**Abstract:**

A “Ball Balancing Platform” is a dynamic control system that is designed to stabilize a ball by adjusting the orientation of the platform. A 4-wire resistive touchpad is used as the platform to obtain position feedback. The platform is mounted on a 3RRS (Revolute-Revolute-Spherical) parallel manipulator to control the orientation of the platform. A PID (Proportional-Integral-Derivative) controller is used to maintain the ball at a target position by constantly adjusting the platform’s angle based on the displacement. The main objective of the thesis is to study control strategies, electronics, inverse kinematics, sensor integration and system modelling.

**Streszczenie:**

“Platforma do balansowania kulką” to dynamiczny system sterowania, który ma za zadanie stabilizować kulkę poprzez dostosowywanie orientacji platformy. Do uzyskania informacji o pozycji wykorzystuje się 4-przewodową rezystancyjną nakładkę dotykową. Platforma jest zamontowana na równoległym manipulatorze o 3 stopniach swobody (3 DOF), który kontroluje jej orientację. Regulator PID (proporcjonalno-całkująco-różniczkujący) jest używany do utrzymania kulki w wybranej pozycji, stale dostosowując kąt platformy na podstawie przemieszczenia kulki. Głównym celem pracy jest zbadanie strategii sterowania, elektroniki, kinematyki odwrotnej, integracji czujników oraz modelowania systemu.

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# Introduction

“Ball balancing platform” is a unique engineering problem that requires combining mechanical design, electronics, and advanced control algorithms. The aim of the project is to design and build a platform that can balance a spherical metal ball at a pre-defined point by tilting the platform to counteract external forces.

The inter-disciplinary nature of this project is what motivated me to building this.

The practical applications of such a control algorithm extends to various fields, including but not limited to Robotics, Aerospace and Industrial Automation.

A blue and yellow robotic device

Description automatically generated

Figure . CAD Model of a ball balancing platform

# Project objectives and requirements

This chapter outlines the objectives of the project in a systematic order of implementation. There are some research-oriented objectives as well for which the results cannot be anticipated in advance and thus may not have been defined in the list. Requirements for both hardware and software development are listed as well.

## Project Objectives

Due to the interdisciplinary nature of the project, the implementation has been divided into three sections :

## Requirements

### Electronics

1. [Teensy 4.1 Microcontroller](https://www.amazon.com/PJRC-Cortex-M7-Processor-iMXRT1062-Without/dp/B088JY7P2H/ref=sr_1_4?crid=36CI81XOWM0Z0&keywords=teensy+4.1&qid=1677474562&s=electronics&sprefix=teensy+4.1%2Celectronics%2C139&sr=1-4)
2. [Nema 17 59 Ncm Stepper Motors (Bipolar)](https://www.amazon.com/dp/B00PNEQKC0?psc=1&ref=ppx_yo2ov_dt_b_product_details)
3. [TMC2208 Stepper Motor Drivers](https://www.amazon.com/dp/B082LSQWZF?psc=1&ref=ppx_yo2ov_dt_b_product_details)
4. [Mini Protoboard + Screw Terminals](https://www.amazon.com/gp/product/B08BWPGSSC/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1)
5. [100uF Capacitor 35V](https://www.amazon.com/dp/B07Y3F194W?psc=1&ref=ppx_yo2ov_dt_b_product_details)
6. [Male and Female Header Pins](https://www.amazon.com/Honbay-Single-Female-Connector-Arduino/dp/B06Y4S6G29/ref=sr_1_8?crid=1W7J1GV4G3XE3&keywords=header+pins&qid=1677475169&s=electronics&sprefix=header+pin%2Celectronics%2C144&sr=1-8)
7. [30V Bench Power Supply](https://www.amazon.com/gp/product/B082FV1PGP/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1) (or any 24V power supply)
8. [22 AWG Wire](https://www.amazon.com/gp/product/B01LH1FR6M/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1)
9. [5V Regulator](https://www.amazon.com/Weewooday-Regulator-Voltage-Converter-Transformer/dp/B08JZ5FVLC/ref=sr_1_2_sspa?crid=28M4EAWMIWBMT&keywords=5v+regulator&qid=1684300783&sprefix=5v+regulator%2Caps%2C198&sr=8-2-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUExSThTTFJLVFozQ0hKJmVuY3J5cHRlZElkPUExMDMyNTI2WEZWTUZFWkhZQVNNJmVuY3J5cHRlZEFkSWQ9QTAxNTE0MDUyUVZGRzBRTkxZMUpBJndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ==)

