AN-NAJAH NATIONAL UNIVERSITY

FACULTY OF ENGINEERING AND INFORMATION TECHNOLOGY

COMPUTER ENGINEERING DEPARTMENT

Hardware Graduation Project

Salamo

Submitted by

Sewar Asaad

Siwar Diab

Supervisor

Dr. Samar Mayaleh

Presented in partial fulfilment of the requirements for Bachelor degree in Computer Engineering.

Contents

Acknowledgment

First and foremost, we thank God for granting us the strength and guidance to complete this project. We would like to extend our sincere gratitude to our beloved families for their constant support and encouragement. Their constant presence has always been our source of strength and motivation.
We extend our sincere thanks to our supervisor, Dr. Samar Mayaleh, for his continuous support and valuable guidance throughout the project.
Finally, we extend our sincere thanks to our dear friends and colleagues who have walked with us along this path and contributed to making this journey unforgettable.

Disclaimer

This report was prepared by students Sewar Asaad and Siwar Diab in the Department of Engineering, Faculty of Engineering, An-Najah National University. It has not been edited or proofread, except for some editorial corrections, as a result of evaluation. It may contain linguistic and content errors. The opinions expressed herein, as well as any findings and recommendations, are solely those of the students. An-Najah National University assumes no responsibility for the consequences of using this report for a purpose other than that for which it was prepared.

Abstract

In recent years, events, product launches, and public gatherings have grown rapidly due to the influence of social media and content creation trends. One essential aspect of such events is providing a warm and engaging welcome for guests. This project introduces a self-balancing reception robot designed to offer hospitality by combining modern technology with cultural values such as generosity and welcoming interaction. The robot enhances the image of events while presenting a futuristic approach to social interaction, making it significant from both technological and social perspectives.

The main objective of this project is to design and develop an interactive self-balancing robot capable of welcoming and engaging guests in a modern and intuitive manner. The robot aims to reduce reliance on traditional human greeters by integrating automation, intelligent sensing, and human–robot interaction features.

The development process involved designing the robot's mechanical and electrical systems, including the two-wheel self-balancing structure and electronic integration. Key hardware components such as motors, sensors, microcontrollers, and a single-board computer were selected and integrated to support real-time balance control and interaction. A feedback-based control algorithm was implemented to enable stable self-balancing using real-time sensor data.

In addition to balancing, the robot incorporates vision-based emotion detection, audio feedback, and a small display that presents interactive digital eye expressions. These features allow the robot to respond to user presence and emotional cues in a more natural and engaging way. The system was tested and refined in real-world conditions to ensure stability, safety, and effective interaction.

While similar hospitality robots exist online, such systems are not commonly available in the local environment, and many do not combine self-balancing control with emotion-aware, multimodal interaction. This project demonstrates a unique approach by integrating balance control with intelligent human–robot interaction in a single platform.

Theoretical Background

PID Control System

The robot is modeled as an inverted pendulum system, which is inherently unstable and cannot maintain balance without continuous control. To stabilize the robot and keep it upright, a Proportional–Integral–Derivative (PID) controller is implemented.

The PID controller continuously calculates the error between the desired tilt angle (upright position) and the measured tilt angle obtained from the IMU sensor. Based on this error, the controller generates a corrective control signal that adjusts the motor speed and direction in real time to maintain balance.

:The PID control output is defined as

$$\frac{de(t)}{dt}{}_dK + K_i \int e(t)\,dt + K_p e(t) = u(t)$$

.where $e(t)$ represents the tilt error

PID Components

- **Proportional(P):**
  Reacts to the current tilt error. A higher proportional gain results in stronger corrective action. If set too high, the robot oscillates rapidly; if too low, the robot responds slowly and fails to balance.

- **Integral(I):**
  Accumulates past errors and compensates for steady-state drift, such as a constant forward or backward lean. Excessive integral gain can introduce slow oscillations and instability.

- **Derivative(D):**
  Responds to the rate of change of the error, effectively damping oscillations and improving system stability. High derivative gain may cause noisy or jittery motor behavior.

