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A Dirigible Bowling Ball

Controlling a bowling ball to hit a strike every time

JOEL FRÖBERG

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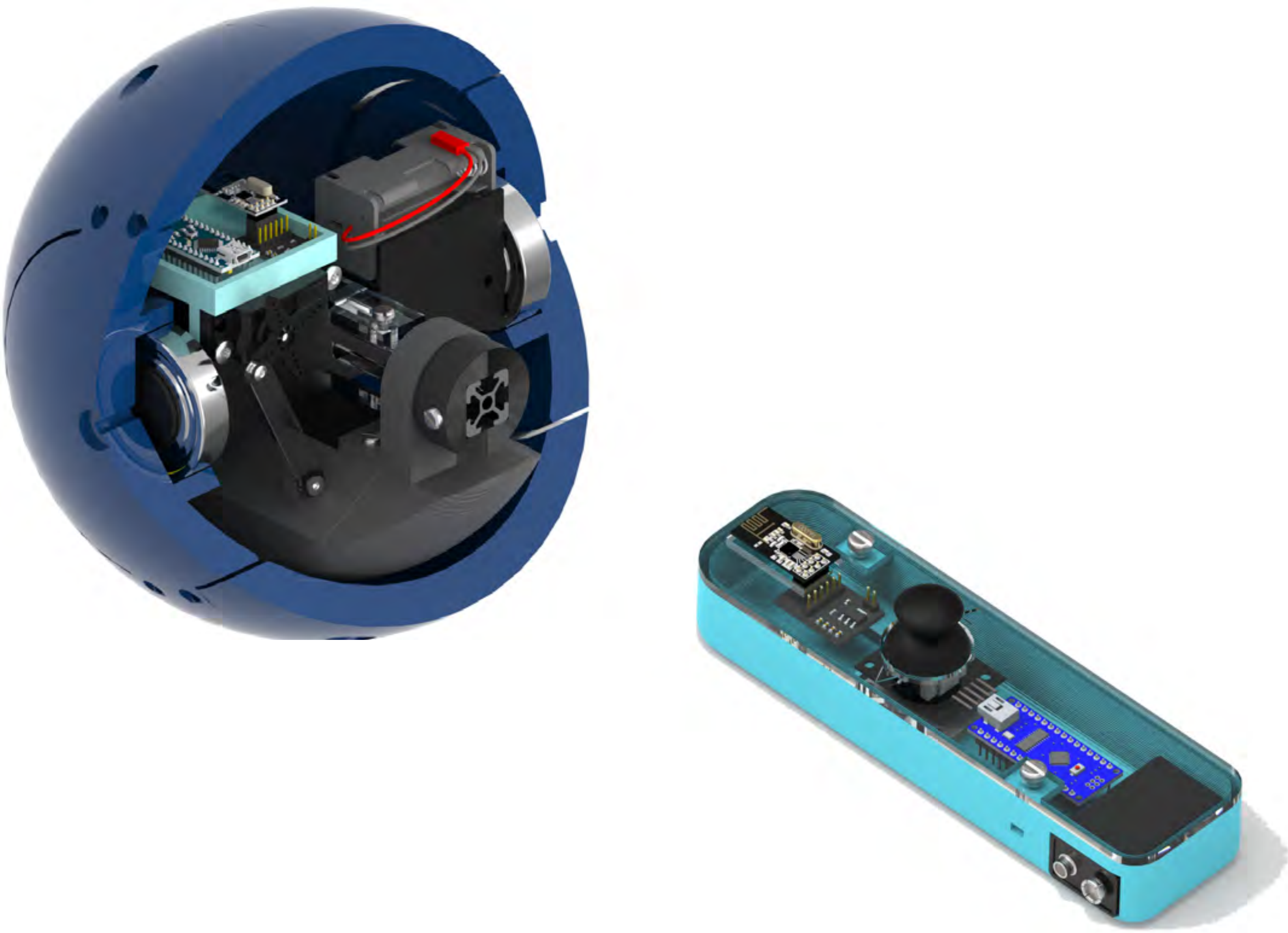

KTH ROYAL INSTITUTE OF TECHNOLOGY
SCHOOL OF INDUSTRIAL ENGINEERING AND MANAGEMENT

A Dirigible Bowling Ball

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Bachelor's Thesis at ITM
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Abstract

The purpose of this bachelor's thesis is to investigate the uses of spherical robots and on a prototype basis construct and control a dirigible bowling ball. The robot is able to steer left and right after being thrown by the user. This occurs due to a weight displacement inside the ball when a weighted pendulum swings left and right by being radio controlled from afar. The goal of the report is to investigate how well this robot will be able to steer and if it can achieve a desired strike. Further, this report will investigate the use of Radio Frequency (RF) signals between a hand controller and the ball and at what distance this method will work. This robot is strictly made for scientific purposes, the authors do not advocate cheating in the sport of bowling in any way.

Keywords
Mechatronics, Spherical movement, Bowling, Radio Frequency, Servo motor.

Referat

Ett styrbart bowlingklot

Syftet med denna kandidatuppsats är att undersöka användningen av sfäriska robotar och på en prototypbasis konstruera och styra ett styrbart bowlingklot. Roboten kommer att kunna styras åt vänster och höger efter att ha kastats av användaren. Detta inträffar på grund av en viktförskjutning inuti klotet då en viktad pendel svänger åt vänster och åt höger genom att radiostyras på håll. Målet med rapporten är att undersöka hur bra den här roboten kommer att kunna kontrolleras och om en strike kan uppnås med den nya och samlade kunskapen. Vidare kommer användningen av Radio frekventa (RF)-signaler mellan en handkontroll och klotet att undersökas, hur väl detta kan implementeras och även på hur långt avstånd denna metod kan fungera. Denna robot är endast gjord för vetenskapliga ändamål, författarna förespråkar inte fusk i sporten bowling på något sätt.

Nyckelord
Mekatronik, Sfärisk rörelse, Bowling, Radio frekvenser, Servo motor.

