Ball Handling System for Tech United Soccer Robots

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Preface

This report is the result of my pre-master project and is performed as closure of the pre-master program for my study Mechanical Engineering at Eindhoven University of Technology. This project is carried out under the section Control Systems Technology. The reserved time for this project is 252 hours, which equals 9 ECTS. I have worked on this project form April until August of 2012.

My pre-master end project is done for the Tech United Robocup team of Eindhoven University of Technology. The Tech United team is a group of students and employees who design, build and program soccer robots to compete in the RoboCup Middle Size League. RoboCup is a worldwide competition in which two teams of autonomous robots play soccer, with the ultimate goal of beating the human world champion team in the year 2050. There are different leagues in RoboCup, including the small-size league, the middle-size league and the humanoid league. The middle-size and small-size league have wheeled robots opposed to the humanoid league where the robots are made to move like humans and therefore have to walk.

This thesis is performed with coaching of Rob Hoogendijk, PhD student at Eindhoven University of Technology and team member of Tech United Eindhoven. For the completion of this report I want to thank the Tech United team for their input in this project, and in particular I want to thank Rob Hoogendijk for his coaching.

Eindhoven, August 28, 2012

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Chapter 1

Introduction

1.1 Background

RoboCup is an international research and education initiative, attempting to foster artificial intelligence and robotics research by providing a standard problem where a broad range of technologies can be integrated and examined, as well as being used for integrated project-oriented education.

For this purpose the RoboCup organization chose to use the soccer game as a primary domain, since it is the most popular sports game in the world. Choosing a popular field creates more affinity in the community thus more exposure in the field of education and media. Every year RoboCup organizes the Robot World Cup Soccer Games and Conferences. The contest currently has four major competition domains, each with a number of leagues and subleagues[1]:

- RoboCup Soccer
  - Standard Platform League
  - Small Size League
  - Middle Size League
  - Simulation League
    - 2D Soccer Simulation
    - 3D Soccer Simulation
  - Mixed Reality Competition
  - Humanoid League

- RoboCup Rescue
  - Rescue Robot League
  - Rescue Simulation League

- RoboCup@Home

- RoboCupJunior
  - Soccer Challenge
  - Dance Challenge
  - Rescue Challenge
  - General
Each team is fully autonomous in all RoboCup leagues. Once the game starts, the only input from any human is the referee.

Team Teach United from Eindhoven University of Technology currently participates in the Middle Size League, Humanoid League and the RoboCup@Home. In the year 2012 team Tech United won the title in the Middle Size League after having lost the finals for four years in a row.

In order for a robot team to actually perform a soccer game, various technologies must be incorporated, including: autonomous agent collaboration, real-time planning and control, robotics and sensor-fusion.

The RoboCup federation proposed the ultimate goal of the RoboCup Initiative to be stated as follows:

“By 2050, a team of fully autonomous humanoid robot soccer players shall win a soccer game, complying with the official FIFA rules, against the winner of the most recent World Cup of Human Soccer.”[1]

1.2 Motivation

This report presents a study to improve the performance of the ball handling system for soccer robots of team Tech United. This year’s regulations state a robot must make a pass before crossing the middle line of the field opposed to previously where a robot which has possession of the ball would dribble from anywhere on the field towards the opponent’s goal and try to score. The current robots have an excellent ball handling capability but have limited performance when accepting passes. In order to stay competitive in the MSL a gain in performance with accepting passes is desired.

1.3 Objectives

The aim for this project is to design a new ball handling system for the soccer robots of team Tech United. The main objective is a working system whereof the performance is better over the current ball handling mechanism. Within the framework of the author the objectives of this thesis are listed as follows:

- Analyze the current design and identify where the reduced performance when accepting a pass is originated;
- Model the current ball handling system (using Matlab SimMechanics) and analyze the performance;
  - Compare results from the simulation with measurements of the robots to test accuracy of the model;
- Generate an improved design of the ball handling system;
  - Realize a prototype of the new design;
  - Setup a test plan to evaluate the constructed prototypes;
  - Perform field tests and compare to original design to see if there is an increase in performance.

1.4 Outline

Chapter 2 describes the principle design of the ball handling system on the current Turtle soccer robots, explaining the working principal, listing the advantages and disadvantages. Furthermore the requirements for an improved design are given in this chapter.
Chapter 3 describes the simulation model made of the ball handling system.

Chapter 4 shows the design proposal for increasing the performance of the ball handling system on the Turtle soccer robots.

Chapter 5 describes the tests required to assess the performance of the designed ball handling mechanism.

Chapter 6 lists the conclusions and recommendations of the design of an improved ball handling system.
Chapter 2

Current Design

This chapter briefly describes the Turtle robot and the regulations to which it has to comply. An in
depth view of the current ball handling system gives a perspective where the reduced performance
when accepting a pass originates. Furthermore, a list of requirements for the new design is made,
these requirements and the analysis of the current design lead to a design proposal constructed in
Chapter 4.

