BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 318 (January 2023)

Control System Laboratory

Final Project Report

Section: B1 Group: 03

Human Following Cart

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Academic Honesty Statement:

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1 Abstract

This project introduces an innovative solution for precise cart positioning using ArUco markers, computer vision, Bluetooth communication, and real-time control systems. It combines image capture and processing to calculate positioning errors, communicates through Bluetooth to an Arduino Uno for real-time adjustments, and maintains a feedback loop for continuous correction. The project emphasizes testing, calibration, and reliable power supply, making it a robust and adaptable solution for various applications.

2 Introduction

This project delves into the intricate realm of achieving precise cart positioning within dynamic and demanding environments. The need for accurate cart control transcends numerous industries, including manufacturing, healthcare, and logistics, where efficient and dependable cart movement is fundamental to operations. However, ensuring pinpoint positioning in real-time within ever-changing settings presents a formidable and multifaceted engineering challenge. The complexity of this engineering challenge is multifaceted and rooted in several factors:

- **Dynamic Environments:** The project operates within environments characterized by unpredictability. The cart's path may be subjected to sudden alterations or obstacles, necessitating continuous adaptation and instantaneous responses.

- **Exacting Precision:** The objective is to attain a level of precision that surpasses what manual control alone can deliver. The margin for error is slim, demanding extraordinary accuracy.

- **Interdisciplinary Nature:** Successfully resolving this problem calls for the seamless integration of diverse fields, including computer vision, wireless communication, control systems engineering, and robotics. Coordinating these multiple domains adds layers of intricacy.

- **Real-Time Responsiveness:** The system's effectiveness hinges on its ability to respond in real-time to ever-evolving conditions. Swift and precise detection of errors and rapid corrective actions are paramount.

Possible Alternative Solution:
In contrast to the current approach, an alternative solution could involve:

- **Laser-Based Precision Mapping:** Replace markers with lasers to create an ultra-precise grid or reference points along the cart's path. Laser-based systems offer unparalleled accuracy and adaptability in fluctuating environments.
- **Advanced Communication Technologies:** Transition from Bluetooth to advanced communication technologies such as Ultra-Wideband (UWB) for real-time positioning updates. UWB's centimeter-level accuracy and reduced susceptibility to interference can enhance performance.
- **Machine Learning Integration:** Implement advanced machine learning models for predictive error correction. By analyzing historical data and environmental variables, the system can proactively identify and mitigate positioning errors.
- **Enhanced Computer Vision:** Incorporate state-of-the-art computer vision techniques, including deep learning, to refine marker detection accuracy, even in challenging conditions.
- **LiDAR Sensing:** Integrate LiDAR sensors for 3D mapping and obstacle detection, enabling robust navigation and safety enhancement.

Each alternative solution offers its own unique set of challenges and advantages, underscoring the multidimensional nature of the cart positioning problem and the requirement for a well-thought-out engineering strategy. The choice of solution would ultimately depend on the specific needs and constraints of the given application.

3 Design

3.1 Design Method

- **ArUco Marker Detection:** Utilize mathematical camera calibration and scientific image processing techniques with OpenCV to identify ArUco markers.

- **Error Calculation:** Apply mathematics to measure the difference between detected marker positions and the desired cart location.

- **Bluetooth Communication:** Engage scientific understanding of Bluetooth protocols and engineering skills to create mobile applications for real-time error transmission to the Arduino Uno.

- **Arduino Motor Control:** Implement mathematics and engineering by using kinematic equations to adjust motorized wheels based on received error coordinates.

- **Feedback Loop:** Continuously integrate marker detection, error calculation, and motor control for real-time cart positioning.

- **WiFi Connection:** Ensure a stable WiFi connection between the mobile device and laptop for seamless communication.

- **Testing and Calibration:** Employ scientific testing and engineering adjustments to validate system performance and optimize control algorithms and sensor settings.

- **Power Supply:** Engineer a reliable power supply system with voltage regulation and current management for uninterrupted operation.

This approach showcases the synergy between mathematics, science, and engineering applied throughout the project to achieve precise cart positioning using ArUco markers and real-time control. Specific equations and derivations may vary depending on hardware and calibration requirements.