Acknowledgements

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Furthermore, we want to express a tremendous gratitude to the assistants Amir Avdic and Malin Lundvall for their competence, availability and generous guidance throughout the entire process.

Additionally, we are very appreciative for the opportunity to work at school in a safe and interactive environment considering the circumstances of Covid-19.

Contents

List of Figures

Acronyms

3D Three Dimensional. 2, 8, 9, 13, 15

CAD Computer Aided Design. 2, 7–10, 13

IDU Inside Driving Unit. 1

IMU Inertial Measurement Unit. 19, 23

MCU Microcontroller Unit. 2, 4, 10, 11

PWM Pulse Width Modulation. 4

RF Radio Frequency. 5, 10, 12–14, 17, 19, 23

Chapter 1

Introduction

1.1 Background

Spherical robots have become increasingly popular over the years. The ball shaped exterior can offer an advantage in environments where other mobile robots suffer due to skidding, tripping over or friction with the surface which makes them vulnerable or inefficient. A spherical robot works in many different ways; one way is to utilize omnidirectional wheels in a spherical body which is controlled remotely and therefore able to move smoothly on the desired path [1]. Another method is to use a weighted-pendulum to transfer the center of mass for a movable sphere [2]. Moreover, using a Inside Driving Unit (IDU) is another adaptable method that moves the inner surface of the sphere to get the wanted movement [3]. In this project a pendulum will be utilized to steer a bowling ball in a certain direction to be able to achieve a strike.

We chose this project because it seemed fascinating, educational and usable to develop a dirigible bowling ball. An inspiration for this project was how the mechanical- and electrical engineer James Bruton and former Nasa engineer Mark Rober made a controllable bowling ball with sensors [4]. The project was based on a spherical robot with a pendulum that moves the rolling bowling ball's center of mass to make it controllable.

1.2 Purpose

The main purpose of this project is to examine how a spherical robot can be implemented into a bowling ball and to make it controllable. In addition, to investigate how well this contraption can be stabilised inside the bowling ball by keeping its horizontal and vertical planes at constant angles. The spherical robot will be implemented into a rolling bowling ball and will be remotely controlled to turn left and right by moving it's center of mass. The displacement of the bowling ball's center of mass is done by a pendulum that is driven by a servomotor. With the use of a Microcontroller Unit (MCU) all the movements and stabilization will be programmed and given to the different components. The following research questions will be answered:

1. How can the center of mass be altered so the bowling ball moves in a controlled path in real time?

2. How can radio communication be implemented to control the bowling balls' movement in real time?

3. Does the theory behind hitting a strike apply when using the constructed bowling ball?

1.3 Scope

The requirements for this project is to create a prototype that includes mechanical, electrical and programmable elements where everything is documented in a final report. The scope of this project is to implement a spherical robot into a controllable bowling ball to accomplish a strike for every throw. The duration of this project is approximately 4 months with a given budget of 1000 SEK. An additional restriction to this project is the limitation of access to prototyping tools and equipment due to the current Covid-19 pandemic.

1.4 Method

The beginning of this project is mostly theoretical and contained plenty of research to expand our knowledge in the required areas. With the gathered information, the second segment of construction began. The components are dimensioned, a 3D model is made in CAD using Solid Edge [5] and code is written for the electronics parts as well as assembling the prototype. The entire process contains a lot of iterative tests and trials to achieve a functioning and final product.

Chapter 2

Theory

This chapter covers all the theoretical background that has been used for this project.

2.1 Pendulum movement

The bowling balls' movement can be steered by a weighted pendulum inside that drastically changes the spheres center of mass and direction. One of the possible movements of the bowling ball is visualized in Appendix A and illustrated in Figure 2.1 with an exaggerated scale for clarity. The pendulum connected to a shaft inside the center of the body without touching the outer shell of the bowling ball. The bowling ball is moving forward because of the throw, but will steer left or right because of the weighted pendulum. The spheres' rotation is obtained by an oscillating pendulum with an angle α, which moves the center of mass and gives the ball an angular velocity ω to right or left. The result of this is a horizontal movement to the desired direction.

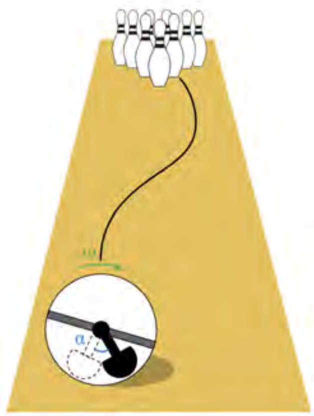

Figure 2.1. Illustration of how the pendulum and center of mass makes the bowling ball move to the requested direction. Created in Google Docs.

2.2 Microcontroller

A Microcontroller Unit (MCU) can be described as a small computer which is installed into products and devices that must automatically be controlled in certain situations. These controllers are everywhere, in cars, computers, smartphones/tablets and many toys [6].The device collects and processes data and the controller then gives different outputs and inputs depending on what data was given, for example making a servomotor rotate. Microcontrollers have two types of memory: program memory and data memory. The program memory handles the instructions that needs to be processed while the data memory is used for temporary storage of data while the program is running [7].

2.3 Servo motor

A servo motor is a self-contained electrical device, that rotates parts of a machine with high efficiency, feedback and great precision. They are used in a plethora of devices, for instance in a robotic arm or for controlling the rudder on a boat [8]. Servo motors are controlled by sending a series of electrical pulses with various width, which determines the position of the output shaft and this is called Pulse Width Modulation (PWM). Based on the duration of the pulse the rotor will turn to the desired position as seen in Figure 2.2. A pulse of 1 ms corresponds to the neutral state of 0 ° while 1,5 ms and 2 ms provides an angle of 90 ° and 180 ° respectively [9]. The angle movements are possible because of a potentiometer that reads the emitted voltages and adjusted resistances as different signals for the shaft position [10].

