranging appropriate blocks of codes and on the right shows the actions of the MiRo robot modelling by the code on the left.

the actual MiRo robot. The languages simulator uses were Python and ROS, run by Linux system same as actual MiRo robot. With using this simulator, the initial designs of ball control motions were made. Unfortunately, it is been found later that the spec of MiRo robot in simulator and the actual robot were different and many physics factors were not involved in the simulator. For example, the motor power of the robot, the materials of the ball and the robot and the friction caused by collision of objects were not implemented. Detailed information about changes of design for each motion will be shown below.

4.0.4 Walking

As it is researched in the literature survey, MiRo robot had two wheels at the centre-bottom of its body. The bulging circular dot is at bottom-backend to make the robot balances and make the height of the robot parallel to the ground. This bulging dot also helps MiRo robot to not lose balance for abrupt acceleration. To make the MiRo robot walk, the method is very simple, which is making the wheels rotate. Similarly, depends on the degree of direction change, the speed of each wheel is differed or even rotates in reverse direction. This allowed the robot omnidirectional movement, which is the advantage of the two-wheeled robots that discussed in literature survey part. The walking state is when the robot does not control the ball, but moves around with the constant speed. For the MiRo robot, the main agent that detects the world is vision sensor attached in front of the head (the high resolution cameras), hence, it is important to maintain the vision sensors able to see the world while travelling, which means the head should always look towards. One consideration is the viewing angle of the cameras. If the inappropriate viewing angle, such as the head is facing towards upward too much, it possibly does not detect anything on the ground even if there is the ball right in front. By this reason, the head should look downward enough to see both the further objects on the ground and object right in front of the robot.

4.0.5 Dribbling

(a) Side view of initial dribbling design

(b) Upper view of initial dribbling design

(c) Side view of final dribbling design

(d) Upper view of initial dribbling design

Figure 4.4: Pictures of designs of dribbling

Dribbling is one of the two most important motions to play football. Dribbling is the extension of walking, that the speed of wheels is different depends on the situation. It requires uses of more sensors than normal walking as the main aim of this behaviour is to walk with ball control. At initial design, it is chosen to use MiRo robot's head to dribble with various reasons. As it been shown from Figure 1.1, the cameras and the sonar sensor is attached on the head. The advantages of using those two sensors for dribbling are for grasping the situations of the changing environment in real time while dribbling and use of sensors to check the distance between the MiRo robot and the objects on the ground with object detection. However, this design had to be changed due to several reasons. The first reason was the neck of the MiRo robot does not lift to downward as much as it is expected. Another reason is that the MiRos head is originally not designed for playing football, the shape was not appropriate to dribble the ball. These factors led the ball stuck between the MiRos head and the ground instead of going forward. The main obstacle was the rubber attachment for the nose, as the ball is usually made of rubber or foam and the strong friction is made between them, disturbing the ball move. It is considered to remove the rubber attachment, however, the sonar sensor is worked only if the attachment is attached in its position. The chosen alternative method was by using MiRo robots body. It had cliff sensors and light sensors attached at the front. These sensors are used to check whether the ball is in control instead of cameras. While those sensors are used to control the ball, yet the vision sensor is used to see the world. When the transition of motion from walking to dribbling is translated into action, the head of the MiRo robot needs to be lifted. By this, both purposes of ball controlling with body part and looking at the world by cameras are achieved. The main sensor to be used for controlling the ball position will be cliff sensor. It was considered to use light sensor, as if the ball goes to left or right side of the robot's body, the light sensor can sense which direction the ball went since the ball hides the light when it comes in front of the sensor. However, it is been found that the brightness world light affects the sensor, which means if the room is too dark, robot get confused about which direction the ball went. For such reason, cliff sensor is chosen. Cliff sensor does not affect by other factors and only can detect the ball's movement.

4.0.6 Shooting

Another of the most important motions is shooting the ball. In order to score the goal, shooting motion is needed. For a similar reason to the dribbling, the initial design of the shooting is using the head part of the MiRo robot, so that it can headbutt the ball to score. Again, the MiRo robots head design was not suitable for accurate ball control, which also means the accuracy of shooting the ball was not guaranteed too. Furthermore, when the ball is controlled by the head, the cameras were not able to see the surrounding as the most of the scenes are blocked by the ball. This is critical because if it cannot see the surrounding, MiRo robot cannot decide what to do next by the decisions of motions are done through the vision based. In addition, since the ball dribbling is using the body part, shooting the ball also needed to use the body part for easier transition between motions. The chosen method to shoot the ball was sending the ball by transferring the power from the impact caused by hitting the ball with the accelerated robot. Another reason behind choosing such method is due to it was hard to attach any extra kicking devices in order to MiRo robot kicks the ball since the MiRo was not designed to put any extra attachment to it.

4.0.7 Ball stopping

As the majority of the ball controls are happening from the head and the front of the body part, the ball stopping also uses any of those two. The ball stopping is typically required for goal posting, therefore it needs to make sure the ball stops, and otherwise, there are chances of losing ball control. As its researched from the literature review, there are various ways and the chosen method is the similar way how humanoids stop the ball. The jaw of MiRo robot acts as foot part of humanoid. It pushes the ball to the ground, stamps on the ball. The force is mainly from the necks motor. The benefit of this design is MiRo still able to see the front view as the face is heading towards, helps decide what to do for next behaviour.

4.0.8 Passing

The most challenging part of the design was passing the ball. The design of passing the ball to the front is the same is kicking the ball. On the other hand, passing the ball to the left or right made many changes of the designs. The initial design was sending the ball to left or right by positioning ball next to the head and pushes it with shaking the head. This approach seemed work well when it is performed by human hand, however, turned out the power of the motor of the neck was not enough even to move the ball. The next designed approach was sending the ball by hitting the ball using the head with the rotation of whole body. From the simulation, this approach showed the greatest power to send the ball but had a problem when applied in real. The problem was the ball moves before the robot tries to perform passing by the interaction caused by the rotation of the robot body during preparation of passing motion. As the ball moves before the robot hits it, it either misses or send the ball to the wrong direction.

After several possible approaches are considered and the most reliable methods was using the rotation of both body and neck. With only using the rotation of either the body or neck, the power would not enough to push the ball hard. It could increase the speed of the rotation due to higher the speed gives a bigger impact on the ball, however, it is found out that the possibility of the MiRo robot loses the ball position got higher. This is followed by the MiRo robot more likely to touches the ball during action in proportion to bigger action the MiRo robot performs the motions. Therefore, the approach needed to be designed with the least rotations of MiRo robot with the biggest power it could transfer to the ball to move.

Figure 4.5: The shape of the MiRo robot's head. The general shape is an round inverted triangle.

To find the good impact point, many experiments were required. From the Figure 4.5, it shows the shape of the MiRo robot's head is an inverted triangle. With this shape, when it rotates, the direction of pointy part of the triangle is towards below the diagonal. This direction is towards the ground and any object is getting the force diagonally, it is either actively pushed to the ground or to the side way depends on the friction caused between the contacting objects. Therefore,

4.0.9 Evaluation and experiments

The testing for each performance of motions are necessary to find each motion activates well. The purpose of the testing is to figure out each motion are suitable for in real robot football game or not. They need different experimental conditions as their purposes and operation methods are different to each other. The data collected from these experiments will be used in future in order to compare and contrast with other solutions. It is important to maintain the experimental conditions for the measurement of accurate and non-biased results.