### General Parts

1. [8.4" 4 Wire Resistive Touch Panel](https://www.amazon.com/dp/B07TZGVY8K?psc=1&ref=ppx_yo2ov_dt_b_product_details)
2. [1" Steel Bearing Ball](https://www.amazon.com/dp/B07CHZ94W9?psc=1&ref=ppx_yo2ov_dt_b_product_details)
3. [22mm long m3 tie rod](https://www.amazon.com/dp/B09JLKLK73?psc=1&ref=ppx_yo2ov_dt_b_product_details)
4. [m3 x 6mm threaded inserts](https://www.amazon.com/dp/B07LBQRYR3?psc=1&ref=ppx_yo2ov_dt_b_product_details)
5. [M3 x 5mm Standoffs](https://www.amazon.com/dp/B07M7D9PRM?psc=1&ref=ppx_yo2ov_dt_b_product_details)
6. [M3 x 5mm Screws](https://www.amazon.com/Dahszhi-Phillips-Machine-Metric-Thread/dp/B099ZK3NK9/ref=sr_1_5?crid=18J5PGUV1ZTGU&keywords=m3%2Bx%2B5mm%2Bscrews&qid=1681514624&sprefix=m3%2Bx%2B5mm%2Bscrews%2Caps%2C110&sr=8-5&th=1)
7. [M3 x 8mm Screws](https://www.amazon.com/Socket-Screws-Metric-Stainless-Machine/dp/B07NSW9RBQ/ref=sr_1_6?crid=3EDVNS6LIQKI2&keywords=m3+x+8mm+screws&qid=1677476973&sprefix=m3+x+8mm+screw%2Caps%2C93&sr=8-6)
8. [M3 x 10mm Screws](https://www.amazon.com/Socket-Screws-Metric-Stainless-Machine/dp/B0BJ1V4FKY/ref=sr_1_6?crid=3EDVNS6LIQKI2&keywords=m3%2Bx%2B8mm%2Bscrews&qid=1677476973&sprefix=m3%2Bx%2B8mm%2Bscrew%2Caps%2C93&sr=8-6&th=1)
9. [M3 x 35mm Screws](https://www.amazon.com/M3-0-5x35mm-Stainless-Machine-Eastlo-Fastener/dp/B07X2Q33NW/ref=sr_1_19?crid=A5V6SF3S5SII&keywords=m3%2Bx%2B35mm%2Bscrews&qid=1681514731&sprefix=m3%2Bx%2B35mm%2Bscrews%2Caps%2C106&sr=8-19&th=1)
10. [M3 Nylon Locknuts](https://www.amazon.com/SpzcdZa-Stainless-Industrial-Construction-Fasteners/dp/B08LMQC765/ref=sr_1_1_sspa?crid=282O9LSLQ01JO&keywords=m3%2Block%2Bnuts&qid=1681514827&sprefix=m3%2Block%2Bnuts%2Caps%2C93&sr=8-1-spons&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEyTU1XQ09ESVpPWDFLJmVuY3J5cHRlZElkPUEwNzkyMTI5MUxaUlVaT1ZFVFdDRyZlbmNyeXB0ZWRBZElkPUExMDEzOTM5WURaQlZUUzNBV0k0JndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ&th=1)
11. [M4 x 20mm Screws](https://www.amazon.com/Socket-Screws-Metric-Stainless-Machine/dp/B07KRFQJK1/ref=sr_1_6?crid=3EDVNS6LIQKI2&keywords=m3%2Bx%2B8mm%2Bscrews&qid=1677476973&sprefix=m3%2Bx%2B8mm%2Bscrew%2Caps%2C93&sr=8-6&th=1)
12. [M4 x 25mm Screws](https://www.amazon.com/Socket-Screws-Metric-Stainless-Machine/dp/B07KRS36P2/ref=sr_1_6?crid=3EDVNS6LIQKI2&keywords=m3%2Bx%2B8mm%2Bscrews&qid=1677476973&sprefix=m3%2Bx%2B8mm%2Bscrew%2Caps%2C93&sr=8-6&th=1)
13. [M4 Nylon Locknuts](https://www.amazon.com/SpzcdZa-Stainless-Industrial-Construction-Fasteners/dp/B08LMNFS5P/ref=sr_1_1_sspa?keywords=m4%2Blocknuts&qid=1681514944&sr=8-1-spons&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzRU5YVFhHV09QRFJUJmVuY3J5cHRlZElkPUEwMTIzODg3QlQ4SjVKVUcwVDFUJmVuY3J5cHRlZEFkSWQ9QTAzMTgzMDlGQUdMUDM5Vzc4TjImd2lkZ2V0TmFtZT1zcF9hdGYmYWN0aW9uPWNsaWNrUmVkaXJlY3QmZG9Ob3RMb2dDbGljaz10cnVl&th=1)