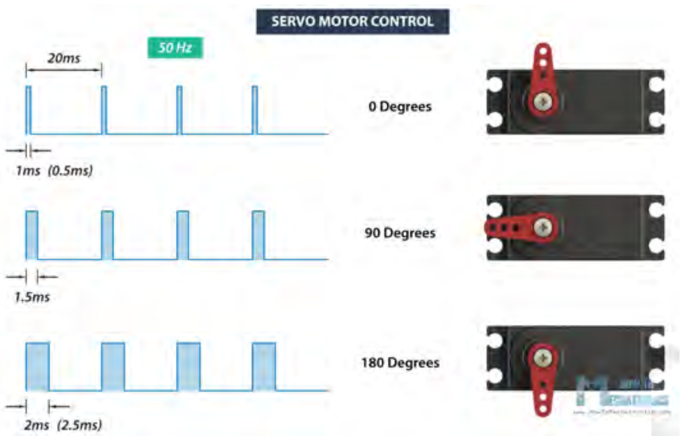

Figure 2.2. Correlation between the PWM and the shaft angle [9].

2.4 Radio Frequency Communication

Wireless communication is a necessity for transferring information to a mobile robot since a physical connection with a wire is not possible for the throw of a bowling ball during a game. Therefore, the communication between the bowling ball and the remote control will consist of wireless Radio Frequency (RF) Communication. This form of communication is used in many industries in today's society; including television broadcasting, mobile platform networks and remote controls [11].

An RF signal is a form of communication with electromagnetic radio waves that identifies frequencies between 30kHz and 300GHz, and enables a connection between a sender and a receiver[11]. The transmitter sends out directives to the receiver that through radio waves obtains and uses the given information. For instance, a remote control with a transmitter inside can steer a robot to left and right with the receiver in it.

2.5 How to hit a strike

The physics behind hitting a strike in the sport of bowling begins with the bowling ball itself. Its center of mass is misplaced, because when throwing the ball you want to achieve a spin or so called "a hook". This is the sideways deflection δ of the ball from the original (straight) trajectory, seen in Figure 2.3. To achieve a hook the bowler spins the ball at the throw with the angular velocity of ω_o, because of the displacement of mass this results in a curved trajectory where you want to hit the pins at an angle θ [12]. As seen in Figure 2.4 this angle results in the normal force of the ball to be on a straight line down the first row following the second row in line and finally the balls' momentum takes down the last of the pins[4].

When using a pendulum to control the bowling ball, the hook will not be achieved by the spin as discussed. Here the ball will be able to steer left and right as the controller is telling it. However, the needed angle that the bowling ball needs to hit down all the pins are still the same to achieve a strike.

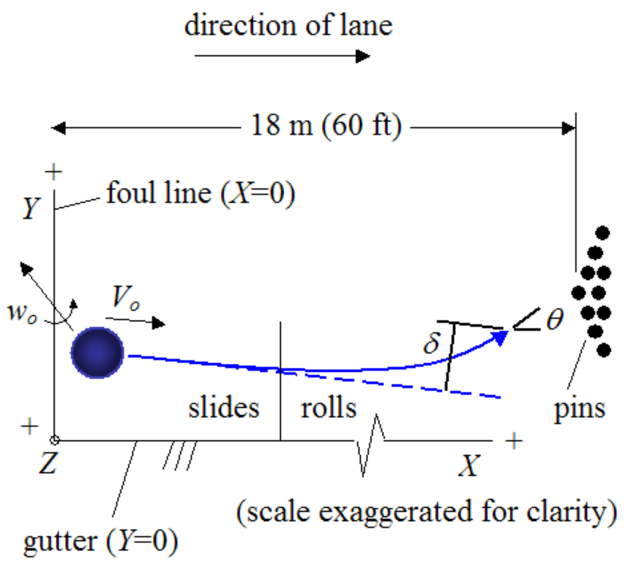

Figure 2.3. Illustration on how to get a strike [12].

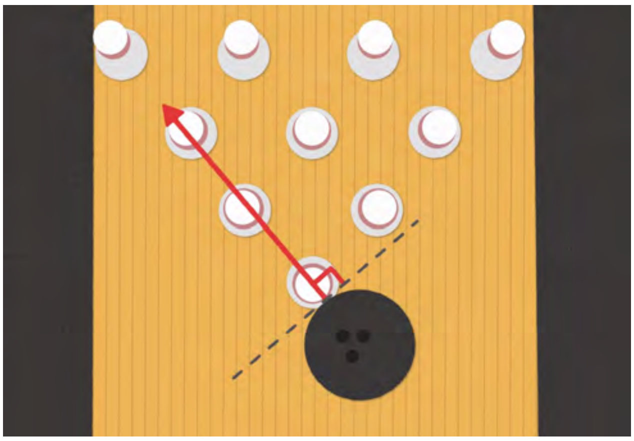

Figure 2.4. Illustration on how the normal force of the bowling ball affects the bowling pins [4].

Chapter 3

Implementation

The following chapter lists and describes the mechanical components, electrical components and the software that was used to create the prototype. The robot prototype and joystick case were both created in Solid Edge. A render of the bowling ball is displayed in Figure 3.1 as a CAD-model with its components inside.

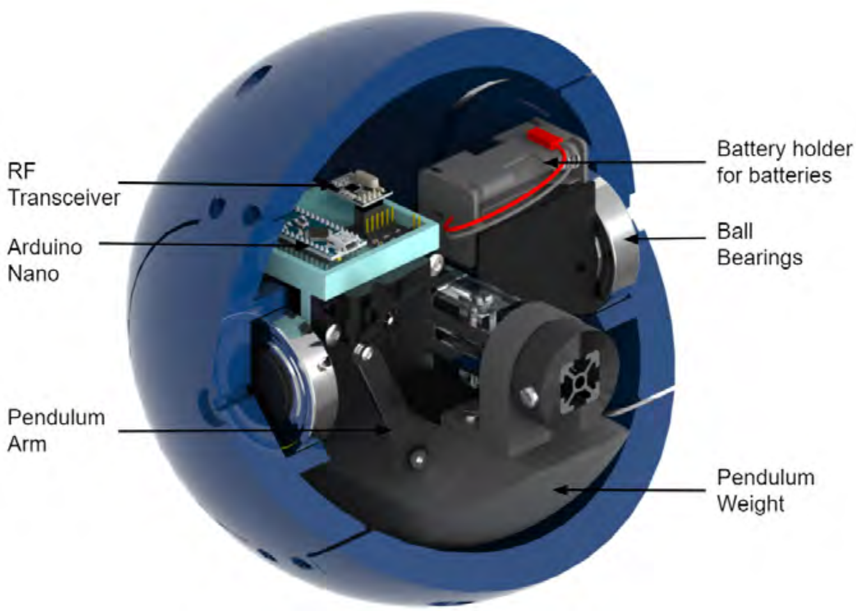

Figure 3.1. A CAD rendering of the robot. Created in Keyshot.