2.1 RoboCup Rules and Regulations

Robots that participate in the Middle Size League should comply to the rules and regulations
of the league [2]. The rules relevant for the ball handling mechanism are extracted and are as
following:

- During a game the ball must not enter the convex hull of a robot by more than a third of its
diameter except when the robot is stopping the ball. The ball must not enter the convex hull
of a robot by more than half of its diameter if the robot is stopping the ball. This case only
applies to instantaneous contact between robot and ball lasting no longer than one second.
In any case it must be possible for another robot to take possession of the ball.

- The robot may exert a force onto the ball only by direct physical contact between robot and
ball. Forces exerted onto the ball that hinder the ball from rotating in its natural direction
of rotation are allowed for no more than one second and a maximum distance of movement
of one meter. Exerting this kind of forces repeatedly is allowed only after a waiting time of
at least four seconds. Natural direction of rotation means that the ball is rotating in the
direction of its movement.

- Ball rotation also implies that the ball is rotating continuously, even if slightly slower than its
natural rotation speed. Movements of the ball such as “roll-stop-roll-stop” are not considered
a valid ball rotation and will be considered ball holding.

- Dribbling the ball backwards, that is, dribbling while the robot is moving towards the op-
posite direction of its relative position to the ball is allowed for a maximum distance of two
meters. During the backward dribble the ball must also be rolling in its natural direction.
Once any particular robot has dribbled the ball backwards for more than one meter, it can-
ot repeat the same backward dribbling action again before the ball has been completely
released by that robot or until the robot has engaged a new ball struggle against an opponent
robot (i.e. the ball is actively disputed between the two opponent robots for more than two
seconds).

- Violating any of the above rules is considered ball holding.
Item one is clarified by Figure 2.1. The insertion of the ball holds for both top view and side view. The current design of the ball handling system of the Tech United Turtle robot makes no use of the rule that when stopping a ball it may be inserted in the robot by half its diameter.

![Diagram](image)

(a) Ball stopping  
(b) Otherwise

Figure 2.1: RoboCup ball stopping

### 2.2 Turtle Soccer Robot

The soccer robots used by team Tech United are named ‘Turtles’ which stands for Tech United RoboCup Team Limited Edition. During a soccer match five robots per team are at play. For team Tech United all of the robots have equal hardware, except for the goal keeper, which has a different platform with four instead of three wheels. The base of the field robots consists of an aluminium platform which can move unidirectionally due to three omniwheels. Robots determine their position with a camera mounted on top. This camera faces upward towards a parabolic mirror, creating omnivision. Communication is done with the use of a wireless connection, the robots signal their position to the other team members so each of the robots knows the position of one another. At the front of the robot the ball handling- and shooting mechanism is positioned. The ball handling provides ball manipulation capabilities when the shooting mechanism creates the ability to pass/shoot the ball. The shooting mechanism consists of a kicker leg which is actuated with a solenoid piston. The height of the pin that impacts the ball is variable creating the ability of shooting high or low passes. The ball handling mechanism is described in more detail in Section 2.3. The remaining space on the robots is reserved for the batteries and control computers. Figure 2.2 illustrates the Turtle robot.

### 2.3 Current Ball Handling System

The current ball handling system relies on two wheels to actively exert forces on the ball for manipulation. The wheels are mounted to spring loaded arms, keeping the wheels in contact with the ball. At the bottom of the robot two omniwheels are mounted and are used to prevent the ball being inserted into the shell of the robot by more than one-third of the diameter of the ball. Both of these wheels are fitted with an solenoid operated brake, when passing a ball the ball handling wheels pull the ball all the way back against the omniwheels with the brake applied stopping the rotation of the ball prior to shooting. To control the movements of the ball, the wheels feature a closed-loop two level control architecture [4]. This controller enables the robot to keep the ball while performing complex dribbling manoeuvres. The controllers low level regulates the wheels angular velocities. At the high level a supervisory loop determines wether or not the ball handling
system needs to be activated such that the wheels are driven to match the velocity of the robot. The different velocities of the components of the ball handling mechanism are depicted in Figure 2.3.

On the arms of the robot a potentiometer gives feedback on the arms position, which gives information on the position of the ball relative to the robot. The arms rotate about a pivot point on the base of the robot and at the top of the arms a stroke limiter with a spring is connected. The springs provide the arms the ability to exert a force on the ball in the forward direction. Figure 2.4 shows the ball handling system of the current Turtle robots.

2.3.1 Positive Features Current Ball Handling

The system with the two-wheels is to be seen as a proven concept. Team Tech United introduced this system on the third generation of their Turtle robots in 2007, being the the first team with a ball handling system consisting of two moveable arms with actively controlled wheels. Nowadays most of the teams participating in the MSL use a version of the two-wheeled ball handling system. The main distinctions in ball handling systems originate in wheel position, wheel type and underlying controllers. Therefore a total new concept will not be developed, rather a new iteration of the current system. The positive features are listed as follows:

- The arms are able to hinge inwards about a pivot point on the base, meaning when the robot is in a head on collision with an opponent, the arms will hinge inside the body rather than
Figure 2.3: Different velocities of the components of the ball handling mechanism during dribbling. Note that in both figures the nett velocity of the ball is always directed at the robot, ensuring the ball being pushed towards the robot.

