Design a Mechatronic System (Robot) to Transfer Table Tennis Balls

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Abstract. Advancement of technology and human needs has contributed to the convergence of multiple engineering disciplines. Mechatronics engineering is an applied discipline that focuses on the design and study of complete engineering systems including mechanical, electrical, electronic, and control systems. This paper is concentrated on design a mechatronic system (robot arms) to transfer Ping-Pong balls. The aim of this paper is to explain the design process of producing a robot that will compete in a competition. The robot will be operated either wired or wireless within its designated area in performing the ball collection during a two-round match. Duration of 10 minutes is going to be allocated for every round. Top two teams that collect most balls between the 2 rounds will proceed to subsequent round (if quite 4 teams are competing). The performance evaluations will be in terms of number of Ping-Pong balls successfully placed inside the collection buckets.

Keywords—Robot arms, Mechatronics system, Control system.

1. Introduction

1.1. Robotic Arms
The arm used by Andersson (1988) [1] and his team at the AT&T Bell Laboratories was the PUMA 260 arm developed by Unimation, which is a 6 degree freedom arm shows in Figure 1. Since this project had a fairly limited budget, it was not a choice to purchase an expensive 6 degree liberty weapon. As a result, it was appropriate to construct an arm and so literature was found on various configurations of the arm. Colson and Perreira (1985) [2] dealt with different structures typically used in industrial robots. Those were researched to gain an understanding of how connections between the weapons worked and how specific problems were resolved. Keramas (1998) [3] and Siciliano (2004) [4] were then used with their workspaces, advantages and disadvantages to analyze common weapon configurations.
1.2. Robotics Fundamentals and Control

Fundamentals of Robot Technology provided an overall general overview of the mechanism without going into any specific information about the mathematics involved. Such measures involved kinematics, dynamics and the generation of trajectories. Definitions of kinematics were consistent through Lee (1982) [5], Mayer (1981) [6]. Only Craig (2005) [7], Siciliano (1999) [12] introduced a new updated scheme, which has no supporting text but is easier to understand, so this approach was abandoned. The remaining texts all used the same method and identically described the mathematics. Lee (1983) [8] was the most user-friendly, so he took much of the syntax out of his article.

Dynamics of the robots vary widely across various documents. Most older texts like Paul (1981) [9] and Lee (1983) [8] measure dynamics using the variance of the Lagrangian dynamics. Hollerbach (1980) [10] contrasts the Lagrangian in Newton-Euler to a newer alternative. Hollerbach (1980) [10] shows that the Newton-Euler is much more effective than the Lagrangian and should be used for real time applications. Hollerbach (1980) [10] notes the Newton-Euler equations, but does not provide adequate details for their implementation. Corke (1996) [11] states the equations in a user-friendly format; however, the approach described in Siciliano (1999) [12] takes a greater number of physical factors into account and thus offers a more practical response.

A number of conventional robot control systems including PID, decentralized feed forward calculation, and computed torque control were investigated. These have been discussed both in joint and centralized management. Siciliano (1999) [12] and Khalil (2002) [13] provide the most detailed explanations of the new control schemes such as computed torque. Papers such as Paul (1981) [9] and Mayer (1981) [6] provide information about less sophisticated control systems and how they are paid to meet robotic manipulator control requirements.

2. Conventional methods

Weber (1965) [14] has suggested a Pulse Width Modulation (PWM) based DC control to change the voltage applied to the engine to regulate the speed of a DC series field motor at different appropriate torque rates. For any specific constant voltage, the motor speed is defined solely by the specifications of the torque and the peak speed is reached under minimal torque. A series motor has been used in automobiles as a traction engine. Motor voltage is regulated to meet the many torque requirements of grades, speed and freight. The common method of varying the motor speed is by adding R serial resistance with motor to lower the power supplied. This method of motor speed control is extremely inefficient due to the loss of battery power due to the loss of I2R, in particular under high current and high torque conditions.

Chevrel et al (1996) [15] proposed a conceptual approach for the design of an efficient DC motor speed controller, assisted by switched quadratic regulators. This control strategy is contrasted in terms of efficiency, robustness and complexity, with two cascade control design methods. Switched
LQ (Linear Quadratic) regulators were particularly compatible with the performance-robustness tradeoff handling. Given giant parametric uncertainties, the performance robustness for the strategies has been proven. System stability analysis was not performed to demonstrate whether or not the system is stable.

Chevrel and Siala (1997) [16] suggested a DC servo motor speed control when this is the only option. To estimate the speed and thus the load torque, a LQG (Linear Quadratic Gaussian) controller is expected to assemble an integral LQ state feedback and a Kalman observatory. The robustness and performance are debated and evaluated experimentally. It is constrained by switching from speed regulator to current regulator if necessary. An impression design has been presented that performs well the balance between speed control efficiency, robustness and current dc-motor limitation as there is no mechanical sensor. Especially good results were obtained experimentally when the parameters of the motor were established at engine start. It is also shown that the resistance variance causes a non-zero steady state error and shows that no linear regulator can solve this problem. Limitation is that precise speed control without a mechanical sensor requires on-line detection of the gradually changing resistance and also the use of adaptive control.