3.1 Mechanical components

The different mechanical components that were used for this project were purchased or 3D printed and will be introduced in this section.

3.1.1 Pendulum

The pendulum movement consists of a fluctuating arm that directs a pendulum weight, which is seen in Figure 3.2. The pendulum arm will move the mass to the left and right, therefore steering the bowling ball to the desired direction. A servo motor is attached to an aluminium profile that powers the arm which moves the weighted pendulum mass, and thereby the bowling ball. The arms' attachment point to the pendulum weight is directly under the servo motor for maximum momentum and force to move the weighted shell. In the prototype, the pendulum mass is a 3D printed shell that is purposely hollow so it can be filled with a required and adjustable amount of weights.

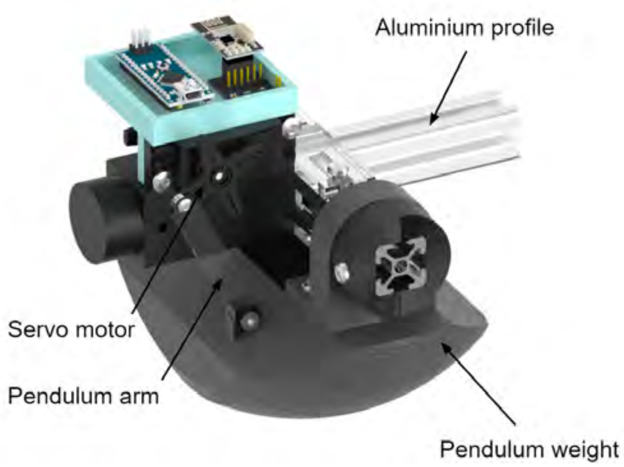

Figure 3.2. A CAD rendering of the pendulum. Created in Keyshot.

3.1.2 Bearing

Bearings were needed to allow the bowling ball to spin around its own axis, while the inside construction remains in a non rotating position. Also, bearings were required for the pendulum so it can swing left and right when steering the ball. Ball bearings were the first choice and SKF standard bearings were used to find the right dimensions to fit inside the bowling ball. A lifetime calculation was made for the bearings' perseverance, which can be seen in Appendix B. It showed that the chosen bearing would survive enough throws of the ball before the use of a replacement. The bearings were fitted inside an outer part to make sure that they were centered inside the bowling ball, see Figure 3.3. The bearings for the pendulum were a cheaper and more iterable choice. They were made by using 3D printed plastic bearings. It was made clear that the friction between the PLA plastics were low enough for it to spin. This led to the decision to 3D print the bearings between the pendulum and the mounting rig which also simplified the design iteration process as many different sizes could be made with little time and low cost.

Figure 3.3. A CAD rendering of the bearings inside the Bowling ball. Created in Keyshot.

3.1.3 Sphere

To create a prototype that resembles a bowling ball, two half spheres were 3D printed, like in Figure 3.4, and connected through plastic dowels in between. The two hollow half spheres creates an outer shell for all the components inside that are attached on two aluminum profiles. Two ball bearings are attached to the sphere and they enable a rotation for the outside shell while the inside components stay stationary. The two sphere halves stay connected and united by using a threaded rod by a hole throughout the entire bowling ball and gets tightened by a screw-nut on each side.

Figure 3.4. A CAD rendering of half of the sphere. Created in Keyshot.

3.1.4 Mounting Rig

The mounting rig for all the electrical- and mechanical components consists of two t-slot aluminum profiles, which is seen in Figure 3.5. They were assembled into a cross section to allow both the pendulum and the bowling ball to rotate. The components that were attached to this mounting rig are a servo motor, a Microcontroller Unit, a battery pack and an RF transceiver. The T-slot profiles were used to attach and screw on the components at different lengths and then be easily adjustable which the chosen profile provides.

Figure 3.5. A CAD rendering of the mounting rig. Created in Keyshot.

3.2 Internal electrical components

This section presents all the electrical components that were used for the prototype.

3.2.1 Arduino Nano

When choosing a Microcontroller Unit, several different aspects are taken into consideration such as power efficiency, hardware architecture, processing power and cost [13].The hardware architecture was highly taken into consideration due to the importance of everything fitting inside of a bowling ball. In this project an Arduino UNO was suggested due to its plethora of pins. However, an Arduino Nano was preferable and chosen since it is smaller and more compact for the prototype while still offering the same usage. This device is shown in Figure 3.6.

Figure 3.6. Arduino nano [14].

3.2.2 Servo motor

Since the servo motor has a precisely controlled shaft and an internal position servomechanism, it is a very appropriate choice for the steering of the bowling ball in this project [15]. The chosen motor is seen in Figure 3.7. When the motor spins, it moves an added arm which swings the pendulum. This directs the spheres' movement by relocating the center of mass. Furthermore, the servo motor is compact and small which is desired in this project to minimize the mechanical parts inside the bowling ball. Servo motor specifications is found in Appendix C.

Figure 3.7. HS-625MG standard servo [16].

3.3 Steering of robot

This section describes the steering of the bowling ball by a joystick with radio communication.