Sensor Feedback and Actuation

The MPU6050 IMU provides real-time tilt angle and angular velocity measurements. Sensor fusion is used to obtain a stable angle estimate, and the PID output is converted into PWM signals that control the motor drivers to regulate DC motor torque and maintain balance.

1 Introduction

Reception services in public institutions often depend on manual interaction, which can be repetitive and time-consuming, especially during busy periods. With the advancement of robotics and embedded systems, automated reception solutions have become feasible and effective.

This project aims to design and implement an intelligent reception robot capable of assisting visitors by providing guidance and basic information. The robot integrates hardware components with software algorithms to perform interactive and assistance tasks efficiently. The significance of this project lies in reducing human workload while enhancing service efficiency and user experience through the use of smart robotic technologies

1.1 Background

The use of service robots in public facilities has increased with the advancement of robotics and embedded systems. Reception areas require continuous guidance and interaction with visitors, which can be challenging during busy periods. Autonomous mobile robots provide an effective solution by offering consistent assistance, improving efficiency, and reducing the workload on human staff

1.2 Significance

The significance of this project lies in enhancing the efficiency of reception services through the use of robotic technologies. And improve service availability and user experience, reduce human effort during busy periods in public facilities

2 Constraints and Standards

2.1 Standards

Control System Standards:

- **Inverted Pendulum Model:**
  The control system is designed based on the mathematical model of an inverted pendulum, which serves as the foundation for balance control and system stability.

- **PID Control Implementation:**
  A PID controller is used to continuously correct the robot’s tilt angle by adjusting motor speed and direction, ensuring fast response and stable operation.

Electrical Standards:

- **Reliable Wiring:** Standardized electrical connections ensure all sensors, motors, controllers, and communication modules function reliably without risks of short circuits or electrical failures.
- **Component Compatibility:** All electronic components, including sensors, Arduino Mega, ESP modules, and motor drivers, are selected and connected according to established electrical safety and reliability standards.

2.2 Constraints

Vision-Based AI Dependency:

The robot relies on camera-based artificial intelligence techniques to analyze visual cues and interact with humans, such as detecting presence, facial expressions. The performance of this visual analysis is affected by environmental factors including lighting conditions, camera angle, and image quality. Poor illumination or occlusions may reduce detection accuracy, which can limit the effectiveness of human–robot interaction.

Load Distribution Constraint:

Load distribution was a significant constraint in the system. The weight and placement of components directly affected the robot’s center of mass, which influenced balance stability. Uneven load distribution increased control difficulty, requiring careful arrangement of components to maintain stable operation.

3 Literature Review

The integration of robots into service sectors has increased significantly in recent years due to their potential to improve efficiency, reduce human workload, and enhance user experience. Traditional automated reception systems, such as ticketing machines and information kiosks, are commonly used in public spaces to perform predefined tasks. While these systems improve operational flow, they lack intelligence and do not support natural interaction with users.

Human receptionists, on the other hand, provide flexible and interactive services in environments such as hotels, universities, and service centers. However, relying entirely on human staff increases operational costs and may lead to fatigue, especially during peak hours. This has motivated research into intelligent reception robots that combine mobility, sensing, and artificial intelligence.

Recent studies have explored the use of service robots equipped with cameras, microphones, and conversational systems to enable human–robot interaction. These robots utilize speech recognition, speech synthesis, and artificial intelligence models to communicate with users in a more natural manner. Vision-based systems are also used to detect human presence and enhance interaction. Despite these advancements, challenges remain in achieving reliable interaction under varying environmental conditions and ensuring system stability.

In parallel, self-balancing robots based on the inverted pendulum model have been widely studied due to their compact structure and maneuverability. These robots require precise control algorithms and real-time sensor feedback to maintain stability. Integrating intelligent interaction capabilities into self-balancing platforms adds further complexity, as the system must maintain balance while processing sensory and interaction data.

The limitations of traditional reception systems and the challenges associated with intelligent robotic interaction highlight the need for a self-balancing reception robot that combines stable control with artificial intelligence–based human interaction. This motivates the proposed system, which aims to provide an efficient, interactive, and adaptable reception solution for modern service environments

4 Methodology

4.1 System Workflow

The system follows a distributed architecture, where low-level balance control is handled by the Arduino, high-level perception and decision-making by the Raspberry Pi, and visual display control by the ESP32.