The designs of experiments for each motions are shown in Table 4.1.

To find the external factor that matters to the performance of the motions, it is been decided to change the types of the ball for the experiments. The Figure 4.4 shows the chosen balls to be used in the experiment. For the implementation of final designs, which will be described in next chapter, ball 4 is used as the base by light weight and fewer frictions made

Tested motion		Dependent variable	Independent variable
Walking	1	How straight the robot goes	The speed of the robot
	2	What degree of change in angle required to change the direction	The angular change of the robot
Shooting	1	The average/maximum distance the ball moved	The speed of the robot
	2	The accuracy of ball goes straight	The types of ball
Dribbling	1	The success rate of the robot carries the ball to the goal	The speed of robot
	2	The number of times the robot lose the ball control	The types of ball
Passing	1	The success rate of the ball passing	The position of the ball
	2	The distance ball moved	The types of ball
Ball stopping	1	The success rate of the robot keeps the ball when other robot bumps to the ball	The speed of other robots which bumps to the ball
	2		The types of ball

Table 4.1: The experiment conditions of testing motions.

between objects. The designs of experiments for each challenges are shown in Table 4.2.

(a) Ball 1. Weight: 90g, Diameter: 11cm, Material: Foam

(b) Ball 2. Weight: 200g, Diameter: 15cm, Material: Polyurethane

(c) Ball 3. Weight: 292g, Diameter: 17.6cm, Material: PVC

(d) Ball 4. Weight: 88g, Diameter: 15.5cm, Material: Foam

(e) Ball 5. Weight: 172g, Diameter: 13.5cm, Material: Rubber

(f) Ball 6. Weight: 118g, Diameter: 16cm, Material: Rubber

Figure 4.6: Pictures of balls that will be used in experiments

Tested challenge		Dependent variable	Independent variable
Penalty kick	1	The success rate of the MiRo robot goals the score	The positions of the MiRo robot and the ball
Corner kick	1	The success rate of MiRo robot passes the ball to other MiRo robot	The position of MiRo robot which scores the ball
	2	The success rate of MiRo robot goals the score after get the ball from another robot	

Table 4.2: The experiment conditions of testing challenges by implemented motions

Chapter 5

Implementation and Testing

In this section, the implementations of the methods designed previously and the testing of them will be shown. Furthermore, the description of how such designs are actually realized and the difficulties followed by them will be shown too. The motions are grouped into two, open-loop and closed-loop. The main aim of the project is to make the MiRo robot to play football. From this aspect, it is important to figure out the chosen methods are suitable to implement for real robot football. After the experiments of each method, the testing of methods implemented on the challenges, performing penalty kick and corner kick, is done.

The main algorithm of calling the motion is following; as thee robot runs, within the program there is the main loop with containing lots of loops and definitions. Whenever the motions are required and conditions are met, the programmed motions are called and performs the set activity. The degree of angle or speed of wheels are controlled by imported 'publishers' and data from the sensors are collected by 'subscribers'. For every loop, the sensory data is collected from those 'subscribers' and the kinetics parameters are sent to those 'publishers'. When the kinetics parameters are changed, the motors activated.

5.0.1 Open-loop algorithm motions

The motions with open-loop algorithm require the continuous updated data of surrounding environment. These motions usually collaborates with sensors, never ends until wanted results are happen and part of progress to perform the motions with specific goals.

5.0.2 Walking

Walking is the motion which needs the constant updating data from the scene perception, hence needed to be made as open-loop algorithm. Figure 5.1 shows the algorithm of walking motion. In the loop, the 'Scene perception' constantly updates the view of the robot from the camera and 'Strategy' finds where the exact locations and directions of the objects. Mainly, the walking motion is used to find the ball and go towards it. If the robot cannot find the ball, it rotates the body until finding the ball. When the MiRo robot is walking towards the

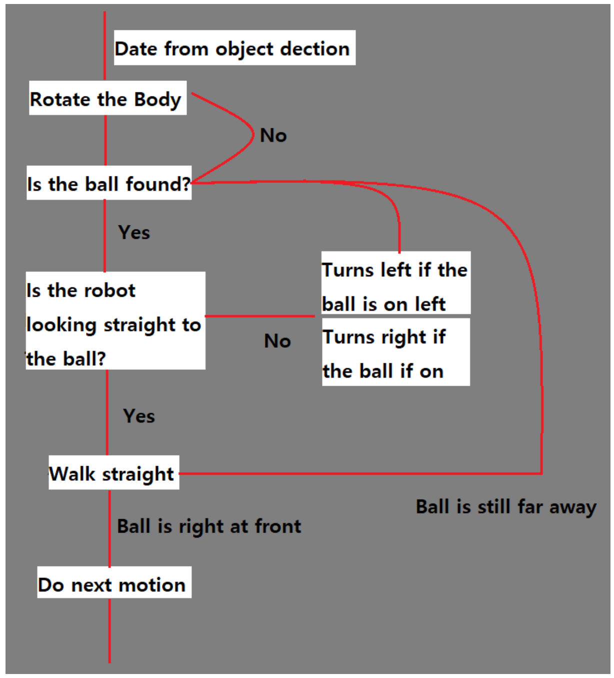


Figure 5.1: Algorithm of walking motion.

ball, it could not go straight to where the ball is, hence the direction of changes depends on the location of the ball. If the ball is on the left, the right wheel rotates faster than left wheel and vice versa. After the robot finds the ball and is right at front of it, depends on the situation, it carries out next motions judged by 'Strategy'. To test the walking motion, simply put the robot in random position of the field and make it walk with sending different kinetics parameters, mainly speed and angular change of wheels rotation, to the 'publishers'.

5.0.3 Dribbling

Dribbling is another open-loop algorithm motion that constantly gets the cliff sensors' data. In order to activate the dribbling, it has to make sure that the robot has the ball in front of it, otherwise it will waste time to find the ball. When the dribbling motion is activated, MiRo robot starts to go forward slowly and the cliff sensors starts to sense the movement of the ball. If the ball moves, any cliff sensor can detect it and make the body rotates left and right. The speed of going forward and the degree of changing the direction are the keys from this motion. The good balance between them are very important because if the speed is too high, it gets harder to change the direction of the robot. Figure 5.2 shows the algorithm of dribbling motion. The loop continues until the user orders stopping or other motion is activated. To test the dribbling motion, place the robot in set start position and make it dribble until the goal position and measure the time it takes and see the overall performance of dribbling with changing velocity of robot dribbles.

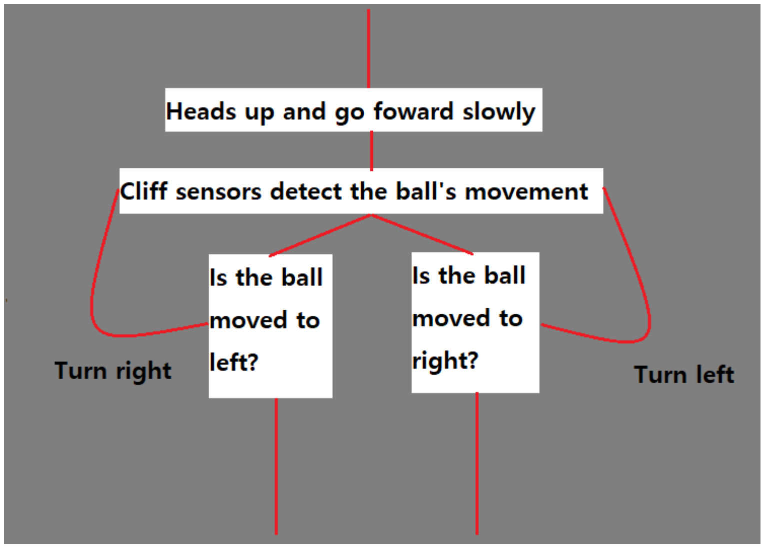


Figure 5.2: Algorithm of dribbling motion.