### Tools

1. needle nose pliers
2. wire cutters
3. wire strippers
4. 2.5mm allen wrench
5. soldering iron
6. exacto knife
7. hot glue gun

# Assumptions

This chapter constitutes the detailed list of assumptions made in work. As the Ball Balancing Platform is a demonstration built in a lab environment, the required assumptions are not very rigid. The following assumptions were made:

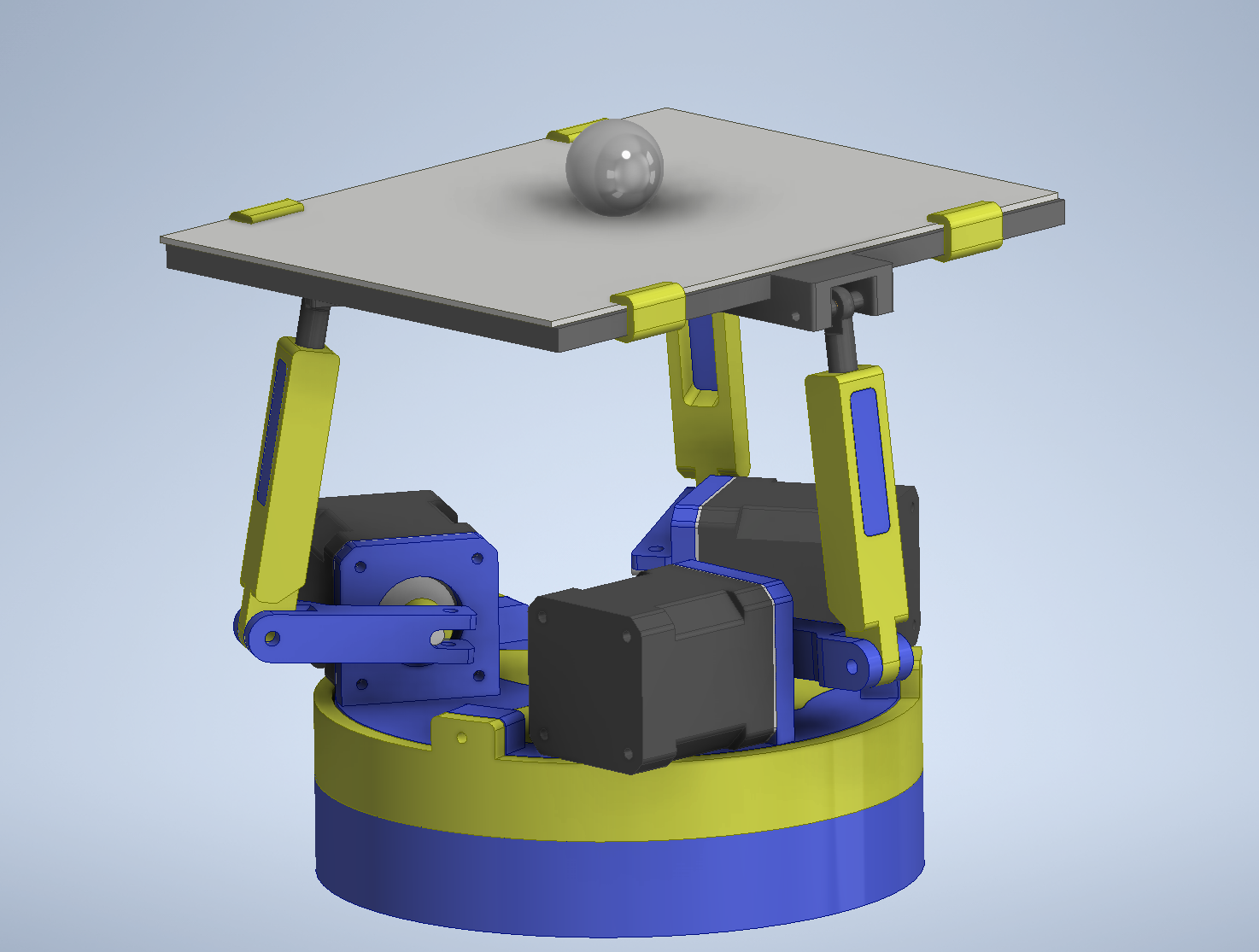
1. The platform’s operation is intended to be demonstrated in a lab environment.
2. A PID controller will be used primarily. Similar control strategies may be explored.
3. An Arduino UNO microcontroller will be used as the brain of the system. The selection was made due to its features like real time control, low latency and floating-point calculation.
4. Areas like control theory, microcontrollers, Mechanical design and kinematics were studied.

# Hardware - Mechanical

This section details the mechanical design, fabrication and testing of the 3RRS platform. The 3RRS platform has 3 degrees of freedom and 3 points of actuation. 3 stepper motors with TMC drives are used for precise actuation. Thanks to the KN-Humanoid club’s 3D printer - 3D printing was used to fabricate most of the structures.

## Mechanical Design

The chapter describes the mechanical design of the 3RRS(Revolute-Revolute-Spherical) platform.



4

2

3

5

6

1

Figure . Ball Balancer mechanical design (description below)

A metallic ball **1** is placed on a resistive touchpad **2** which outputs the position of the ball by detecting the contact point and returning it as a cartesian point. The platform is connected to the actuator legs with a spherical joint **3.** The actuator leg has two links connected by a revolute joint **5.** The lower leg is connected to the rotor of the stepper motor **6** with a revolute joint **4.**

## Inverse Kinematics

The inverse kinematics required to orient the platform according to the position of the ball is derived in this sub-chapter. The equations derived are then verified in MATLAB.

Given a unit normal vector of the platform plane, the IK equations than compute the required angles

A drawing of a triangle with lines and dots

Description automatically generated

Figure . Kinematic Diagram of the ball balancing platform

Table . Description of symbols in Figure 4.2

|  |  |  |
| --- | --- | --- |
| SYMBOL | DESCRIPTION | UNITS |
| O | Origin of the global co-ordinate system | [0,0,0] |
|  | The rotor angle that will be controlled | radians |
|  | The revolute joint angles between the two links | radians |
| h | Height between two platforms | cm |
|  | Perpendicular distance between the steppers | cm |
|  | Length of the first link | cm |
|  | Length of the second link | cm |
|  | Unit normal vector of the top platform plane |  |
| d | The distance between the origin and steppers | cm |