3.2 Necessary Equipment:

- Arduino Uno
- Bluetooth module (HC-05)
- DC Motor
- Wheels
- LiPo battery
- Motor driver
- PVC board

3.3 Codes

Python codes:

Code for importing coordinate to the bluetooth module(HC05):

```
In [1]: import serial
        ser=serial.Serial("COM3",9600,timeout=1)
        ser.write(bytes(f"{1},{1}\n", 'utf-8'))
```

Code for detecting ArUco marker:

```
import cv2 as cv
from cv2 import aruco
import numpy as np

calib_data = np.load("./MultiMatrix.npz")
cam_mat = calib_data["camMatrix"]
dist_coef = calib_data["distCoef"]
r_vectors = calib_data["rVector"]
t_vectors = calib_data["tVector"]
coordinate = "0,0"


MARKER_SIZE = 8  # centimeters
marker_size = 8
marker_dict = aruco.getPredefinedDictionary(cv.aruco.DICT_4X4_50)
param_markers = aruco.DetectorParameters()
detector = cv.aruco.ArucoDetector(marker_dict, param_markers)

cap = cv.VideoCapture(0)
while True:
    ret, frame = cap.read()
    if not ret:
        break

    gray_frame = cv.cvtColor(frame, cv.COLOR_BGR2GRAY)
    marker_corners, marker_ids, reject =  detector.detectMarkers(gray_frame)

    if marker_corners:
        marker_points_3d = np.array([[-marker_size/2, -marker_size/2, 0],
                                     [marker_size/2, -marker_size/2, 0],
                                     [marker_size/2, marker_size/2, 0],
                                     [-marker_size/2, marker_size/2, 0]])
```

Code for calculating distance:

```
        marker_corners = np.array(marker_corners)
        marker_corners = marker_corners.astype('float32');
        testval,rvec, tvec = cv.solvePnP(marker_points_3d, marker_corners[0], cam_mat, dist_coef)
        for ids, corners, i in zip(marker_ids, marker_corners, range(0, marker_ids.size)):
            cv.polylines(
                frame, [corners.astype(np.int32)], True, (0, 255, 255), 4, cv.LINE_AA
            )
            corners = corners.reshape(4, 2)
            corners = corners.astype(int)
            top_right = corners[0].ravel()
            top_left = corners[1].ravel()
            bottom_right = corners[2].ravel()
            bottom_left = corners[3].ravel()

            distance = np.sqrt(tvec[2] * 2 + tvec[0] * 2 + tvec[1] ** 2)


            x = tvec[0] - (tvec[2] * 0.087 + 5)
            y = tvec[2]
            if (ids[0] == 1):
                coordinate = str(int(x)) + "," + str(int(y))

            ser.write(bytes(f"{int(x)},{int(y)}\n", 'utf-8'))
            print(coordinate)

    cv.imshow("Aruco_viewer", frame)
    key = cv.waitKey(20) & 0xFF
    if key == ord("q"):
        break

cap.release()
cv.destroyAllWindows()
```

Arduino code:

Variable and pin number declaration:

```
//Include the motor driver library
#include <SoftwareSerial.h> // Include the SoftwareSerial library
#define RX A0
#define TX A1
SoftwareSerial BTSerial(RX, TX);   // RX, TX pins for Bluetooth module

// Motor Pins
#define LMEnable 9
#define LMBackward 6
#define LMForward 7
#define RMEnable 3
#define RMBackward 5
#define RMForward 4

//Set the speed of the motors
#define motorSpeed 130

int Ythres = 30;
int Xthres = 10;

int errorX = 0;
int errorY = 0;

void setup() {
  Serial.begin(9600);
  BTSerial.begin(9600); // Initialize the Bluetooth module

  // Setting PinMode
  pinMode(LMEnable, OUTPUT);
  pinMode(LMForward, OUTPUT);
  pinMode(LMBackward, OUTPUT);
  pinMode(RMEnable, OUTPUT);
  pinMode(RMForward, OUTPUT);
  pinMode(RMBackward, OUTPUT);

  // Initialize
  digitalWrite(LMForward, LOW);
  digitalWrite(LMBackward, LOW);
  digitalWrite(RMForward, LOW);
  digitalWrite(RMBackward, LOW);

  analogWrite(LMEnable, motorSpeed);
  analogWrite(RMEnable, motorSpeed);
}
```

Code for receiving coordinate from laptop and converting that to integer:

```
void loop() {
  if (BTSerial.available()) {
    // Read the serial data as a string
    String data = BTSerial.readStringUntil('\n');

    // Split the string into two parts (x and y)
    int commaIndex = data.indexOf(',');
    String xString = data.substring(0, commaIndex);
    String yString = data.substring(commaIndex + 1);

    // Convert the string values to integers
    errorY = yString.toInt();
    errorX = xString.toInt();

    // Print the (x, y) coordinate to the serial monitor
    Serial.print("Received coordinate: ");
    Serial.print(errorX);
    Serial.print(", ");
    Serial.println(errorY);
  } else{
      errorX = 0;
      errorY = 0;
    }
    // Fixing misleading values
  if(errorY > 800 || errorX > 200 || errorX <-200) {
    errorY = 0;
    errorX =0;
    }
```