5.0.4 Closed-loop algorithm motions

Closed loop algorithms do not require further inputs and therefore very accurate and stable. This means the motions do not get any interruptions during the process and always does the same motions when it is called. To make sure the algorithm is closed-loop, limiting the performance time is required. Figure 5.3 shows the algorithm of limiting the motions' activity time, where xk is the signal of computing the drive time, t is the ratio of changing angle of motor, v is the ratio of changing velocity of wheel over time, t_now is the current time which increases every loop, Tq is initial and final ratio of changing state, T is the ratio of changing state during process. After the set time, the MiRo robot deactivates the motion and breaks the loop. By adjusting these parameters, the degree of angles and speed of wheels are decided for each closed-loop algorithm motions.

Shooting

To shoot the ball straight, the body needs to hit the ball straight, therefore there is no unbalanced rotation of each wheel while shooting motion. To make sure the body 'hits' the ball, there are two conditions. One is the body has to have enough speed (power increases as the speed increases due to Newton's second law of motion, $F = ma$) to move the ball and two is the speed of the ball has to be faster than the speed of body after impact in order to be get 'fired'. Unfortunately, the motor power of the current MiRo robot was not enough to make the ball moves faster than the robot after impact. From this, the solution was presented, which is either stop or make the robot fall back after hit the ball for certain distance. The final decision was making the robot falls back. Figure 5.4 shows the algorithm of shooting motion and Figure 5.5 shows the experimental condition of testing the shooting motion. The MiRo robot performs shooting motion to the ball with 40 cm away from it. This condition

```
xk = math.sin(t_now * f_kin * 2 * math.pi)
t = xk * np.radians(55.0)
v = 0
Tq = 0.1
T = 1.0
t1 = Tq
t2 = t1 + T
t3 = t2 + T
t4 = t3 + Tq
if t_now < t1:
        v = 0.0
elif t_now < t2:
        v = (t_now - t1) / T
elif t_now < t3:
        v = 0.3 - (t_now - t2*0.6) / T
elif t_now < t4:
        v = 0.0
else:
        self.active = False
```

Figure 5.3: Algorithm of limiting motion time.

will be maintained for all 10 trials for experimenting each types of ball.

Passing

Passing is one of the motion with the most complex calculation of changing angle of rotating body and head. Figure 5.6 shows the picture every frame of passing the ball to left motion. All frames are continued smoothly and robustly since it is closed loop. Notice that the rubber attachment of the nose is removed to prevent any causation of friction between the ball and the attachment. As it is expected from the design, when the rotation of the body is too big, the ball more likely to escape from robot's control. The calculation of the degree to not make the ball too much in between frame 1 to 2 was the key and this degree is adjusted by many trials and errors. Figure 5.7 shows the algorithm of ball passing motion. To test the passing motion, number of trials of passing for each ball are made and measures the maximum distance the ball travelled and the rate of passing motion is succeeded.

Ball stopping

The ball stopping motion was the simplest motion to implement the design, which was simply making the head lifts down. To give the even pressure on the ball, the touching surface between the robot and the ball has to be parallel to the ground. The purpose of this is to focus the force to the ground and the gravity together to the ground. Figure 5.8 shows the algorithm of ball stopping motion. To test the ball stopping, several trials of ball stopping motions were executed for each balls and pushed the ball to other direction with hands to

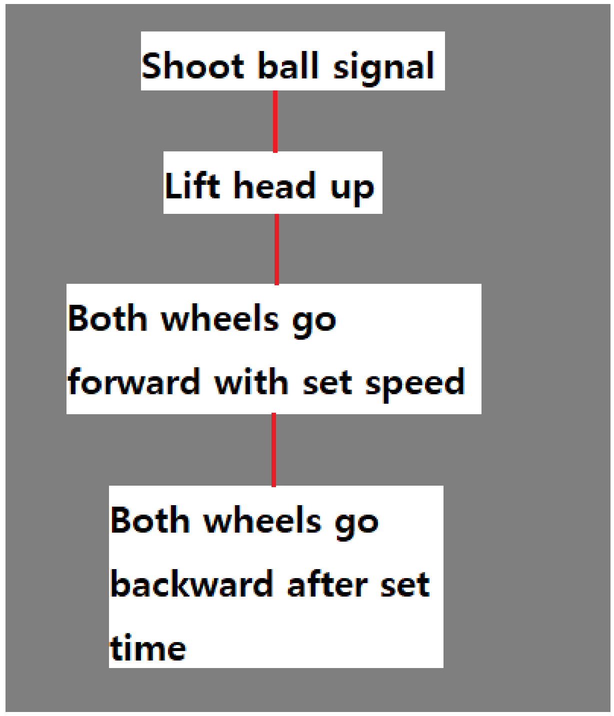
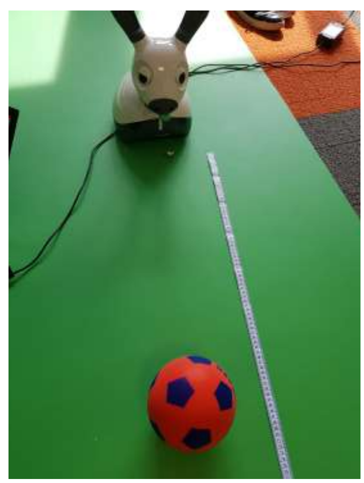


Figure 5.4: Algorithm of shooting motion.

(a) View of testing shooting from back



(b) View of testing shooting from front

Figure 5.5: Pictures of testing shooting

observe how strongly the ball is locked up.

(a) Front view of first frame of passing motion.

(b) Front view of second frame of passing motion.

(c) Front view of thirst frame of passing motion.

(d) Top view of first frame of passing motion.

(e) Top view of second frame of passing motion.

(f) Top view of thirst frame of passing motion.

Figure 5.6: Pictures of each frames of passing motion

5.0.5 Challenges

Some motions from above are implemented in order to find the robustness and reliability of them. The biggest challenge from this part was combining all the techniques and solutions from different tasks into one. The most collaborated task was 'Scene Perception' since the task is related about handling all the data and signals to execute any motions were from.