The proposed system is designed to operate as an intelligent interactive reception robot that responds automatically to human presence and interaction. The system workflow begins with a presence detection phase, followed by human verification, emotion analysis, user interaction, and guidance delivery.

Initially, an ultrasonic sensor is continuously used to monitor the surrounding area. When a person approaches the robot within an approximate distance of 40 cm, the system is activated and transitions from the idle state to the interaction state. At this point, the camera module is enabled to capture visual input.

The captured image is first processed to verify the presence of a real human face, ensuring that the system responds only to actual users and not to objects or false triggers. Once a human face is confirmed, the system performs facial emotion recognition to classify the detected emotion into one of the predefined categories: happy, sad, angry, or neutral. Based on the identified emotion, the robot plays a corresponding emotion-based audio message.

At the same time, the detected emotion is sent from the Raspberry Pi to the ESP32, which controls the tiny display. The display updates in real time to show animated digital eye expressions that match the detected emotion, providing visual emotional feedback to the user and enhancing the overall interaction experience.

Each audio message includes a welcoming response adapted to the detected emotion, along with instructions prompting the user to select one of the available options using hand gestures.

Following the emotional interaction stage, the system proceeds to hand gesture recognition. The user selects an option by raising fingers in front of the camera: showing one finger selects the English placement test, two fingers select the Computer Science test, and three fingers selects General assistance. If no finger gesture is detected, the system plays a dedicated audio message indicating that no selection was made. In the case of an invalid gesture (any number other than one to three), an error audio message is played to inform the user of the incorrect input.

If the user successfully completes the interaction sequence, including emotion recognition and option selection, the robot plays the corresponding guidance audio and then enters a cooldown period of 30 seconds. After this period, if the user remains present, the system automatically restarts the interaction workflow from the beginning.

At any stage of the workflow, if the ultrasonic sensor indicates that the user has moved away, the system immediately interrupts the current process, plays a farewell audio message, and returns to the idle state. This design ensures efficient operation, prevents unnecessary processing, and maintains a natural and responsive human–robot interaction.

4.2 Hardware Parts

- Arduino Mega 2560
- power bank
- MPU6050
- 2 DC motors 12v 210rpm with encoder
- 2 wheels 85 diameter
- 2Motor driver BTS7960
- Ultrasonic
- Lithium Battery Pack
- speaker
- ESP32
- Tiny display
- Raspberry pi 4 plastic clear case +fan
- Camera
- Connecting wires

4.3 Description

4.3.1 Arduino Mega 2560

Figure 1: Arduino Mega 2560

The Arduino Mega 2560 is used as the main controller for wheel motion and balance control. It processes real-time data from the IMU sensor and applies a PID control algorithm based on the inverted pendulum model to maintain robot stability. The Arduino directly controls the motor drivers, ensuring fast and accurate wheel response required for self-balancing operation.

4.3.2 Power Banks

Figure 2: Power Banks

One power banks supply stable power to critical low-voltage components such as the Ar- duino Mega and Raspberry, ensuring consistent and uninterrupted operation. These dedicated power supplies enhance reliability and prevent power fluctuations from affecting sensitive electronics.

4.3.3 MPU6050

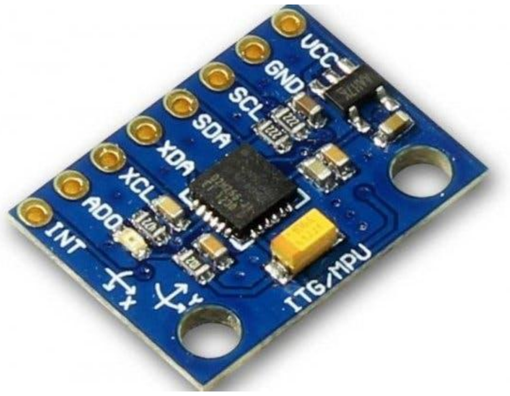

Figure 3: MPU6050

The MPU6050 is a 6-axis IMU sensor that combines a 3-axis accelerometer and a 3-axis gyroscope. It is used to measure the robot's tilt angle in real time and provide orientation data to the Arduino Mega. This data is essential for the PID control algorithm, allowing the robot to maintain balance based on the inverted pendulum principle.