3.3.1 Radio frequency receiver and transmitter

For the RF control of the robot, the range of the modules needed to be a full bowling lane which is approximately 20 meters. Also, the communication needs a steady connection and the modules need to be fit inside the bowling ball. As of this, it was decided to use the nRF24L01+ transceiver (see Figure 3.8) [17]. This module works both as a transmitter and a receiver depending on how it has been coded. The module is designed to operate in 2.4 GHz worldwide ISM frequency band, which is an international unlicensed band for low powered devices. There are different versions of this device which offers different types of range. The module for this project has a built in antenna and a range of up to 100 meters in open space.

An RF signal is very sensible to power supply noise if the module is not connected to a stand-alone battery. To prevent this, it is helpful to place a 10 µF filter capacitor across the power supply to make sure that constant power is supplied. There are also adapter modules that were built in for an easier fix [18]. See full specifications in Appendix C.

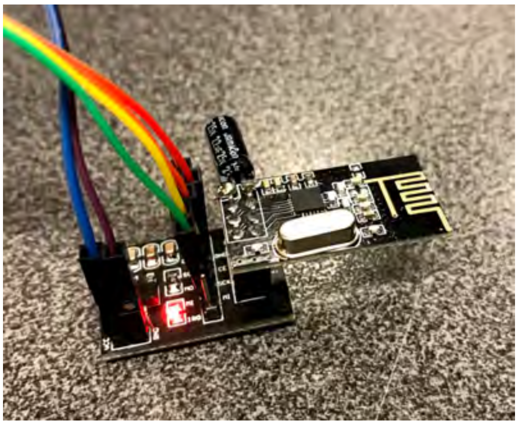

Figure 3.8. The nRF24L01+ module with a soldered on capacitor and an adapter module. Picture taken by authors.

3.3.2 Remote control

A remote control will be used to steer the bowling balls' direction to left and right with a joystick which is seen in Figure 3.9. The joystick is connected to an RF transmitter module that sends out directives to the bowling ball with an RF receiver inside. Thereby, the joystick will only direct the bowling ball in x-direction, left and right, while the throw moves it forward in y-direction. Furthermore, an outer shell is 3D printed to create a console for all the protruding parts, and is also covered with a lasercut acrylic plate. The remote control contains a battery, an Arduino Nano, a joystick and the RF transmitter with connecting cables.

Figure 3.9. A CAD rendering of the remote control for steering the bowling ball. Created in Keyshot.

3.4 Software

The communication between the joystick and the bowling ball is made through an Arduino code in Appendix D with the guidance from a website provided with the code, all imported libraries and the wiring for the Arduino [19]. The communication between joystick and sphere is visualised in a flowchart seen in Figure 3.10 and uses the following steps:

1. System initialized by including libraries, initializing variables and configuring in- and outputs.
2. Data is read from the joystick and the analog value is computed into an angular value which the servo motor can read.
3. The RF transmitter sends the computed angle to the receiver located inside the bowling ball.
4. The RF receiver checks if a message is received. If true, the Arduino sets the servo motor to received angle. Else, the angle is set to mid point.
5. Repeat from step two.

For full circuit diagram see Appendix E.

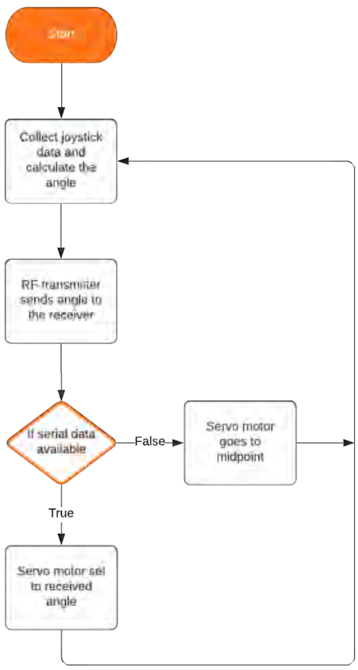

Figure 3.10. A flowchart for the Arduino code. Made with Lucidchart.

3.5 Prototype

Ultimately, a prototype was created by combining all the 3D printed parts and the purchased components. This resulted in a functional and dirigible bowling ball with a remote control that can be seen in Figure 3.11, 3.12 and 3.13.

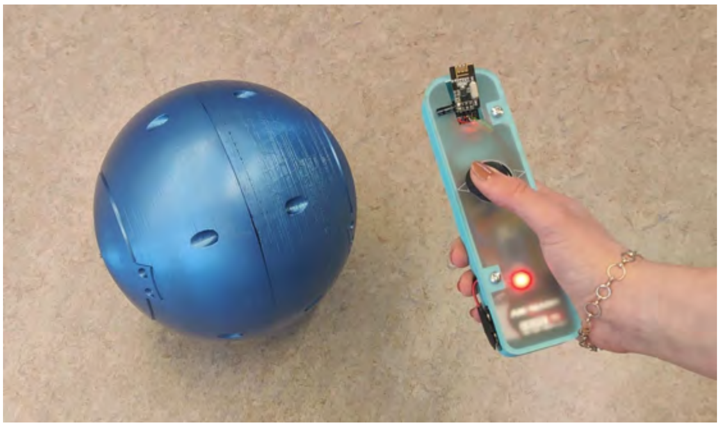

Figure 3.11. The final prototype, consisting of a dirigible bowling ball and the controlling remote. Picture taken by authors.

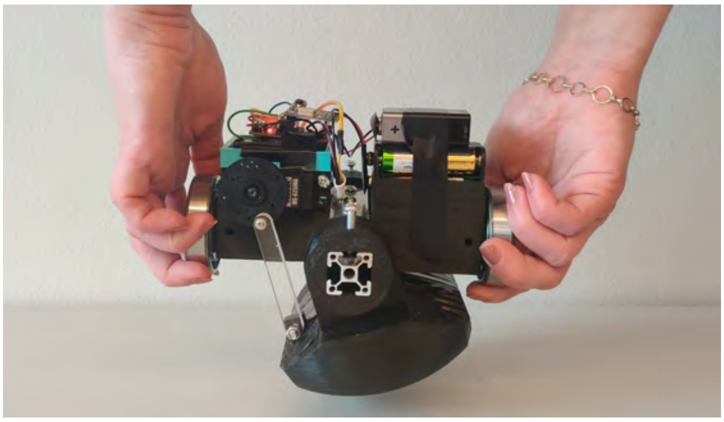

Figure 3.12. The inside mechanism showing the servo motor swinging the weighted pendulum. Picture taken by authors.