Penalty kick

The penalty kick is the situation where the ball is further from the goal post for certain distance in stationary state and the kicker shoots the ball to score. The required motions for the penalty kick challenge were walking and shooting. Walking is the main motion to

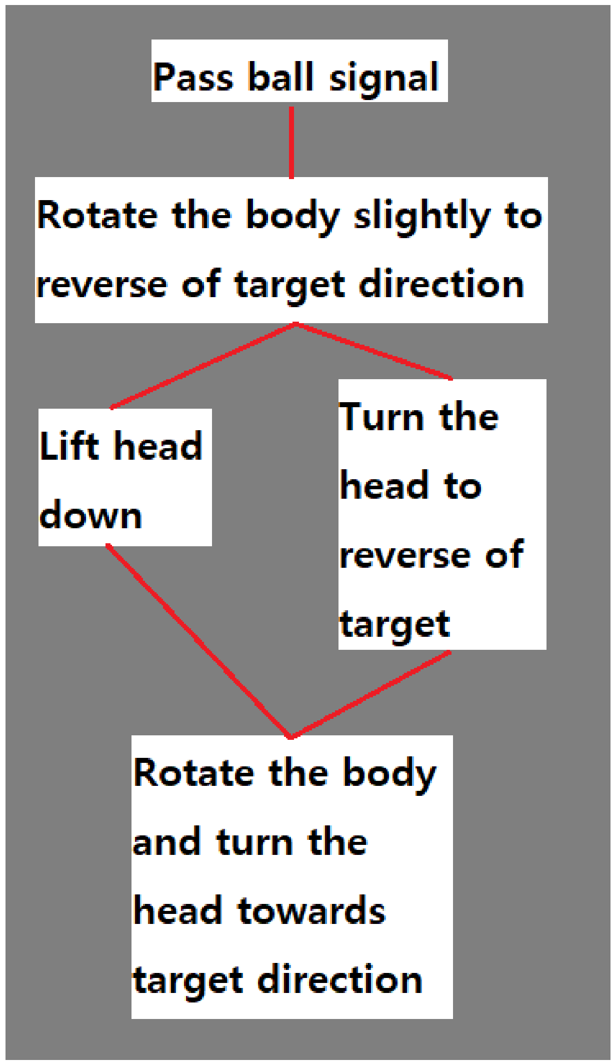


Figure 5.7: Algorithm of passing motion.

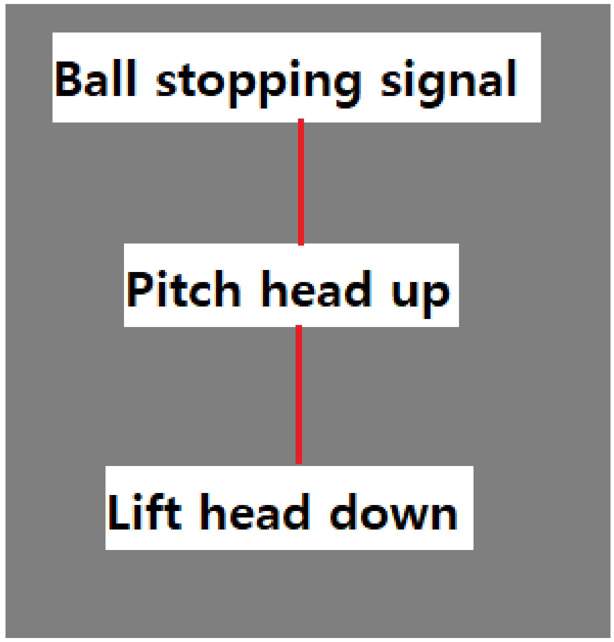


Figure 5.8: Algorithm of ball stopping motion.

MiRo robot detects the ball and approach to it after in order to execute the shoot motion and Shooting is the main motion to score by kicking it.

To implement the codes written for this project, the existing GUI (Figure 5.9)of the MiRo robot is used. This GUI is in the package of MiRo development kit and let the user control the robot manually and see the related parameters.

Once the 'Display Camera' button is pressed, the camera displays the view that the robot is currently viewing (Figure 5.10) and the robot starts to move forward slowly, activates walking motion. From this, 'Scene Perception' detects the objects and 'Strategy' shows which directions the objects are. While the 'walking' motion is activated, the robot follows the direction where the 'strategy' is telling the location of the ball detected by 'Scene Perception'. The additional implementation of the sensor that was not mentioned from the design section or the 'walking' of current section above is usage of the sonar sensor. The purpose of using the sonar sensor is to find whether the ball is right at front and detects how close the ball is from the head of the robot. Even though the 'Strategy' tells the distance between the robot and the object, since the 'Scene Perception' detects too many objects at once, it's hard to tell for the robot to know which objects are with which distance away from it. The logic of using the sonar sensor is since there are only 3 objects, ball, MiRo and the goal post, on the field, if the MiRo robot goes towards to the ball and the sonar sensor detects that there is an object in front, then it must be the ball. Once the MiRo certains the ball is within range, the 'shooting' motion is activated. During walking motion, in order to detect the ball the robot's head lifted down to limit the view that it able to see as a threshold and by this, an

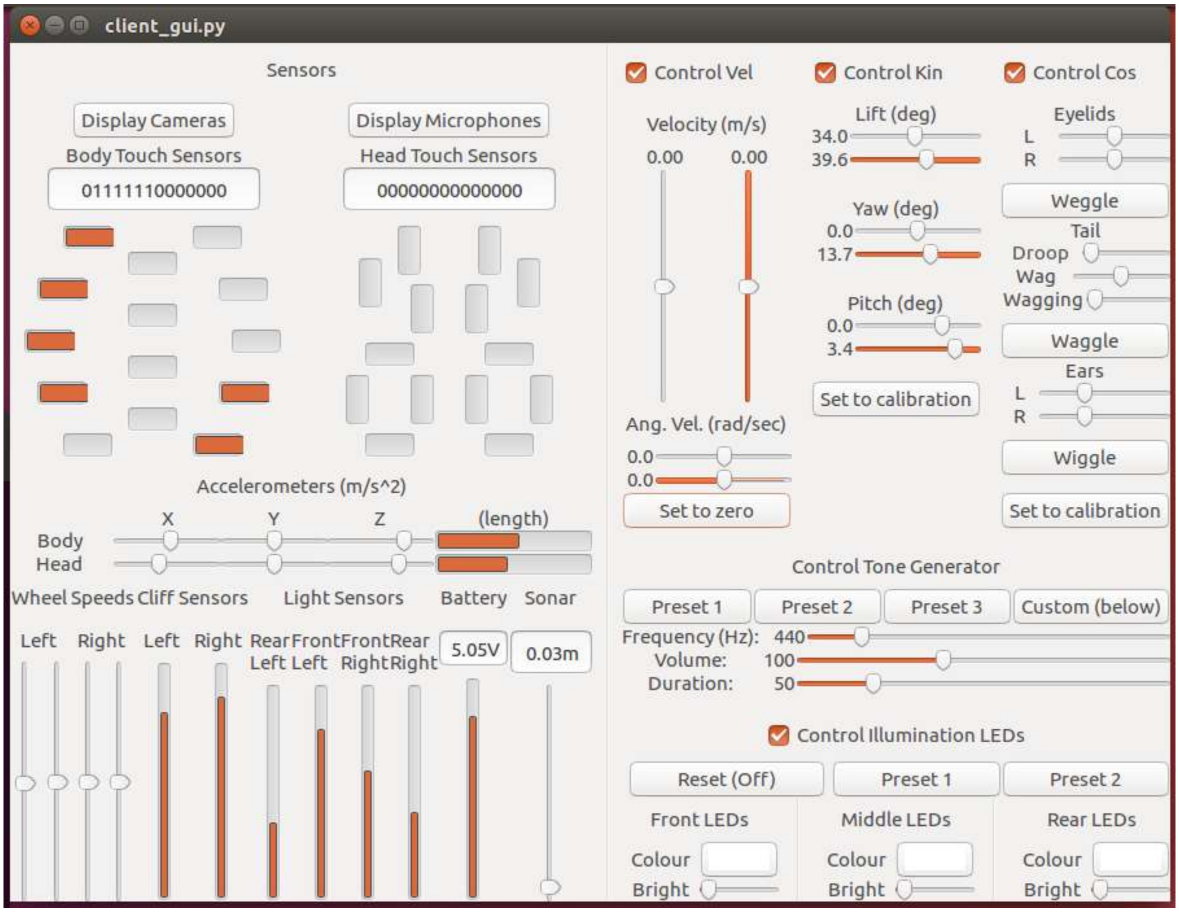


Figure 5.9: GUI of the MiRo robot. Various parameters can be set and seen by the users.