Code for calculating the speed error value which is needed to be compensated to reach the required position:

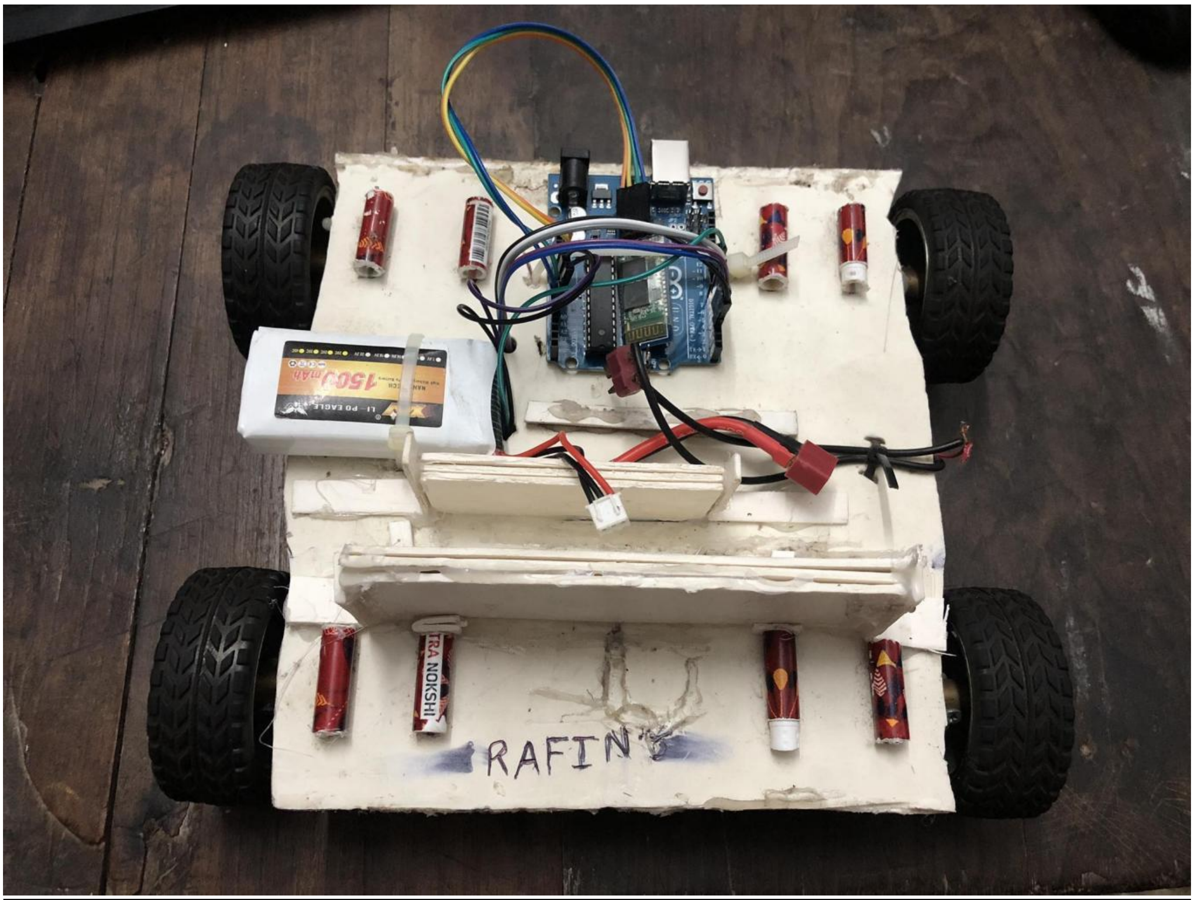
```
// Speed error correction while turning
int delta = 0;
if(abs(errorY) > 400){
   delta = abs(errorX)*0.5;
 }else if(abs(errorY)>300){
  delta = abs(errorX)*0.8;
  }else if(abs(errorY)>200){
  delta = abs(errorX)*1.6;
  }else if(abs(errorY)>100){
  delta = abs(errorX)*2;
  }else if(abs(errorY)<100 && abs(errorY)> Ythres){
  delta = abs(errorX)*3.2;
  }

if (errorX > 10) {
  // The robot is to the left of the desired position
  leftMotorSpeed = motorSpeed + delta;
  rightMotorSpeed = motorSpeed -delta;

} else if (errorX < -10) {
  // The robot is to the right of the desired position
  leftMotorSpeed = motorSpeed - delta;
  rightMotorSpeed = motorSpeed +delta;

}else if(errorY > Ythres) {
  // Motor should move forward
  leftMotorSpeed = motorSpeed + errorY/5;
  rightMotorSpeed = motorSpeed + errorY/5;
}

if(leftMotorSpeed>250 && rightMotorSpeed > 250){
  // Fixing Overspeed issue
      leftMotorSpeed = 250;
      rightMotorSpeed = 250;
    }

// Setting Speed to the Enable pins
analogWrite(LMEnable, leftMotorSpeed);
analogWrite(RMEnable, rightMotorSpeed);
```