4.3.4 2DC motors 12v 210rpm with encoder

Figure 4: DC motors

Two 12V DC motors with integrated encoders are used to drive the robot's wheels. The motors provide the necessary torque and speed for movement, while the encoders generate feedback signals that represent wheel rotation and speed. This feedback is used by the control system to monitor motor behavior and improve balance stability by ensuring accurate and synchronized wheel motion

4.3.5 2 wheels 85 diameter

Figure 5: wheels

Two 85 mm diameter wheels are used to provide stable and smooth motion, supporting effective balance control and reliable ground contact during robot operation.

4.3.6 Motor driver BTS7960

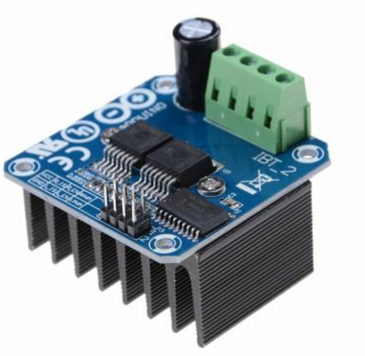

Figure 6: Motor driver

Two BTS7960 motor drivers are used to supply sufficient current to the DC motors. They enable reliable control of motor speed and direction, ensuring stable and responsive wheel operation required for the robot's balancing system.

4.3.7 Ultrasonic HC-SR04

Figure 7: Ultrasonic Sensor HC-SR04

The ultrasonic sensor is used to detect the presence of a person in front of the robot by measuring distance using sound waves. When an object is detected within a predefined range, the sensor triggers the interaction process. This helps the robot respond only when a user is present and return to the idle state when the area is clear.

4.3.8 Lithium Battery Pack

Figure 8: Ultrasonic Sensor HC-SR04

Three lithium-ion batteries are used to power the robot. These batteries provide a stable and efficient power source with high energy density, making them suitable for mobile robotic applications. The batteries are connected to supply the required voltage and current for the motors, ensuring continuous and reliable operation during movement and balancing.

4.3.9 Speaker

The speaker is used to give the robot a voice and make interaction with users more natural and engaging. It is connected to the Raspberry Pi, which controls when and what audio is played based on the system's decisions. Through the speaker, the robot can greet users, guide them during interaction, respond to detected emotions, and signal when the interaction starts or ends. This audio feedback helps users understand the robot's behavior more easily and creates a more friendly, human-like experience rather than a silent mechanical response.

4.3.10 ESP32

Figure 10: ESP32 Module

The ESP32 microcontroller is dedicated exclusively to controlling the small electronic display used for visual expression. It receives facial emotion classification data from the Raspberry Pi through serial communication and translates this data into corresponding animated eye expressions displayed on the screen. By offloading display control tasks to the ESP32, the system ensures smooth and responsive visual updates without affecting the real-time processing and control functions handled by other system components.

4.3.11 Tiny Display

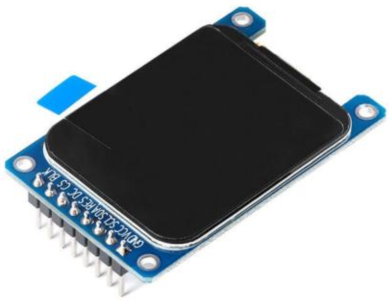

Figure 11: Tiny display

The robot is equipped with a tiny display (1.69in) that uses animated digital eyes to represent facial expressions and serve as a non-verbal communication channel. The display is controlled by an ESP32 microcontroller, which communicates with the Raspberry Pi to receive facial emotion classification results. Based on the detected human emotion, the ESP32 dynamically updates the eye animations to reflect expressions such as happiness, sadness, anger, or neutrality. This visual feedback complements the audio interaction system, enhances human–robot interaction, and makes the robot appear more expressive, engaging, and lifelike during communication.