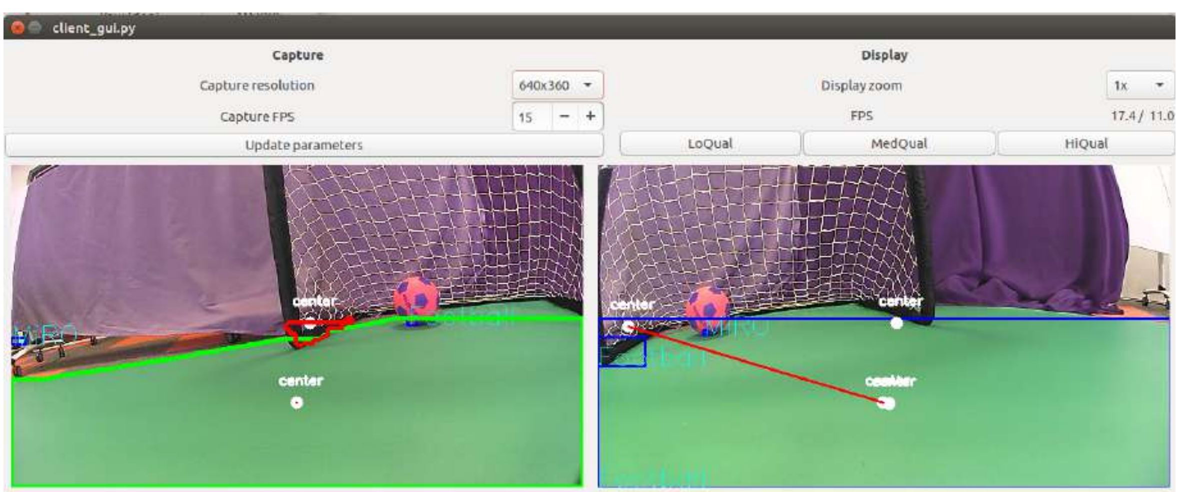


Figure 5.10: Camera display of GUI.

algorithm of lifting the head up is added to the 'shooting' motion to hit the ball with body.

Corner kick

To complete the corner kick challenge, at least two MiRo robots were required, so that one can pass to the other from the corner and the other can shoot to the goal post, other than this, the rest of the requirements are same as penalty kick challenge. From the field, MiRo 1 stands in front of the goal post, wait for the ball passed from the MiRo 2, which stands at side of the goal post. The ball is passed from the MiRo 2 to the MiRo 1 by either shooting or passing motion depends on the direction MiRo 2 is facing. Once the ball is seen by MiRo 1, starts 'walking' to the ball and execute 'shooting' to score the goal.

Chapter 6

Results and Discussion

This section shows the results of various experiments of implementations of methods and how successfully the challenges are completed. After showing the results, the discussion about each motion and the challenges are presented.

6.0.1 Results from the experiments

Walking

As mentioned before, the walking motion is very simple for wheeled robot, in contrast to the humanoids need to solve problem of balancing for gait generation. The GUI (Figure 5.9) was the main tool for this experiment by adjusting the 'velocity' and the 'angular velocity' parameters. Table 6.1 shows the result of relationship between the angular velocity and velocity of the robot. From the table, for every 1.0 radian per second, the maximum speed the robot can do omni-directional movement increases by 0.08 m/s. This also implies for every 0.1 rad/sec, the maximum velocity increase by 0.008 m/s. When the angular change is 5.0 rad/sec, the maximum velocity that the robot can make the omni-directional movement is 0.4 m/s, but this is due to 0.4 m/s was the maximum velocity that the robot can make. However, from the implication in previous sentence, it can be assumed that above velocity of 0.4 m/s would not make the robot omni-directional movement.

Angular change (rad/sec)	Velocity (m/s)
5.0	Until 0.4
4.0	Until 0.32
3.0	Until 0.24
2.0	Until 0.16
1.0	Until 0.08
0.5	Until 0.04

Table 6.1: The maximum speed of the robot which it can make omni-directional movement instead of changing direction. Omni-directional movement means the robot stays in same location but able to changes the direction.

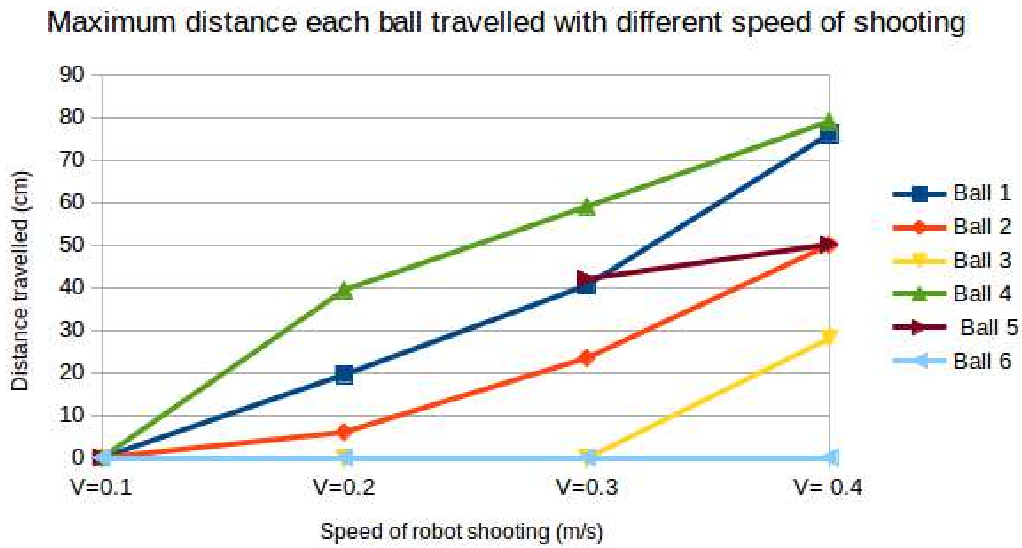


Figure 6.1: The maximum distance each ball travelled with different speed of shooting

Shooting

Figure 6.1 shows the results of the experiment about shooting based on the condition shown in design section. In general, as the speed of robot shooting increases, the distance balls travel increases too. The longest shot is when Ball 4 is shot by the robot with velocity of 0.4 which is the fastest speed the robot can make. The shortest shot that is more than 0 cm moved was when the ball 2 is shot with robot's shooting velocity of 0.2 m/s. For the ball 3, when the shooting velocities were below 0.4 m/s, it went forward a bit when it's hit and came back to the start point, so it's recorded as 0 cm distance travelled. For the ball 6, the ball get stuck between the floor and the robot for every shot, unable to make any records. Ball 4 showed the best result, for every velocity, it went farthest. For most of the trials, all the balls that were not made of foams showed poor performance and the accuracy of moving straight.