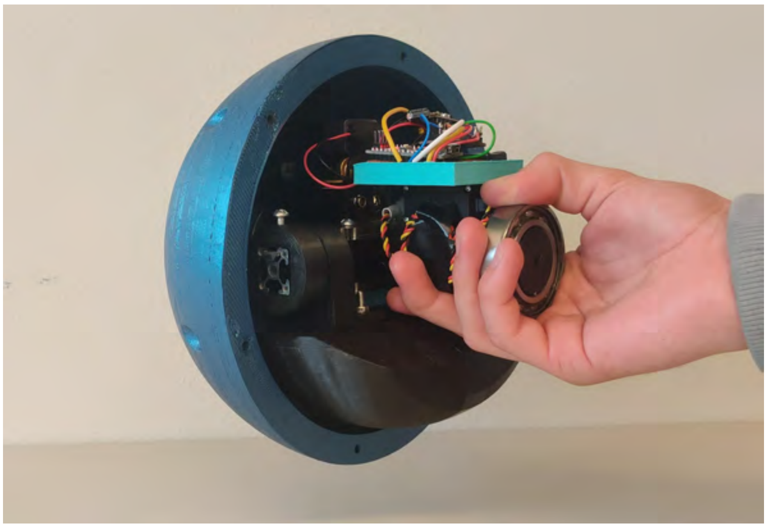

Figure 3.13. The mechanism inside the hollow bowling ball. Picture taken by authors.

Chapter 4

Result

This chapter contains the results from all the tests that were performed with the robot.

4.1 Range of Radio Frequency Transceiver

To test if the bowling ball would be able to roll down a full bowling lane without any disturbances, the ball and remote control were separated while measuring the distance. Up to 25 meters the connection worked perfectly, past this limit the connection was not working at all.

4.2 How well the bowling ball can be controlled and hold its course

The bowling ball was thrown both on normal flooring and on a bowling course. On normal flooring the ball held the course fairly well and was able to steer left and right by the remote control. However, when thrown on a bowling course with a hard and laminate flooring that is covered two-thirds of the way with oil, the bowling ball lost its grip and was unable to steer and keep a straight course.

4.3 The ability to hit a strike

The bowling balls' capability to hit a strike was primarily tested on plastic toy pins to analyse the theory behind a strike. It worked perfectly well as long as the bowling balls' angle of approach was approximately three to six degrees. Further, the theory is also legitimate on real and heavier pins. Seeing that a strike was possible even though the prototype is much slower and lighter than a real bowling ball. When tests were made on the plastic pins it resulted in 6 out of 10 strikes, while for the real pins there were not enough tests to draw a conclusion.

Chapter 5

Discussion

This chapter provides a discussion about the results presented in the previous chapter.

5.1 The importance of internal balance

It was noted from the results that internal balance is crucially important for the bowling ball to move correctly, otherwise it will tilt and roll in an unwanted direction. It is essential that the weight of the bowling ball is evenly distributed and that the pendulum is the dominant weight and correctly centred. This was a constant problem for our prototype since its' components weigh differently. We tried to place them with equal weights on each side of the pendulum, but it still differed in weight so we fixed the balance by adding some known weights. The pendulum was filled with gravel which made it slightly heavier in comparison to the other components, still when the bowling ball lost its course too much, the weight of the pendulum was not enough to keep the ball steady and it started to spin around the wrong axis.

To solve this imbalance and wobbling, we both would need a heavier pendulum and to implement PID regulation. To do so an Inertial Measurement Unit (IMU) is needed. It measures and reports a body's specific force, angular rate and sometimes the orientation of the body. With this data the Arduino would be able to tell the servo motor when the bowling ball is about to loose its course and swing the pendulum to counteract it.

5.2 Alternative communication

When using RF communication, we achieved a stable connection at a distance up to 25 meters. Since a bowling lane is only 18 meters this was an acceptable choice of communication between the bowling ball and remote control. However, the nRF24L01+ transceiver module that was used for this project had a lot of trouble at first to get a stable connection. We had difficulties to give it enough power to constantly send and receive signals. This was later solved by adding a capacitor and connecting it to an adapter module which gave it the right amount of power at a constant rate.

Even though the module worked in the end and gave us a long enough connection, other options of communication such as Bluetooth and WiFi should have been considered instead.

5.3 Ethics and the invention of a new game

A controversial aspect of this project was the questioning around ethics and moral. To steer the bowling ball with a remote control can be considered as cheating and unfair against the other players. We do not want to advocate this forgery. Therefore, we have solved this issue by creating a new game where everyone has the same circumstances. An obstacle run where every player will use a dirigible bowling ball to avoid obstacles on the course. For instance, the bowling ball needs to be steered under a tunnel, over a bridge or away from moving objects on the track.

Chapter 6

Conclusion

The three scientific questions that were posed in the beginning of this report has now been answered as following:

1. *How can the center of mass be altered so the bowling ball moves in a controlled path in real time?*

   The center of mass was altered by using a weighted pendulum inside the hollow bowling ball and steering it to the desired direction. This worked fairly well but due to uneven weight distribution some wobbling occurred and the ball sometimes leaned more to one side. The wobbling could be solved by implementing PID regulation by adding an IMU.

2. *How can radio communication be implemented to control the bowling balls' movement in real time?*

   This was solved by using a transmitter in the joystick that sends directives to the receiver inside the bowling ball. The ball will thereby move accordingly to the desired direction. This worked at a distance of a bowling lane which is approximately 20 meters without any disturbances.