Figure 2.4: Front view of the current ball handling mechanism. The arm on the left is depicted in the lower position while the right arm is fully retracted.

- To protect the arms against sideways impacts the arms hinge shafts are mounted in rubber blocks for extra compliance axially;
- The driven wheels force the ball to rotate during dribbling actions. The RoboCup rules state that during dribbling actions the ball should always rotate in its natural direction;
- At all times the current motor has enough power to spin the wheels.
2.3.2 Negative Features Current Ball handling

The current ball handling system lacks performance when accepting passes. When looking at the points where the ball is able to contact the robot one can see from Figure 2.5 that the wheels contact the ball only at the outer most edge of the tire. Resulting from this edge contact are some negative aspects. The negative features are listed as follows:

- **Limited horizontal interception angle:**
  The hinges of the base are placed at an angle of 46.2 degrees referenced from the robot center line. When a ball approaches at an angle the nett angle between the direction of the ball and the hinge line is reduced, compromising the working of the hinge, which works best being perpendicular to the approach direction of a ball.

- **Small contact area between tire and ball:**
  When the rubber tires deforms under the impact of the ball, a reasonable chance exists the ball contacts the aluminium rim of the wheel. This hard contact between the ball and the rim results in the ball bouncing away from the robot, resulting in unwanted ball loss.

- **Wheel is mostly covered by the construction of the arm:**
  To protect the wheel from impacts of opponent robots during soccer matches the arms are constructed in such a way the arm covers most of the wheel, except the areas coming into contact with the ball during normal use. There are situations imaginable where the ball contacts the arms instead of the wheels.

- **Location of the hinge results in the spring force being directed to the ball:**
  The hinge location of the arms being at the base of the robot and the spring mounted horizontally at the top of the arms, during dribbling the force of the springs is directed at the ball, pushing the ball away from the robot.

2.4 Design Requirements

- **Comply to rules and regulations of the middle size league:**

- **The horizontal angle at which the robot is able to catch the ball should be as large as possible:**
  By enlarging the angle at which the robot is able to catch a ball, the number of successful ball interceptions increases.

- **The ball handling mechanism should form as less as possible an obstruction when passing/shooting the ball:**
  The shooting mechanism remains unchanged as it is functioning correctly within the current performance requirements. Maintaining this performance means the new ball handling mechanism may not obstruct the current shooting mechanism.

- **The new design should fit in the current Turtle robot:**
  Tech United intents to use the current robot for the coming season, but extra performance on the ball handling mechanism is desired, meaning a proposed improved design fits the current platform of the robot.

- **The new ball handling system makes use of the current wheels and electric motors:**
  The ball manipulation / dribbling behavior depends largely on the underlying controller. The current controller is based on these wheels and motors. By making use of the current components the controller remains unaltered. Furthermore for cost reduction the motors are kept.
Figure 2.5: Front view of the current ball handling mechanism. The arm on the left is depicted in the lower position while the right arm is fully retracted. The contact point between the tire and the ball is clearly visible.

- The design should be robust, i.e., able to withstand the impact force of an opponent robot; This requirement is not so much valid for a prototype, but for a final design even more so. During a soccer match collisions between the robots and their opponents occur on regular basis. Having a robust ball handling system means the system will not have to be replaced every match.

- High performance dribbling behavior; Increasing the ball catching performance may not be at the expense of the dribbling behavior. Both dribbling and ball interception occur at a frequency during soccer matches and the robot should excel at both.

- When the dribbling mechanism is in contact with the ball, the position of the ball is measurable; For the robot it is important to have the position of the ball with respect to the robot. When for instance a maneuver is planned were the robot makes a turn around the center of the ball, knowing the location of the center of the ball is key.
Chapter 3

Ball Catching Simulation

In order to optimize design parameters of the ball handling system a model is made. The design parameters include the mass and stiffness of the arms, the amount of damping and the geometry of the system. This chapter focuses on a model made of the current situation. The choice made to model the current situation lies in the opportunity to evaluate the results by comparing them to measurements done on the actual robots. Furthermore the model will be assessed to see if it can be used to predict the ball catching behavior of a new design. The process of creating a model is split into different sections. In Section 3.1 a simple mass-spring-damper model is made for general understanding. Section 3.2 describes the more elaborate model made of the current design.

3.1 Basic mass-spring-damper system

For general understanding of the software first a simple mass-spring-damper model is made and both analyzed analytical and using SimMechanics, see Figure 3.1. The model represents a ball with a certain velocity contacting a mass which is connected to the world with a spring-damper combination. In this model the mass reflects the mass of the arms on the ball handling mechanism.

![Figure 3.1: Simplified 2D model of the ball handling mechanism](image)

3.1.1 Analytical solution

The input of the system is a force $F_b$ which acts on the mass $m_a$. This force is the impact force of the ball on the arms. The impact force is equal to

$$F_b = v_b \sqrt{m_b k_b}, \quad (3.1)$$

where $v_b$ is the ball velocity, $k_b$ the ball stiffness and $m_b$ the mass of the ball.