4.3.12 Raspberry pi 4

Figure 12: Raspberry pi 4

The Raspberry Pi Model B is used as the main processing unit for high-level tasks in the robot. It handles data from the ultrasonic sensor and the camera, performs image processing and artificial intelligence analysis, and manages audio output through the connected speaker. The Raspberry Pi is responsible for detecting human presence, recognizing facial expressions and hand gestures, and generating appropriate audio responses

4.3.13 Camera

Figure 13: camera

The camera is used as the main perception component for human–robot interaction. It captures real-time visual data of the person standing in front of the robot and enables computer vision processing. The camera is used to verify the presence of a real human face, analyze facial expressions for emotion detection, and recognize hand gestures used for option selection. This visual input allows the robot to interact intelligently with users and respond dynamically based on their actions and expressions.

5 Results and Discussion

The proposed self-balancing reception robot successfully achieved its primary objectives, demonstrating stable balancing performance based on the inverted pendulum principle. By utilizing real-time orientation data from the MPU6050 sensor and applying a PID control algorithm, the robot maintained its balance effectively under normal operating conditions. The motors responded accurately to control signals, enabling smooth and stable wheel motion during operation.

The balance control system showed reliable performance, with rapid correction of tilt angles and minimal oscillations. Proper tuning of the PID parameters played a crucial role in achieving system stability and preventing excessive vibrations. Minor adjustments were required during testing to improve response time and reduce overshoot, resulting in a stable and controlled balancing behavior.

The ultrasonic sensor performed effectively in detecting the presence of a person in front of the robot. When a user approached within the predefined range, the interaction process was triggered as expected. The sensor also allowed the system to immediately stop processing and return to the idle state when the user moved away, improving system efficiency and responsiveness.

Vision-based interaction using the camera proved successful in identifying human presence and enabling facial emotion analysis and hand gesture recognition. The robot was able to respond appropriately by playing emotion-based audio messages and processing user selections. However, the accuracy of visual detection was influenced by environmental lighting conditions and camera positioning, which occasionally affected recognition performance.

The tiny display showed digital, interactive eyes, making the robot feel more expressive and easier to interact with. The eye expressions changed automatically based on the emotion detected by the camera, allowing the robot to visually show feelings such as happiness, sadness, or neutrality. This visual feedback helped users quickly understand the robot's reactions and made the interaction more natural and engaging.

Audio interaction through the speaker connected to the Raspberry Pi provided clear and understandable responses, enhancing the overall user experience. The integration of speech processing and artificial intelligence enabled natural interaction with users.

The integration of multiple hardware components, including the Arduino Mega, Raspberry Pi, MPU6050 sensor, DC motors with encoders, motor drivers, ultrasonic sensor, camera, and audio system, required extensive testing and debugging. After careful calibration and system adjustments, stable communication and reliable operation were achieved.

Real-time constraints were carefully considered to ensure that balance control was not affected by vision or interaction processing.

In summary, the proposed robot successfully combined self-balancing control with intelligent human–robot interaction. Despite minor challenges related to environmental conditions, the system demonstrated strong potential as an interactive reception solution for real-world applications.

6 Conclusion and Recommendation

In conclusion, this project successfully implemented a self-balancing reception robot that combines control systems and artificial intelligence to provide interactive assistance. The robot maintained stable balance using a PID control algorithm based on the inverted pendulum principle, supported by real-time data from the MPU6050 sensor. Human–robot interaction was effectively achieved through camera-based analysis, audio responses, and presence detection using an ultrasonic sensor.

Despite the successful implementation, the system faced minor challenges related to lighting conditions affecting visual analysis and achieving optimal PID tuning required careful testing and calibration to minimize oscillations and improve stability. Overall, the robot demonstrated strong potential as an intelligent reception solution for indoor environments.

6.1 Recommendations

For future development and enhancements, the following improvements are recommended:

- **Improved Vision Robustness**: Enhance camera positioning and lighting compensation techniques to improve emotion and gesture recognition accuracy.
- **Load Handling:** Optimize the robot's physical design to comfortably handle heavier or multiple trays, expanding its delivery capabilities.
- **Expanded Interaction Features:** Incorporate additional interaction methods, such as touchscreen interfaces or multilingual support, to improve accessibility.

Implementing these enhancements would significantly improve the robot's reliability, flexibility, and overall performance in real-world reception environments.