3. *Does the theory behind hitting a strike apply when using the constructed bowling ball?*

   The theory was proven to work by hitting the pins at the right angle, all pins were knocked down and resulted in a strike. Fundamentally, the theory behind hitting a strike is not by hitting the pins straight on which is a common misconception. In fact, the bowling ball needs to hit the first pin at a certain angle between 3 and 6 degrees. Next, the normal force vector of the ball takes out the first row of pins following the second row in line and finally the ball's momentum takes down the last of the pins and hitting a strike.

Chapter 7

Recommendation and future work

This chapter presents a few improvements and guidelines for future experiments.

7.1 Recommendations

Firstly, to improve the connection between the Radio Frequency transceivers, use a capacitor and additionally an antenna for a further range. Secondly, it is important to wire both the power source and the devise to ground on the breadboard, for instance one ground for the servomotor and another one for the battery. Lubricate the bearings with a lubricating oil to enhance the desired rotation, such as sewing machine oil. Lastly, include a switch for the remote control and the bowling ball to skip the manual unplugging of the battery to save its lifetime. Alternatively, use a battery with longer life span.

7.2 Future work

For future work on this project a few improvements would be made. Firstly, the configuration of bearings and components would be implemented inside a real bowling ball. This by cutting the bowling ball in half and carving out the internal mass, then be replaced by the inside components and be connected by dowels like the prototype. The pendulum is recommended to be made out of a more dense material than plastic due to its importance to be the dominant weight in the robot. To reduce wobbling a PID-regulator would be implemented using an IMU. By doing this the ball would recognise when beginning to tip in the wrong direction and swing the pendulum to counteract the motion. The robot is right now powered by non rechargeable batteries, a better choice would have been a lithium polymer battery which is a low weight rechargeable battery. Due to budget limitations this was not used in this project.

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Appendix A

Acumen Code

```
// A simulation of a dirigible bowling ball that hits a pin.
// Joel Froberg, Magdalena Smolic.

model Main(simulator) =
initially
  t   = 55, // Startposition   bowling ball (magenta)
  t'  = -8, // Velocity        bowling ball
  t'' =  0, // Acceleration    bowling ball

  u   =  1, // Startposition   pin (white)
  u'  =  0, // Velocity        pin
  u'' =  0, // Acceleration    pin

  _3D =()
always
  t'' = 0,
  u'' = 0,
  if t<1.0 then t'+ =0.00 noelse,   // Bowling ball
  if t<1.0 then u'+ =5.00 noelse,   // Pin

  _3D+ = (Box                       // 3D object (Bowling lane)
          center=(0,0,-0.15)        // Center point
          size=(0.01,3,15)          // Size in (x,y,z) form
          color=0.85*yellow         // Color
          rotation=(0,-pi/2,0),     // Orientation

          Box                       // 3D object (Pin)
          center=(u/10,-u/10,0.1)   // Starting point in (x,y,z)
          size=(0.15,0.15,0.5)      // Size in (x,y,z)
```

```
color=white                    // Color
rotation=(0,u/10,0),           // Orientation

Sphere                         // 3D object (Bowling ball)
center=(-t/10,0.5*sin(0.2*t),0.05)   //Starting point(x,y,z)
size=(0.2)                     // Radius
color=magenta                  // Color
rotation=(0,-t,0))             // Orientation
```

Appendix B

Ball bearing Lifetime Calculation

The lifetime calculations for a ball bearing from the SKF standard is following

$$L_{10} = (\frac{C}{P})^p \tag{B.1}$$

Where L_{10} is the nominal service life (at reliability 90percent) [million laps], C is the basic dynamic load rating [kN] and P is the radial and axial forces on the bearing [kN]. p is the exponent of the lifetime formula which is 3 for ball bearings. The bearing used is 6006-2RS1 and it has C=13.8kN and the force applied is considered solely radial and for a bowling ball gives P=0.04kN. When added into equation B.1 gives $L_{10} > 2x10^5$ million laps before breakage.

Appendix C

Servo motor and RF Specifications

Name	HS-625MG standard servo
Voltage [V]	4.8-6
Torque kg/cm	4.8
Speed [s/°]	0.15/60
Weight [g]	55.2
Rotation [°]	0-180
Size [mm]	40.6 x 19.8 x 36.6

Table C.1. Servo Motor Specifications

Name	nRF24L01+
Voltage [V]	3.0 – 3.6
Current(transmitting) [mA]	115
Current(receiving) [mA]	45
Current(resting) [uA]	4.2
Bandwidth [GHz]	2.400 - 2.525

Table C.2. Radio Frequency Specifications

Appendix D

Arduino Code

D.1 Transmitter Code

```
/*
Arduino A Dirigible Bowling ball
Date : 2021 -04 -11
Written by: Joel Fr berg and Magdalena Smolic
Inspired by: Dejan Nedelkovski, www.HowToMechatronics.com
Examinor : Nihad Subasic
TRITA -nr: 2021:18
Course : MF133X
Bachelor  s  thesis at KTH in mechatronics
Library: TMRh20/RF24, https://github.com/tmrh20/RF24/

The code :
Transmitter Code:
  Takes analog value from joystick and translates it to an angular value(in degrees) for the servo motor.
  The Data is sent to the receiver module.
*/

// --- INCLUDED LIBRARIES - - -//
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>

RF24 radio(7, 8); // Pins CE and CSN are connected to the module.
const byte addresses[][6] = {"00001", "00002"};
boolean buttonState = 0;
void setup() {
```

```
  pinMode(12, OUTPUT);
  //Adress where the RF transceiver will operate.
  radio.begin();
  radio.openWritingPipe(addresses[1]); // 00002
  radio.openReadingPipe(1, addresses[0]); // 00001
  radio.setPALevel(RF24_PA_MIN);
}
//Reads the joysticks directions and moves the servo motor with the required angle
void loop() {
  delay(5);
  radio.stopListening();                              //Sets module as transmitter.
  int potValue = analogRead(A0);                      //Reads the potential value from output
  int angleValue = map(potValue, 0, 1023*2, 0, 180*2);  // Reads the potential value and translates it to the servo motors angle, with a range between 0 and 180
  radio.write(&angleValue, sizeof(angleValue));       //Sends data to receiver module.
  delay(5);
}
```