Creating a free body diagram of the system illustrated in Figure 3.1, the equation of motion results in

$$F_b = m_a \ddot{x}_a + b_a \dot{x}_a + k_a x_a, \quad (3.2)$$
Figure 3.2: Response of the system with a ball approaching at different velocities, result produced using Matlab

To view the response to the input $F_b$, a Laplace transformation is applied to (3.2) resulting in the transfer function

$$H(s) = \frac{1}{m_a s^2 + b_a s + k_a}.$$  \hspace{1cm} (3.3)

The system is evaluated with the parameters listed in Table 3.1. The spring rate results from a catalog value from the spring manufacturer, the damping coefficient is an estimate based on the other model parameters and the stiffness of the ball results from a paper[6]. The ball mass used is the mass of an official FIFA approved indoor soccer ball. The response of the arms (mass $m_a$) is plotted in Figure 3.2.

### Table 3.1: Model parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_a$</td>
<td>Spring rate</td>
<td>$6.6 \times 10^2$</td>
<td>$[N/m]$</td>
</tr>
<tr>
<td>$b_a$</td>
<td>Damping coefficient</td>
<td>$1.0 \times 10^2$</td>
<td>$[N/(m/s)]$</td>
</tr>
<tr>
<td>$m_a$</td>
<td>Mass arms</td>
<td>1.2</td>
<td>[kg]</td>
</tr>
<tr>
<td>$m_b$</td>
<td>Ball mass</td>
<td>$4.34 \cdot 10^{-1}$</td>
<td>[kg]</td>
</tr>
<tr>
<td>$k_b$</td>
<td>Ball stiffness</td>
<td>$22.2 \times 10^3$</td>
<td>$[N/m]$</td>
</tr>
<tr>
<td>$v_b$</td>
<td>Ball velocity</td>
<td>2-8</td>
<td>$[m/s]$</td>
</tr>
</tbody>
</table>

### 3.1.2 SimMechanics solution

The same basic system is analyzed in SimMechanics. The system is evaluated with the same parameters as the analytical solution. In order to verify the correctness of the model the solution is produced with four different ball velocities. The mass $m_a$ is represented by a body with equal mass and inertia properties. The spring damper combination is reproduced with a body spring
and damper block. Appendix A shows the model used in this simulation. In Figure 3.3 the results of the simulation are plotted. When comparing the results to the plot in Figure 3.2 one can see the results are equal.

Both the models produced analytically and with SimMechanics produce equal results, meaning the SimMechanics is valid, though the model is simplified in such a way it does not accurately represents the ball handling mechanism. In Section 3.2 a description is given of a more accurate model.

### 3.2 Model of the current ball handling system

The model of the current ball handling system consists merely of bodies, joints, springs and dampers. For this model the contact between the tire and the ball is not included. The ball is connected to the arms with a massless body. Between the body and the arm a spring damper combination is added simulating the elasticity of the ball. In the real world situation the ball is only able to exert a force on the robot in the direction towards the ball is traveling. To simulate this the spring-damper combination is fed through and if-else block. The force vector is compared to zero, when negative, the vector is set to zero, when positive the vector keeps the value it had originally.

#### 3.2.1 Simulation results

The results from this simulation show the initial part of the ball catching process where the energy of the ball is absorbed by the springs and provided damping in the system. On the Turtle the ball position is controlled after the arms used their full travel, this is seen in Figure 3.5(a). In the simulation model the control software and tire model are not included, resulting from this the ball position is not controlled when the full stroke of the lever is used. The result of the lever hinge angle of the simulation is plotted in Figure 3.5(b). To compare the plots only the area between the vertical lines is relevant. The area of the plot between the lines show similarity between the
simulation and measurement. A plot of the velocity of the ball is given in Figure 3.6, where it can be seen that the velocity approaches zero when the levers use their full stroke. With the information of this simulation the spring damper combination can be optimized to dissipate all the energy of the ball for a certain ball velocity, however this is difficult to accomplish in the Turtle robot. The damper constant in the model is an estimation of that of the Turtle robot. In the Turtle robot no physical damper is constructed in the robot, the dampening in the system results from the control software of the ball handling mechanism and is therefore not constant which makes it difficult to simulate.

To conclude the simulation, the initial part of the simulation shows similarity with the measurements on the Turtle robot but the model misses depth to accurately replicate the process of ball catching on the robot. Due to time restrictions for this project and complexity the model is not expanded to include the controller and tire model. Not having a tire model means the position of the wheels on the ball have no influence in this simulation. To find improvements for the current ball handling system the simulation is further not used.
Figure 3.5: Plots of the arm hinge angles from both simulation and measurement on the Turtle robot
Figure 3.6: Ball velocity during simulation
Chapter 4

Concept Design

From the list of requirements in Section 2.4 a concept design is generated. The ideas for this concept come from the analysis of the current ball handling system, discussion with other Tech United members and with the people from the Equipment and Prototype Center of Eindhoven University of Technology. This chapter gives an in depth view of the new ball handling mechanism. First the basic idea of making an adjustable wheel position is discussed, followed by the technical realization of the concept.