Praesomboon et al (2009) [17] suggested a sensorless speed control of the DC using a Kalman filter. Kalman filter takes mathematical model of the DC motor. The model will start from endless space of state into a discrete space type of state. Unit inputs are the voltage of the armature, and thus the current of the armature with noise. The device performance is that of projected velocity. Kalman filter used to measure the velocity without interference with the noise. The effect of the approximate velocity was compared with the reference velocity and thus the controller would use the velocity error to regulate the linear amplifier. The final output was the DC motor constant velocity. Although the DC motor load has shifted, the DC motor velocity remains constant under power. The results show that the Kalman filter is able to reject the noise from the system and estimate the DC motor speed with a high precision. The calculated speed is becoming a support for operating the machine at constant speed. Speed can be a big constraint when transforming continuous signal to discrete signal.

The location regulation of DC servo motors was proposed by Bindu and Namboothiripad (2012) [18] as they are extensively deployed in various servomechanisms. The transient response of DC servo motors is normally enhanced by PID controllers. Most tuning methods are usually configured to provide workable initial values, which are then further adjusted manually for a particular requirement. A flexible and fast tuning method supported by the Genetic Algorithm (GA) is needed in order to work out the optimum PID controller parameters for the given device specifications. Simulation results show that the proposed tuning approach meets a strong range of requirements with respect to the PID parameters. Limitation is within the range of requirements and can be broadened by raising the size of initial population, but the amount of generations needed to converge to optimum value will increase.

3. Methodology

From the previous section, the exploration was presented and the proper components and related control approach for this research were determined. Accordingly, this venture was structured through a few stages and by gathering all information for all instruments that have been use. Details of this project will be discussed in this chapter. The flow chart in Figure 2 was indicted the flow of this project.
3.1. Design Robot Arm
First step, the model have been designed the robot based on the condition given. The robot requirements during the competition day are to collect table tennis ball from storage bucket to collecting bucket. Figure 3 shows the robot arms that have been design by using Catia software. Before fabricate the components by using 3D printing have been done some analysis which the arm of the robot gets to catch the table tennis ball at the perfect angle. While Figure 4 indicates the robot arm after the printing.

3.2. Robot Gripper
Basically, robot gripper is the critical element for this project. During the competition each group have to catch as much as possible table tennis ball according to the time given. Therefore, the model have been design the gripper very well in order to catch the ball more than one at one time. Figure 5 show...
the robot gripper printed. It is effectively can catch more than one ball at one time. The calculation of the design done by using mechanical criterion, involved the size, weight, material of the ball. The gripper design is actually inspired from the table tennis ball itself. The characteristics are light and round in shape. The angle of the robot arm has been designed to help gripper to move up and down perfectly by following the specification for the competition day. Figure 6 indicates the competition robot operating area.

3.3. Beam
Two beams are divided by two 13-height LEGO boards, producing a vertical 123-unit interval equal to two horizontal units. So the beams can be locked into place with cross-beams and connector pegs — the way to make your LEGO construction fairly sturdy. Figure 7 shows the mechanical components of the robot which has been the main pillar of the robot to stand that is beam.

3.4. Gearing
Switch on a small DC motor, just like the LEGO stock motor, so the shaft spins very quickly, but with almost no torque (turning force). Using your fingertips you can quickly pressure the shaft to stop the motor from spinning. This quick still-weak motor energy is also converted by the magic of drug reduction into a powerful still sluggish rotation, ideal for driving wheels, gripper hands, elbow joints, and the other mechanism. Building successful gear trains is the spouse of the task of making working LEGO machines, alongside structural problems. Thanks to delivering large amounts of torque to a final drive, chain links are often an effective, while providing a gear reduction if necessary. Chain link works best at the slower gearing points, and with very loose contact. Use the bigger gears — the 8–tooth one won't work properly. Hence, Figure 8 indicates the driver of the chain link.
3.5. Control System

Arduino is an open source framework used to develop projects in the field of electronics. Arduino consists of both a physically programmable circuit card (often referred to as a microcontroller) and some software, or IDE (Integrated Development Environment) running on your device, which does not write and upload physical board code. The Arduino does not require a separate piece of hardware (called a programmer) so you'll just use a USB cable to load new code onto the device. Finally, Arduino provides a typical form factor which breaks up the microcontroller's functions into a more accessible package. The Arduino doesn't require a separate piece of hardware (called a programmer) so you can just use a USB cable to load new code onto the device. Ultimately, Arduino offers a standard form factor breaking up the microcontroller's functions into a more usable kit.

The model done by using two Arduino micro controllers, whereby one is to regulate the robot simple movements (front, back, left & right) with DC motors and another to regulate two servo motors for the grab & devour function of the arm gripper. A battery box with four AAA batteries is connected to the Arduino board’s power input jack and therefore the code was sourced online and modified accordingly. Figure 9 shows servo motor while Figure 10 indicates Circuit of the robot.