Dribbling

Figure 6.2 shows the results of the dribbling experiment. The distance between the starting point and the goal line was 3.07 m, which is from one side of the field to the other. The time is started to taken when the robot starts dribbling and ended when the ball crosses the goal line at other side of the field, otherwise the results are not recorded. In general, as the velocity increases, the amount of time taken reduces as expected. The only ball that could record the results with all velocities was Ball 1. It showed good performances for all trials, but as the speed increased, the more likely it looses the ball control increased. Many of the balls could not record results for various reasons. For ball 2, for all velocities, the robot could not dribble the ball because the directions of the ball when it's move were very random

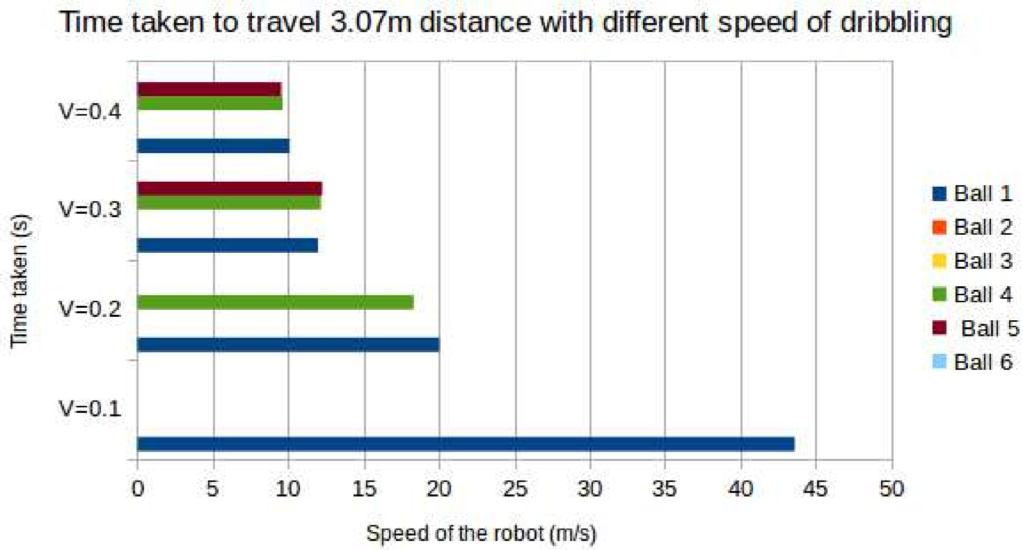


Figure 6.2: Time taken to travel 3.07m distance with different speed of dribbling

and went even further distance than expected when it's dribbled by the MiRo robot. For ball 3, because of the size, it covered both cliff sensors at the same time, as a result the sensors get confused ended up with the robot lose the control of the ball. For ball 4, the only time when it has no record when velocity is 0.1 m/s. This is because the speed of the robot was too slow, the amount of time the robot controls the ball increased. This led to the direction of the robot dribbles toward change before the ball reaches to the goal line ended up with the ball never reaches to the goal line. For ball 5, until the velocity is 0.2 m/s, the robot could not control the ball with the same reason with ball 2, however, from velocity is 0.3 m/s, the robot could catch up the ball before it rolls to random direction and could score the result. Lastly, for ball 6, because the ball gets stuck between the floor and the robot, it was unable to record any results. When it was able to record the results for any balls, there were no lose of ball control.

Passing

Figure 6.3 shows the results of passing experiments. The best result was made by ball 4 with good success rate of succeeding passing motion. Ball 2, 3 and 6 could not make any results. This implies as the size of the ball exceeds certain level, the balls get stuck between the floor and robot's head, prevented the passing motion succeed. Since the passing motion is made of closed loop algorithm and cannot adjust the degree of lifting down the head depends on the size of the ball. The exception is ball 2, where it's smaller than ball 4 and it could make some results, however, the results are too random and sometimes ended up with going further right while it should go to the left. Those results did not make any correlations, therefore not recorded. Ball 1 showed the poorest result due to the MiRo robot's head hardly reached to the ball, so the power to push the ball for passing decreased.

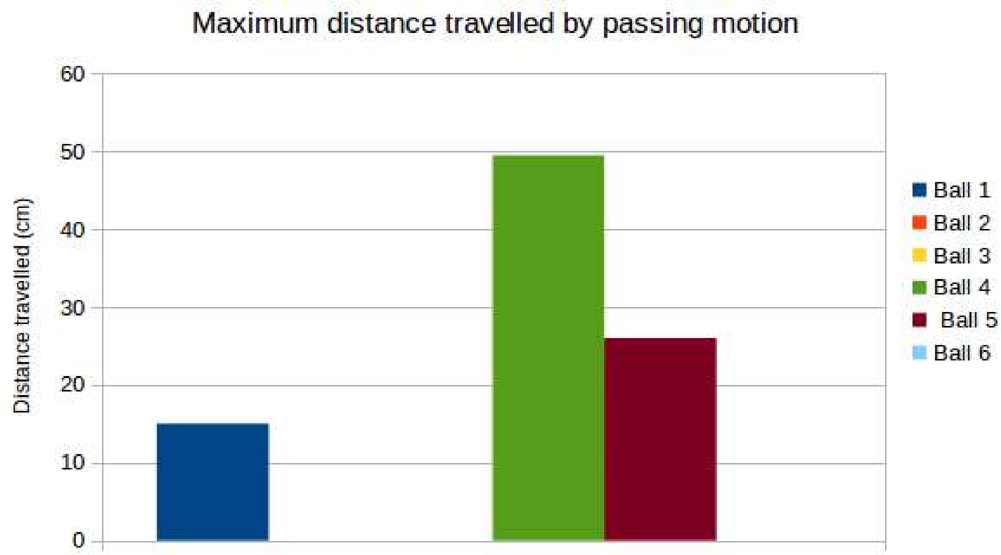


Figure 6.3: The maximum distance travelled by passing motion

Ball stopping

In general, most of the time the ball stopping motion showed good ability to lock up the ball except ball 1 and 3. Ball 1 and 3 were unable to locked up due their sizes were either too small or too big. For multiple times, to pull out the locked up ball by ball stopping motion, it required adequate amount of force. This means the motion was robust to stop the ball's movement.

Challenges

For both penalty kick and corner kick challenges, the success rates were around 20%. All the motions performed well whenever they get the signals to execute. The motions that needed further adjustment were shooting motion and passing motion. For the shooting motion, the input signal is from the sonar sensor detects the object in front and depends on the robots used for the challenges, the performance of sonar sensors varied and caused shooting motion not executed even though the ball is right in front of the nose and nose pushes the ball towards the front during the walking motion. For the passing motion, the motion could not carry out the result of the ball moves to left or right due to the robot's nose attachment. In order to robot finds the ball, the rubber attachment is must need, otherwise the sensor always shows there is an object in 0.03 m away, while it must be removed in order to execute the passing motion successfully. Due to this collision, it was impossible to use the passing motion for the challenges. The background of the field affected to the 'scene perception' by confusing it and this led misdirection of executing some motions, especially the walking motion.

6.0.2 Discussions about the project

In general

Some researched literature were very helpful for this project, especially the control system which affects choosing the type of algorithms for each motion. The humanoids ball control researches were not completely suitable. The methods of humanoids motions were very different to the wheeled robots' motions methods and same for the way of motors usages. The Zero Moment Point based or Center of Mass based approaches were usually applied to the robots with standing by motor supporting legs. Most of the inspirations of designing the ball controls were from the old Robocup videos when the AIBO robots were the main robot in Standard Platform league. The only helpful area was designing the ball stopping motion. This was the only differentiated part between those wheeled robots or AIBO robots and the MiRo robot as the design of head and neck were different.