4.1 Adjustable Wheel Position

Most of the required gain in performance when accepting passes on the ball handling mechanism is expected to be realized by altering the position of the current wheels. At first different wheel positions were visualized in CAD software, discussion of these different positions lead to one conclusion: The different concepts look promising, but all the positions are based on visual estimates and thus impossible to find the optimal concept. After this conclusion the idea of making adjustable arms for testing purposes is proposed. For clarification on the different adjustment possibilities on the wheels a coordinate system is introduced in Figure 4.1. From this point the adjustments will be referred to as rotations over the $\varphi$, $\psi$- and $\theta$-axis, the translations are named $x$, $y$ and $z$. For the ball handling system making the translation over $x$ and the rotations over $\psi$ and $\theta$ are considered relevant. In the upcoming sections the different degrees of freedom are discussed.

4.1.1 Adjustment over $\psi$-axis

Seen in Figure 2.5, the wheels of the current ball handling mechanism contact the ball at the very edge of the tire. Resulting from this, the contact surface between tire and ball is not as large as is possible. For optimization of the grip on the ball it is preferred to place the tire with the center on the ball rather than the edge. By varying the position of the wheel over the $\psi$-axis, different contact points between the tire and the ball can be explored. Figure 4.2 illustrates the wheel in original position at the right side and some possible wheel positions when there is the ability to adjust the wheel over the $\psi$-axis.

4.1.2 Adjustment over $\theta$-axis

At the contact point between the tire and the ball perpendicular to the axis of rotation of the wheel a force-vector can be constructed. The length of this vector is determined by the amount of grip the wheel has on the ball, the friction coefficient and weather there is a speed difference between the surfaces. The direction is determined by the height at which the arms contact the ball and the direction of the rotational axis of the wheel. While the magnitude of the force-vector can be altered by adjusting the position over the $\psi$-axis, the direction can be varied by adjusting the
4.1.3 Adjustment over $x$-axis

By varying the position of the arms over their $x$-axis the distance between the arms is adjusted. The distance between the arms can be of importance when accepting offset passes, therefore testing different positions is preferable.
4.1.4 Remaining Degrees of Freedom

The remaining degrees of freedom are rotation around the $\varphi$-axis and translation about $y$ and $z$. The two translations remain unrestricted, these translations are required for the lever to be able to hinge. The path at which the wheel translates is defined by the length of the lever and the orientation of the hinge-axis. The rotation around the $\varphi$-axis is chosen to be fixed in the new design to reduce the number of possible settings on the ball handling mechanism. The rotations over the $\theta$- and $\psi$-axis are estimated to have a greater influence and are therefore chosen to be made adjustable.

4.1.5 Base Hinge Angle

Modifications are made to the lower hinge base of the arms, see Figure 4.1. The hinge is moved upwards and the angle of the hinge is also altered. Moving the hinge upwards has two advantages over a hinge at the base of the robot. By placing the hinge higher the arms are shorter for an equal position on the ball resulting in lower weight and more important reduced inertia. The other advantage originates in the force the arm can exert on the ball, with a low hinge point the arm pushes against side of the ball, compared to a higher hinge point where the arm presses more on top of the ball. By pressing on the ball an increase in the ability to keep control over the ball in robot to robot scrums is expected.

4.1.6 Spring Mount

To eliminate the influence of the mounting position of the spring on the rotational adjustments on $\theta$ and $\psi$ a lever is constructed on the lower part of the arm. This lever does change position when adjustments to the $x$-axis are made. The mounting point on the robot frame is fixed, meaning the adjustments made will alter the length of the spring, however the difference is spring length between the various settings amounts to only 0.56mm and is therefore negligible.
4.2 Components

In order to determine the optimal geometry for the ball handling mechanism decided is to design a prototype with adjustable geometry. The influence on the ball handling performance of a particular adjustment on the arms can only be determined when the remaining adjustments have no effect on this. For instance when a setting on the $\psi$-axis is modified this has no influence in the $\theta$- and $x$-settings. For the prototype design this independency is accomplished by placing the joints in the hardware on the axis of the desired degree of freedom.

For the realization of the rotational degrees of freedom a shaft placed inside a clamping bush is used. When tightening the clamping bolt the shafts are locked by means of friction. This principal is used for both $\theta$ and $\psi$. To realize the translational freedom, the lower part of the arm, which is mounted in the hinge bracket on the robot, is designed narrower than the width of the hinge bracket, enabling the part to translate. To lock the arm in the desired setting the remaining space on both sides of the hinge axle is shimmed using washers. With the use of standard washers the translation in $x$ direction can be set in increments of 1.6mm. The components of which the new designed arm consists of are depicted in Figure 4.4.

The hinge base is mounted to the base plate of the robot. In the new design the hinge is move upwards by 50 mm, this is done by designing an extended hinge base that is mounted inside the original base. By moving the hinge upwards the force-arm is increased resulting in an enlarged moment on the base. Furthermore the stiffness of the hinge is lowered by placing an extension mounted on the base of the robot. To accommodate for both the reduced stiffness and increased moment a bracket is constructed diverting the force on the hinge backwards towards the base of the robot. The designed components are illustrated in Figure 4.5. Furthermore, two stroke limiters are placed on the extended hinge base for easy stroke adjustment of the prototype arms.