In order to control the movements of our robot, the Arduino servo control & TAYARCABUT application installed onto an Android smart phone that enables wireless control via Bluetooth. Once the application is installed, the settings can be configured to manoeuvre the robot by touching the smart phone screen. Figure 11 shows robot controlling application.
4. Results
The completed table tennis ball catcher robot is shown below in Figure 12 which fulfils the component that mentioned in the previous chapter. The device consists of the main unit and the mechanical unit. Only the kinematic properties of a gripper are considered in the initial stages of testing and design. This is aimed at finding a manipulator concept that is lightweight and capable of catching table tennis ball. The requirements are that it is able reach every ball grip at minimum angle with static arm and represented by the Figure 13. Additionally, the gripper design made it to open and catch widely.

![Figure 11](image1.png) Robot Controlling Application.

![Figure 12](image2.png) Completed Robot.

![Figure 13](image3.png) Gripper testing opens and catches.

The early stage of arm design measurement actually is not effective to catch the ball due to angle of the arm is not suitable. The appropriate action has been taken to redesign the arm. The angle and size taken into account in order to ensure the arm can be used optimally. Physical testing has been made to see the ability of the arm to stand while holding the gripper.

Next, the movement of the motor not responding properly. At first, the discussion has been made to troubleshoot the problems of the motor as the microcontroller can be remotely access through mobile applications by Bluetooth, the problem between Bluetooth connection has been identified first. After several testing, the connection was actually very stable and the poor respond was not come from Bluetooth connection. Another troubleshoot by checking the voltage usage. By using multimeter there was apparently voltage drop. This causes the movement of the robot is not smooth as expected. At the early stage 9V battery been used and as per problem due to not enough voltage changed to 12V battery. The two microcontroller actually has been used that’s was the huge reason this problem occurred. The two microcontroller first for movement of the wheel to move forward backward left and right, while another microcontroller used for arm gripper to move upward, downward, open and catch. On the other major issue is that the robot was a little bit jerking during the movement of the gripper through ups and down. Physical testing has been made and after taken into account several things, the behaviour of the robot based on the components and sizes itself. Due to size of arm and gripper has been amended, the balancing of arm and body quite unstable. However, the weight has been added to ensure the robot is balanced and not jerking.
4.1. Gripper Movement
Gripper move is the significant movement effect to this project objective. In order to evaluate this project, the way of gripper catch the table tennis ball plays the most part. As this project requires robots to collect as many table tennis balls as much as possible at given time. The design proposed actually to grip the table tennis ball minimum one and maximum two table tennis balls at the time. At the early stage, physical testing has been made to see if the group objective to catch maximum two tennis balls at one time success or vice versa. Figure 14 shows the possible movement of the gripper. This is so significant to determine the design fully successful. The initial position of the gripper is upward, and the robot wheel will move and brings the robot to the location needed where the storage bucket placed. When the robot has reached at the storage bucket, the gripper position will be downward.

In order to collect the table tennis ball inside the storage bucket, the level of the gripper need to be controlled appropriately. When the level is fully confirmed, the gripper position will be open. Actually the opening size of the gripper can be control. Therefore, controller needs some skills to ensure the opening size suitable with the area provided. Next, when the position of the gripper looks like very possible to catch the ball, gripper position must be in catch position. At this moment will determine either the ball catches more than one or miss the ball. As the result, this robot gets to catch two table tennis balls at one time.

![Figure 14 Movement of the gripper.](image)

4.2. Competition Day
After all the analysis and improvement made, the most important day to shows the performance of the robot was on the competition day. There are several occurred during the competition. Three rounds of robot show had given within three minutes per round. All those three rounds were at different location. Before the competition, the condition of the robot was at very good and ready. Figure 15 shows the actual area of robot competition.
During the competition, significant problem occurred was at the wheel design. The wheel design is actually chain wheel. This design has been chosen due to simplicity, strength and ability to work in harsh environment. Because of that, the chain was taken off. However, the connector between the chain allowed the group to connected it and continue the competition. Figure 16 shows the chain wheel taken off during the competition. While some of group members try to connect and successfully. Indirectly the competition can be proceeding.

![Figure 15](image1.png)  Area of competition.  
![Figure 16](image2.png) Chain wheel taken off during competition.

5. Conclusions

5.1. Contributions
The objective of this project to design and build a mechatronic system (robot arms) to demonstrate and documented that can be used to transfer table tennis balls also been successfully accomplished and achieved. The most significant effect from this project is our group get to win the competition with the total numbers of 12 table tennis balls collected. This is obviously due to the arm gripper design that already been analyse and testing to see the potential of arm gripper to catch more than 1 table tennis ball at one time. Through the previous chapter, discussion has been made how the obstacles and challenge has been faced by the group to get the optimum design based on condition, cost, area and time given. However, all the objectives have been achieved completely.

5.2. Recommendations
These are several recommendations can be used for the improvement purpose in the future which can make the project better.

- Create competition with different difficulty levels which can challenge each group to make better analysis and design of the robot.
- The design of the chain wheel can be revised due to problem occurs during the competition. Deeper research need to be explored.
- The microcontroller usage can be exploring more. The usage optimization from the students since the student’s lack of understanding at this matter.
- Give appropriate time and consideration to apply more knowledge to the project

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