Discoveries from the results

The MiRo could do some challenges with successful implementation of designed motions with collaborating with solutions from different tasks. From the results and experiments above, it's possible to say the goals are partially achieved and some new discoveries were found.

From the results of walking experiment, it is found that even though the robot is ordered to walk straight, in reality it moved more likely towards to the right. This could be found from the Figure 6.4, the bar with no colour represents the parameter that user order to the robot and the bar with orange colour represents the actual parameters that robot is making. Even though the angular velocity is set to 0 rad/sec, the robot is running with the angular change. The possible cause will be the time lag between the two wheel motors getting the signal. If one side of the motor receives the signal earlier, the wheel starts to rotate earlier than the other side, causing one-sided run of the robot. This can be very critical issue for the robot running for long term.

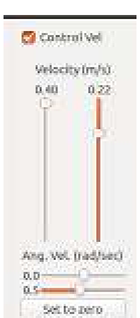


Figure 6.4: GUI showing the robot not walking goes straight.

From the results of shooting experiment, the result shows the lighter balls goes further than those heavier one. In addition, the result shows all the ball that made of foam made good outcomes. All the other balls, especially those with made of rubber made poor outcomes. The friction between the ball and the body is one of the factors that disturbs hitting the ball, but the major causation is the balance of the ball affected by the weight of the valve hole attached to the ball. By the valve hole, the ball likely to put it at the bottom to stand due to the hole's weight and when the ball receives the force from outside, if the force is not enough to roll the ball until the valve hole goes to the other side, the ball returns to its original position as the weight of the valve hole is yet at the side of the robot. Furthermore, if the valve hole crosses the boundary, the ball likely to rolls to the direction the valve hole it falls down, causing bad accuracy of sending the ball to target position.

From the results of dribbling experiment, it showed the size of the ball mattered the performance of dribbling motion. Controlling the smaller ball gives less likely to lose the ball as the small is within the gap between two cliff sensors and gets easier to detect every time the ball tries to go out the range. Another find is similar to the walking, which is the material of the ball affected to the robot controlling the ball. The dribbling motion is continuous open-loop algorithm motion, therefore it gives enough forces until the ball rolls. Nevertheless, enough force is given and the valve hole could cross the boundary, if the velocity of the robot is not faster than the ball rotates, the ball rolls faster than the robot, resulting lose of ball control. This can be seen to all the balls that have valve hole. The last factor is the shape of the ball, where the ball 2 is the only ball with uneven surface and this led the ball rotates to random direction.

From the results of passing and ball stopping experiment, size of the ball influenced again. If the ball is too big, head of the robot cannot fully lifted down and if the ball is too small, the head of the robot could lifted down fully but not enough to reach to the surface of the ball. For the passing motion, position of the balls impacted to the performance of passing motion. It is found that the success rate increases if the motion is passing the ball to the direction and the ball is positioned more likely to the that direction from the center of the robot's body.

From the challenges, as mentioned above, the problem was found from linking walking motion to the passing motion caused by existence of the rubber attachment of the robot's nose. This implies the design of the nose attachment has to be changed if desired to maintain the passing motion or change the passing motion in a way that nose part is not used if desired to maintain the design of robot. Another factor is the lag when two MiRo robots are run at the same time. To use the ROS nodes, roscore must be connected with network. Roscore is the collection of nodes that are essentials of a ROS-based system. Before the fix, there was a problem to the way running the two robots together. When running the two robot, each of them was running connecting to the separate roscore in one network, caused time lag and confusion of sending the data and information from the roscore to the robots. The fix is made by letting both robots use same roscore network and this made fewer lags, though, the little lags still exist. Because the viewing of the cameras are wider than expectation, they catch more views than required, including the surrounding views outside the field. The football field has to be surrounded by one colored and high enough barriers to not give any confusion for object detection.

To conclude, it is discovered the ideal type of the ball for MiRo to show its best performance is small, round, light and made of foam. Most of the motions were robust and performed well with using the ball that closest to the ideal type. There needs a change to either passing motion or the design of the robot for the corner kick challenge and definitely change the environment of football field. Running two MiRo robots requires more research to solve the lagging issue.

6.0.3 Further research

This project is a starting point of how to use MiRo robot in a various ways by making it play football. The project went along as a group project with each participant takes one task each. The progress of the work was slow but steady since it was needed to collaborate with each participants work and implement them together. However, to make clear, there was no collusion during this process. In this section, possible further researches will be discussed, mainly focusing on the topic of ball control. Since this project is very first milestone of the making MiRo robot playing football, current researches will be helpful in the future.

From the current project, it was able to set the good first start point, however, there were some works which could not be completed due to lack of time. One of them is path finding from the start point to target point. While walking or dribbling, if the MiRo robot could find different paths to achieve the goal, more challenges could be tested, such as walking or dribbling with avoiding the obstacle on the field. It can also be used for shooting with avoiding the goal keeper around the goal post. Another work possibly done is accurate calculation of motor power usage. For now, MiRo only goes straight to the forward with full speed. If it can calculate the required time and motor speed depends on the distance between the robot, the ball and the goal post. It can change the direction while running to shoot and save time and battery for executing shooting motion. Finally, from the algorithm of dribbling, there is no element for the robot to recognize the ball is under control. If the ball is removed during dribbling, the MiRo robot will keep rotate around at the point where it missed the ball. These works could be another project in the future.

It is found that there are more investigations prompted by developments in this project. The first possible research will be how to make the MiRo robot able to carries the ball while it is contacting with the ball. As it is mentioned in the previous section, the design of the MiRo robot was not considered to play football. Possible works can be making a new model of MiRo robot with a change of design of the robot itself or developing the attachment only for the football. Changing design of the robot such as making a body less curved or remove the rubber attachment of the nose. Changing the design of MiRo robot requires a high costs of materials and a lot of time. On the other hand, designing the attachments, such as the claw to put in front of the body, could be done simply by 3D printing with lower costs. Another possible solution can be putting more suitable sensors, such as more hidden cameras to the robot. More sensors not only increases more options for playing football but also can give more possibilities for usage of Miro robot for other purposes too. The second possible research will be how to make the motor power more powerful and efficient. If the robot able to put more power to perform an action, it can show a better result, for example, it can shoot further, dribble faster and pass further. The last possible research will be making the multiple robots play football together on same field without order from the user. To do this, it requires making the MiRo robot automatic instead of receiving signals or codes from the users. The codes should be installed in raspberry pi within the MiRo and once it's run, should play the football by themselves. This is expected to be the hardest challenge of all.

Chapter 7

Conclusion

The results of this project was very satisfied. Some aims of the project were not fulfilled, however, it has successfully shown the possibility of MiRo robot entering RoboCup competition. Some challenges were not accomplished due to lack of time, but the basic and main tasks were resolved. The approaches from this project will be given to future researchers who will continue making MiRo robots play football. At the end, it is expected to see MiRo robot competes against other robots in RoboCup league.