![Figure 4.4: Exploded view of the right arm from the new ball handling mechanism](image-url)
4.3 Arm Positions

Due to the large amount of possible settings on the ball handling system visualizing all of them is not possible. In Figure 4.6 a side view of the robot is illustrated. Subfigure (a) illustrates a random setting of the arm where the ball makes the first contact with the robot. In subfigure (b) the ball is at maximum insertion contacting the omni wheels of the ball handling mechanism.

Figure 4.6: Side view of the base of the robot with the new ball handling mechanism

A front view of the ball handling mechanism is given in Figure 4.7, where both the ball at maximum insertion as well as first contact is illustrated. For this image it also holds that just one of the many settings possible is depicted.
Figure 4.7: Front view of the base of the robot with the new ball handling mechanism. On the left the ball is at maximum insertion, on the left the lowest position of the arms is shown.
Chapter 5

Test plan

In this chapter a plan is made to find the setting that gives the best performance of the ball handling mechanism. With the arms having three independently adjustable degrees of freedom, goal is to see if one of these settings has a significant effect on the performance of the ball handling mechanism.

5.1 Performance of the ball handling mechanism

In order to assess the performance of the ball handling mechanism first the term ‘performance’ is described. When accepting passes, the performance is defined as the range of angles, offset and ball velocities the robot is able to successful accept passes. A more detailed description is given in Section 5.1.1. In the area of dribbling behavior the performance of the ball handling mechanism is described as the ability of the robot to keep control over the ball. Section 5.1.2 explains the testing of the dribbling behavior in more detail. Accepting passes and dribbling behavior are of equal importance for the robots, meaning if a particular set of settings work best for accepting passes but the dribbling performance is less as the current design, these settings are not optimal for the overall ball handling performance of the robot.

5.1.1 Accepting Passes

When testing the pass accepting of the ball handling mechanism a soccer ball will be rolled towards the robot. By varying the velocity, approach angle and offset the performance can be assessed. The offset is the distance between the centerline of the robot and the path at which the ball travels. In Figure 5.1(b) the offset is illustrated with the symbol $x$. To improve the performance the amount of offset at which a pass is successfully accepted is important. The camera in the robot is able to accurately predict the path of the ball, but the exact center point off the ball is harder to determine due to different light reflections on the surface of the ball. When a ball approaches the robot will rotate with the ball handling system towards the ball but by not knowing the exact center some offset off the ball path with respect to the robot path will occur. Apart from the numbers of the above criteria the performance off pass accepting furthermore is assessed with camera footage. Due to the high speed at which the arms move, a camera allows to replay the pass at a lower speed giving a clearer view of the situation.

In order to maximize the effect of the settings on the arms of the ball handling mechanism the robot is put in place and held stationary during the testing.

5.1.2 Dribbling Behavior

Using the terminology dribbling, different manoeuvrers of the robot are meant. The following items are included:
• Turning around the center-point of the robot;
• Turning around the center-point of the ball;
• Driving sideways;
• Reverse driving;
• Ability to keep ball control when suffering from sideways / rear impact;
• Driving at maximum velocity;
• Manoeuvring with maximum accelerations.

These items are tested by programming a test course for the robot. During this course the number of ball losses and corrections the robot has to make give an indication of the performance. To see whether the new ball handling system is an improvement over the current one, a base level will be set using a robot with the current ball handling system.

For dribbling performance the ball handling mechanism relies on an feed-forward controller on the wheels. By varying the geometry of the ball handling mechanism and not implementing this into the controls, the performance of the individual settings are difficult to assess. For adequate tests the controller should be modified in such way the angle adjustments on the arms are parameters which can be set. Due to time restrictions this implementation of arm angles in the control is not described in this report.

5.2 Test sequence

This section describes the plan to effectively test the arms. In Table 5.1 the relevant range of settings of each degree of freedom is listed. If a particular setting has a large influence on the performance first a coarse set of settings is tested. Each of the range of settings is split in three values, and is tested with two ball velocities. The coarse test values are listed in Table 5.2. This coarse test results in $3 \cdot 3 \cdot 3 \cdot 2 = 54$ individual tests. Performing 54 individual tests is very time consuming so in order to speed up the process first the different angles of the arms are tested to see if a trend in the results can be found. This first test sequence consists of the settings $\psi_{1,2,3}$ and $\theta_{1,2,3}$ and two ball velocities $v_b_{-1,2}$ resulting in 18 individual tests where the robot needs adjustment 9 times. The velocities of the ball being tested are 3 m/s and 4 m/s. The latter is approximately the passing speed of the robots, thus the most important velocity to test.

<table>
<thead>
<tr>
<th>Adjustment</th>
<th>min.</th>
<th>max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>0 [mm]</td>
<td>19.2 [mm]</td>
</tr>
<tr>
<td>$\psi$</td>
<td>25 [$^\circ$]</td>
<td>35 [$^\circ$]</td>
</tr>
<tr>
<td>$\theta$</td>
<td>15 [$^\circ$]</td>
<td>35 [$^\circ$]</td>
</tr>
</tbody>
</table>

Table 5.1: Relevant range of settings on the new ball handling system.