7 Future Work

Although the proposed self-balancing reception robot achieved its main objectives, several enhancements can be considered for future development to improve functionality and user interaction.

- **Enhanced Voice Interaction:**
  Integrating a dedicated microphone module would enable full two-way verbal communication, allowing users to speak directly with the robot and receive real-time responses. This would improve natural interaction and make the system more intuitive and user-friendly.

- **Mobile Balancing Navigation:**
  Future work may explore enabling the robot to move smoothly within indoor environments while maintaining balance. This includes controlled forward and \backward motion combined with self-balancing behavior. Although challenging, this enhancement would allow the robot to actively approach users instead of remaining stationary.

- **Stationary Balance Optimization:**
  Future work may focus on minimizing drifting while stationary by refining the control loop, compensating for motor dead zones, and applying filtering techniques. This would allow the robot to remain more stable when idle.

8 Limitations

The primary limitations of this project were directly related to the nature of self-balancing systems and their sensitivity to motion and load conditions.

The robot is based on an inverted pendulum control model, where balance and movement are tightly coupled. While stable balancing was successfully achieved, implementing smooth and continuous movement proved to be highly challenging. Any forward or backward motion introduced disturbances that directly affected system stability, requiring precise coordination between motion commands and balance control.

Additionally, the system exhibited high sensitivity to load variations. Even small changes in weight significantly influenced the robot's dynamic behavior, affecting motor response and balance performance. This sensitivity limited the ability to add payloads or additional components without re-tuning the control parameters.

Load distribution was another critical constraint. Maintaining the center of mass near the balancing axis was essential for stable operation. Uneven placement of components such as batteries, motors, or electronic modules led to increased oscillations and reduced control accuracy.

Another limitation of the system is the inability to move to the left or right. The robot is designed using a two-wheel self-balancing configuration, which inherently restricts motion to forward and backward directions only. Achieving sideways movement would require a different mechanical design, such as a minimum of three wheels or omnidirectional wheels, which is outside the scope of this project.

The physical height of the robot is also limited by the wheel size and overall mechanical structure. Since the system relies on maintaining balance around the wheel axis, increasing the robot's height would raise the center of mass and significantly reduce stability. As a result, the robot's vertical expansion is constrained, limiting the ability to build a taller structure without redesigning the balancing mechanism.

Maintaining a completely stationary position was difficult to achieve. Even when the robot appeared balanced, small sensor noise, motor limitations, and minor control inaccuracies caused gradual drifting. This behavior is typical in self-balancing systems, as they must continuously make small adjustments to stay upright, which makes achieving perfect stillness difficult without more advanced control methods or additional sensing.

Due to these factors, the project focused primarily on achieving reliable self-balancing rather than full autonomous movement. Overcoming these limitations would require more advanced control strategies, mechanical optimization, and extensive system modeling.

9 References

- **Arduino Tutorials**
  Official Arduino tutorials covering various projects and concepts.
  https://www.arduino.cc/en/Tutorial/HomePage

- **Ultrasonic Sensor Working Principle**
  Explanation of how ultrasonic sensors detect obstacles and measure distance.
  https://www.electronics-tutorials.ws/io/io_8.html

- **Motor driver bts7960 datasheet**
  BTS 7960 Datasheet

- **MPU6050 Sensor Arduino Tutorial**
  Explanation of how to use the IMU.
  MPU6050 Sensor Arduino Tutorial

- **Raspberry Pi Official Documentation**
  Official documentation covering Raspberry Pi hardware, operating system configuration, camera usage, and peripheral integration.
  https://www.raspberrypi.com/documentation/

- **TensorFlow Lite**
  Lightweight machine learning framework used to perform real-time emotion recognition from camera input on the Raspberry Pi.
  https://www.tensorflow.org/lite

- **MediaPipe Framework**
  Official MediaPipe open-source framework used for real-time face detection and hand gesture recognition in vision-based interaction systems.
  https://github.com/google-ai-edge/mediapipe

- **RoboEyes**
  Open-source graphics library used to render animated digital eyes and expressions on small displays, enabling visual emotional feedback.
  https://github.com/FluxGarage/RoboEyes