This report is focused on ball controlling task within many tasks separated from one big project. The research about ball control, which is main aim and objective of this report, is usually the one of the major sub-topic of other robot football literature. Every developer of robots had to consider the most efficient and powerful ways to perform each motions, thus there were supporting references in the state of the art. The unique design of MiRo robot was the most difficult problem to solve to perform other verified motions from other researches, but good adaptation to its uniqueness was the key for the solution. Some other challenges were from outside, such as technical issues and these led to in-completion of some tasks and set challenges. Each dynamic motions were successfully developed but implementing them with other parts required extra time and effort.

The designs of each motion were changed due to various reasons. It was expected that the results from the simulator and the real world could be different, but it was not expected that the few parts of spec of the MiRo robot in real world did not satisfy the minimum expectation, especially the motors power. The shape of the MiRo robot, such as the round body and the nose, was also insufficient to implement the initial designs of some motions. As a result, many trials and errors were done in order to find the suitable ones ans tested to prove their robustness and reliability.

The present project left some results about various experiments about each developed motions. Some of them showed expected outcomes and some were not. From the results, they showed that the motions functioned for most of the time. The only motions that requires further research is passing motion, which had a lot of limitation to perform its behaviours. The results showed not only the motions themselves, but the outside factors were also important too. Usage of the different types of balls, condition of the field, the condition of the network and even the performance of other linking tasks influenced the overall results of the MiRo robot plays football.

The main objective of the project was fulfilled, it was able to develop the motions to make the MiRo robot plays football, on the other hand, achieving the challenges were different task to do. To find the realistic possibility of usage of the motions to the real football game play, they were implemented to do the penalty kick and corner kick situation with collaboration of development from other tasks, the 'Scene perception' and the 'Strategy', that separated at the early stage of this project. As the result, each challenge was completed partially but showed good possibility about MiRo robot can play the football.

Some limitations were found such as the time lag issue by operating more than one robot together, the condition of the field was not the best and some motions were not performed sequentially well after one is done. Due to lack of time, some parts of the challenges could not be improved, such as finding the path to avoid the obstacles on the path, accurate usage of motor powers to shoot depends on the distance from the ball to the goal post and recognition of existence of the ball under control. From the current project, some suggestions made for production of better results in the future, which are changing the design of the robot, putting more sensors to the robot and making the robot autonomous. These limitations and improvements are expected to be researched in the future.

Lastly, it is believed that this report provides good amount of data and overview about the project of making MiRo robot play football. The project was good practice of development area, provides insights in robotics and improves the task solving skills.

Bibliography

[1] C. Laboratory, "Miro: Introduction," Consequential Laboratory. [Online]. Available: https://consequential.bitbucket.io/Information$_{P}ack_{I}ntroduction.html$

[2] S. Najib, S. Salim, and M. Zainon, *Control Systems Engineering.* UTeM Press, 2010.

[3] H. L. T. Committee. Development of the league. [Online]. Available: https://www.robocuphumanoid.org/league/history/

[4] "Nao documentation aldebaran 2.1.4.13 documentation," Doc.aldebaran.com. [Online]. Available: http://doc.aldebaran.com/2-1/home$_{n}ao.html$

[5] C. Graf, A. Hrtl, T. Rfer, and T. Laue, "A robust closed-loop gait for the standard platform league humanoid," 12 2018.

[6] A. Sandu, "Nao robot football - movement and coordination," 2016.

[7] Robocup.org, "A brief history of robocup," Robocup.org. [Online]. Available: https://www.robocup.org/a$_{b}rief_{h}istory_{o}f_{r}obocup$

[8] B. Mitchinson and T. J. Prescott, "Miro: A robot "mammal" with a biomimetic brain-based control system," in *Biomimetic and Biohybrid Systems*, N. F. Lepora, A. Mura, M. Mangan, P. F. Verschure, M. Desmulliez, and T. J. Prescott, Eds. Cham: Springer International Publishing, 2016, pp. 179–191.

[9] D. Geere. (2015, September) A history of humanoids - how weve recreated mankind in metal through time. [Online]. Available: https://howwegettonext.com/watch-a-history-of-humanoids-9708a4a0d42

[10] M. F. Stollenga, "Advances in humanoid control and perception," 2016.

[11] G. J. D. Todd S. Ellenbecker, *Closed Kinetic Chain Exercise: A Comprehensive Guide to Multiple Joint Exercise.* Human Kinetics, 2001.

[12] R. Kaufman, "Robocup 2010: Could robot versus human be far behind?" 2010.

[13] D. Golubovic, B. Li, and H. Hu, "A hybrid software platform for sony aibo robots," in *RoboCup 2003: Robot Soccer World Cup VII*, D. Polani, B. Browning, A. Bonarini, and K. Yoshida, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2004, pp. 478–486.

[14] M. Akhtaruzzaman and A. Shafie, "Evolution of humanoid robot and contribution of various countries in advancing the research and development of the platform," pp. 1021 – 1028, 11 2010.

[15] J. S. U. S. Thomas Roefer, N. Michael Mayer, "Application of the 'alliance algorithm' to energy constrained gait optimization," in *RoboCup 2011: Robot Soccer World Cup XV*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2012, pp. 472–483.

[16] S. Czarnetzki, S. Kerner, and O. Urbann, "Observer-based dynamic walking control for biped robots," *Robot. Auton. Syst.*, vol. 57, no. 8, pp. 839–845, Jul. 2009. [Online]. Available: http://dx.doi.org/10.1016/j.robot.2009.03.007

[17] H. Kitano, M. Asada, I. Noda, and H. Matsubara, "Robocup: robot world cup," *IEEE Robotics Automation Magazine*, vol. 5, no. 3, pp. 30–36, Sept 1998.

[18] Robocup final 2005 part 1 (sony aibo dogs). Youtube. [Online]. Available: https://www.youtube.com/watch?v=lhYdQbSq5Mo

[19] P. G. Srgio Monteiro, Fernando Ribeiro. (2001, April) Problems and solutions in middle size robot soccer a review. [Online]. Available: http://hdl.handle.net/1822/3176

[20] R. Hoogendijk, "Design of a ball handling mechanism for robocup," 2007.

[21] H. Kitano, M. Asada, Y. Kuniyoshi, I. Noda, E. Osawai, and H. Matsubara, "Robocup: A challenge problem for ai and robotics," in *RoboCup-97: Robot Soccer World Cup I*, H. Kitano, Ed. Berlin, Heidelberg: Springer Berlin Heidelberg, 1998, pp. 1–19.

[22] J.-H. Kim and P. Vadakkepat, "Multi-agent systems: A survey from the robot-soccer perspective," *Intelligent Automation Soft Computing*, vol. 6, pp. 3–17, 01 2000.

[23] F. Ribeiro, C. Machado, S. Sampaio, and B. Martins, "Minho robot football team for 2001," in *RoboCup 2001: Robot Soccer World Cup V*, A. Birk, S. Coradeschi, and S. Tadokoro, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2002, pp. 657–660.

[24] B. Browning, J. Bruce, M. Bowling, and M. Veloso, "Stp: Skills, tactics, and plays for multi-robot control in adversarial environments," *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering*, vol. 219, no. 1, pp. 33–52, 2005. [Online]. Available: https://doi.org/10.1243/095965105X9470

[25] H. Kitano, M. Asada, Y. Kuniyoshi, I. Noda, and E. Osawa, "Robocup: The robot world cup initiative," in *Proceedings of the First International Conference on Autonomous Agents*, ser. AGENTS '97. New York, NY, USA: ACM, 1997, pp. 340–347. [Online]. Available: http://doi.acm.org/10.1145/267658.267738