<table>
<thead>
<tr>
<th>Adjustment</th>
<th>setting 1</th>
<th>setting 2</th>
<th>setting 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>0 [mm]</td>
<td>9.6 [mm]</td>
<td>19.2 [mm]</td>
</tr>
<tr>
<td>$\psi$</td>
<td>25 [$^\circ$]</td>
<td>30 [$^\circ$]</td>
<td>35 [$^\circ$]</td>
</tr>
<tr>
<td>$\theta$</td>
<td>15 [$^\circ$]</td>
<td>25 [$^\circ$]</td>
<td>35 [$^\circ$]</td>
</tr>
</tbody>
</table>

Table 5.2: Settings for coarse testing.
5.3 Test setup

When testing the pass accepting capabilities of the different settings on the arms of the ball handling mechanism it is important to be able to have the ball approaching with a reproducible velocity and direction. Using a second Turtle to pass a ball gives to much variation in velocity and direction meaning an alternative setup is required. An easy way to give a ball a reproducible velocity and direction is using a ramp from which the ball is rolled. The ball velocity when passing is approximately 4 m/s for the Turtle. To check if the passing velocity is achievable with a ramp the approximate required ramp height is calculated in Section 5.3.1.

![Diagram of test setup]

Figure 5.1: Setup for testing the capabilities of accepting a pass for the ball handling mechanism

5.3.1 Ramp height

To test different ball velocities the approximate height required for the ramp needs to be calculated. Assuming the ball has no friction on the ramp surface and has pure rotation the required height is calculated by the energy balance equation

$$\Delta E_g = \Delta E_k + \Delta E_r,$$

where $E_g$ is the potential energy, $E_k$ the kinetic energy and $E_r$ the rotational energy of the ball. Using the formulas for energy, (5.1) can be written as

$$m_b g \Delta h = \frac{1}{2} m_b \Delta v^2 + \frac{1}{2} I_b \Delta \omega^2,$$

where $I_b$ is the inertia of the ball and is calculated using the formulae of a hollow sphere with neglectable wall thickness around an arbitrary rotation axis

$$I_b = \frac{2}{3} m_b r_b^2.$$

Where the angular velocity of the ball $\omega_b$ is related to the velocity $v_b$ by

$$\omega_b = \frac{v_b}{r_b}.$$
Combining (5.1), (5.3) and (5.4) the ramp height is written as

$$\Delta h = \frac{5}{6} \frac{\Delta v_b^2}{g}.$$  

(5.5)

The required height for different ball velocities is plotted in Figure 5.2.
Chapter 6

Conclusion and Recommendations

6.1 Conclusion

The current design of the ball handling mechanism had a very limited contact area between the tire and the ball resulting in reduced grip on the ball. Having grip on the ball is key for a ball handling mechanism, which makes use of two wheels placed on top of the ball to exert forces. Furthermore due to the angle at which the wheels contact the ball the rim is able to touch the ball, the rim having no grip on the ball this results in unwanted situations. This contact between the aluminium rim and the ball also occurs during the accepting of a pass where the path of the ball has a small offset compared to the center line of the robot. Due to this mis-alignment of paths the ball bounces away from the robot rather than being caught.

An attempt is made to simulate the process of ball interception with the objective to extract design parameters for an improved design proposal. Due to time restrictions the simulation only reflects the first part of accepting a pass where the energy of the ball is absorbed by the springs. In the SimMechanics model a tire model and the control software of the wheel motors is not included. The model reflects the ball traveling with a velocity $v_b$ towards the arms of the ball handling system. Clearly visible in the simulation results is the arms using their full stroke and it is seen that is the ball velocity drops to zero during the usage of the arm stroke. The same slope in the plot of the arm stroke is visible in the measurements done on the Turtle robot. Comparing the results of the simulation and the measurements done on the Turtle robot the similarities show the model is reflecting the first part of the ball catching simulation.

A gain in performance is expected by modifying the position of the wheels. The best position of the arms cannot be determined beforehand thus a ball handling system where adjustments can be made to the wheel position is designed. The arms feature three independently adjustable degrees of freedom. The translation on the $x$-axis can be adjusted over a range of 19.2 mm, moving the arms closer together or further apart. The adjustment of the $\psi$-axis determines the sideways angle at which the wheel contacts the ball. If you construct a vector perpendicular to the rotation axis of the wheel, the direction of this vector can be adjusted with the freedom given around the $\theta$-axis. This direction is being seen as important for the dribbling behavior of the robot, thus being very important to test. With the adjustment over the $\theta$-axis the contact area of the wheel on the ball is adjusted. With this adjustment the grip of the wheel on the ball can be varied. Besides making the arms adjustable the hinge axis of the arms is moved upwards by 50mm, as a result the force of the springs is now more directed on top of the ball instead of against the the ball. By exerting more force on the top, it is expected that the dribbling behavior will be improved compared to the current ball handling mechanism. Furthermore, the hinge line is rotated over an angle of 13.2 degrees. As a result a ball approaching with a certain direction differing from the robots direction the chance the direction of the ball becoming parallel to the hinge axis is reduced.
6.2 Recommendations