D.2 Receiver Code

```
/*
Arduino A Dirigible Bowling ball
Date : 2021 -04 -11
Written by: Joel Fr berg and Magdalena Smolic
Inspired by: Dejan Nedelkovski, www.HowToMechatronics.com
Examinor : Nihad Subasic
TRITA -nr: 2021:18
Course : MF133X
Bachelor s thesis at KTH in mechatronics
Library: TMRh20/RF24, https://github.com/tmrh20/RF24/

The code :
Receiver Code:
  Receives angluar value from transmitter and sets the servo motor to recived value.
  If no value received the servo motor is set to midpoint.
*/
// --- INCLUDED LIBRARIES - - -//
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
#include <Servo.h>

RF24 radio(7, 8); // Pins CE and CSN are connected to the module.
const byte addresses[][6] = {"00001", "00002"};
Servo myServo;
boolean buttonState = 0;

void setup() {
  Serial.begin(9600);
  myServo.attach(5);  //Servo connected to pin 5.
  //Adress where the RF transceiver will operate.
  radio.begin();
  radio.openWritingPipe(addresses[0]); // 00001
  radio.openReadingPipe(1, addresses[1]); // 00002
  radio.setPALevel(RF24_PA_MIN);
}
//Receives angular value and sets servo motor to recived value.
void loop() {
```

```
  delay(5);
  radio.startListening(); // Sets module as receiver.
  if ( radio.available()) {
    Serial.println("Mottar meddelande"); //Test if signal
       received.
    while (radio.available()) {
      int angleV = 0;
      radio.read(&angleV, sizeof(angleV)); //Recieves
         message.
      Serial.println(angleV);
      myServo.write(angleV);
    delay(5);
    }
  }
//If no message received, servo set to midpoint.
else{
    myServo.write(90);
  }
}
```

Appendix E

Circuit diagram

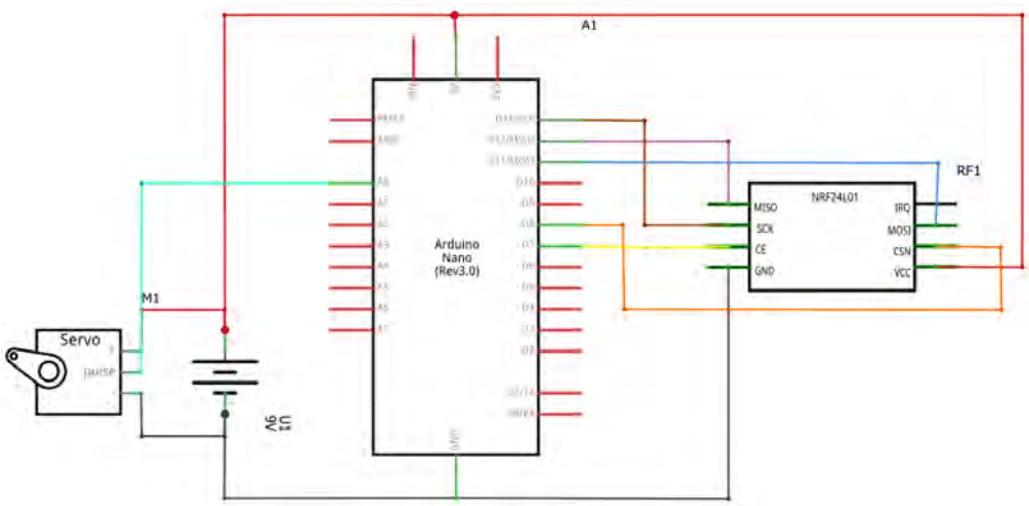

Figure E.1. The circuit diagram for the servo motor inside the sphere. Created in Fritzing.

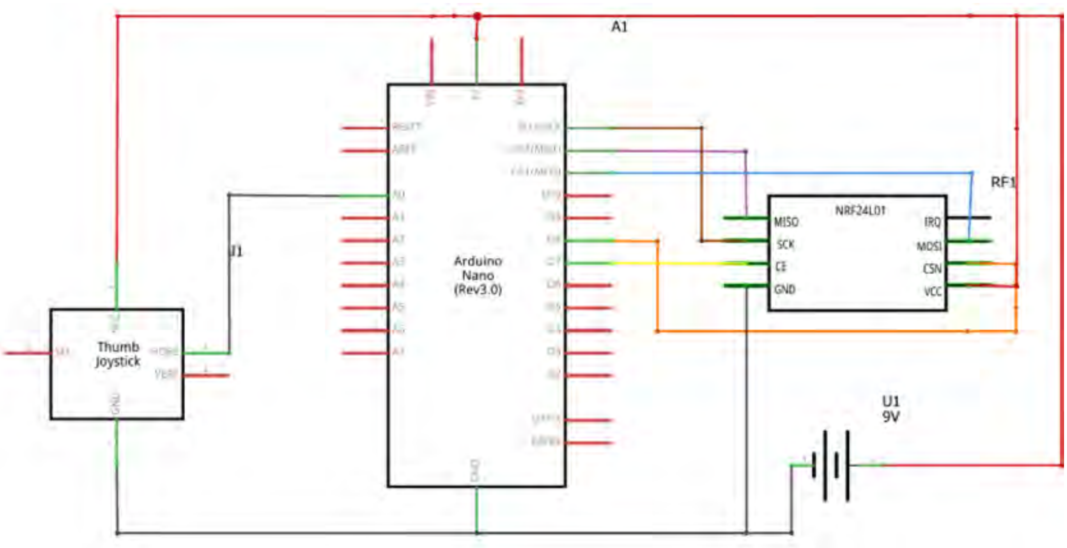

Figure E.2. The circuit diagram for the remote control. Created in Fritzing.

TRITA ITM-EX 2021:36