The following items are recommended for future work on this project:

- Revise the SimMechanics model
  - Integration of a tire model representing the physical contact between the tire and the ball;
  - Include the control loop in the simulation;
  - Parameter optimization of mass, damping coefficient and spring rate;

- Construct a prototype
  - Implement a controller where the arm adjustments can be set as parameters;
  - Perform the tests described in Chapter 5 to find the optimal settings of the ball handling mechanism;
  - Evaluate the real life performance of the prototype;
  - Developing a final design using the optimal settings found during testing of the prototype;
  - Optimization of the dynamic behavior, i.e., tuning mass, damping coefficient and spring rate.
Bibliography


Appendix A

SimMechanics Model

A.1 Basic Mass-spring-damper model

Figure A.1: SimMechanics model of a simple spring-mass-damper system
A.2 Turtle simulation

Figure A.2: SimMechanics model of the ball handling system from the 2011 Turtle robot
Figure A.3: Subsystem Ball
Figure A.4: Subsystem ball contact
Figure A.5: Subsystem bottom hinge

Figure A.6: Subsystem spring
Figure A.7: Subsystem Body Spring & Damper exploded

Figure A.8: Subsystem wheel motor
Appendix B

Matlab Source Code

% simulation parameters Turtle 2011 ball handling system

clear all
close all
clc

% ball approach speed
v_ball=4; % ball speed [m/s]

% spring/damper
k=330; % spring rate [N/m] (estimated value based on global spring dimensions, value from tevema catalog)
b=30; % damping coefficient [N/(m/s)] (estimated value. Current robot has no specific dampers, control system provides damping.)

% ball stiffness
k_pos=22.2e3; % [N/m]
k_neg=1e-9; % [N/m]
b_pos=45; % [N/(m/s)]
b_neg=1e-9; % [N/(m/s)]

% masses
m_wheel=0.118; % [kg]
m_arm=0.664; % [kg]
m_rod=0.023; % [kg]
m_bush=0.031; % [kg]
m_ball=0.434; % [kg]

% wheel speed
v_wheel=0; % [deg/s]

% inertia tensors with respect to global coordinate system
J_arm_right=1e-6*[39595.335 0 0;10279.211 20582.200 20765.253 18570.789 28725.026];
J_arm_left=1e-6*[39595.335 0 0;10279.211 20582.200 0;7635.253 18570.789 28725.026];
J_springguide_rod_right=1e-6*[1237.590 0 0;376.592 1102.646 0;502.458 588.976 792.348];
J_springguide_rod_left=1e-6*[1237.590 0 0;376.592 1102.646 0;502.458 588.976 792.348];
J_springguide_bush_left=1e-6*[1372.754 0 0;362.566 1922.960 0;934.619 462.727 934.26];
J_springguide_bush_right=1e-6*[1372.754 0 0;362.566 1922.960 0;934.619 462.727 934.26];
J_wheel_left=1e-6*[8873.350 0;1756.975 3781.04 0;1326.041 4252.251 6217.3];
J_wheel_right=1e-6*[8873.350 0;1756.975 3781.04 0;1326.041 4252.251 6217.3];
J_ball=1e-6*[50378.938 0 0;7273.893 0 0;12931.513 46499.484];

% left arm DoF axis
rev_1=[93.314 -87.615 0]; % lower hinge point
ax_left_lower=(1/sqrt(rev_1(1)^2+rev_1(2)^2+rev_1(3)^2))*rev_1;
rev_2=[37.095 -29.58 -56.136]; % wheel axis
ax_left_wheel=(1/sqrt(rev_2(1)^2+rev_2(2)^2+rev_2(3)^2))*rev_2;
% right arm DoF axis
rev_3=[-93.314 -87.615 0]; %lower hinge point
ax_right_lower=(1/sqrt(rev_3(1)^2+rev_3(2)^2+rev_3(3)^2))*rev_3;

rev_4=[37.095 29.58 56.136]; %wheel axis
ax_right_wheel=(1/sqrt(rev_4(1)^2+rev_4(2)^2+rev_4(3)^2))*rev_4;

% left damper DoF axis
pris_1=[44.056 75.722 15.692]; %damper extension axis
ax_damp_left=(1/sqrt(pris_1(1)^2+pris_1(2)^2+pris_1(3)^2))*pris_1;

% right damper DoF axis
pris_2=[-44.056 75.722 15.692]; %damper extension axis
ax_damp_right=(1/sqrt(pris_2(1)^2+pris_2(2)^2+pris_2(3)^2))*pris_2;

% ball contact DoF axis
pris_3=[54.102 77.026 55.673];
ax_con_left=(1/sqrt(pris_3(1)^2+pris_3(2)^2+pris_3(3)^2))*pris_3;

% ball contact extension axis left
pris_4=[-54.102 77.026 55.673];
ax_con_right=(1/sqrt(pris_4(1)^2+pris_4(2)^2+pris_4(3)^2))*pris_4;