Code for setting on and off state of the motor:

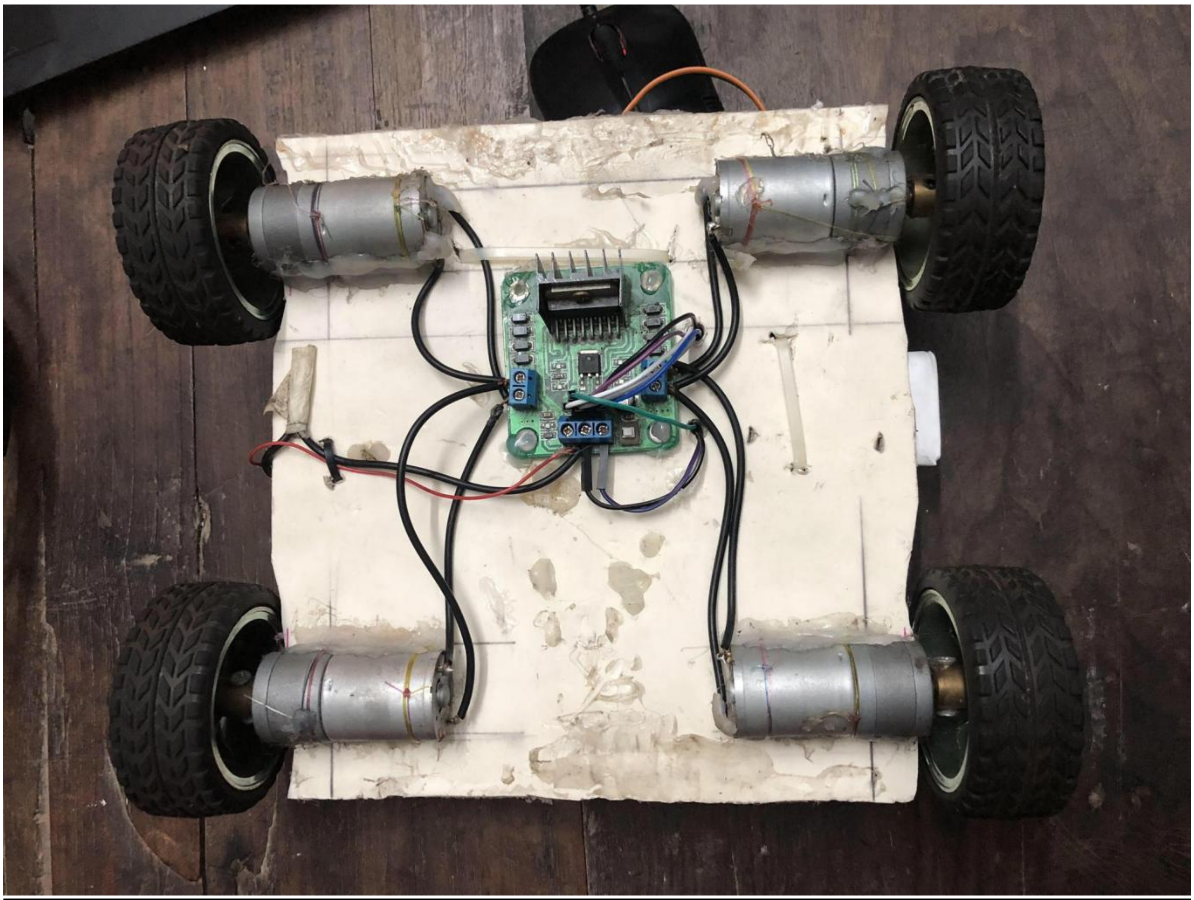
```
// Run and stop robot according to the conditions
if(errorY>Ythres){
    Run();
    Serial.println("Run");
    delay(25);

 } else if(errorY < Ythres && errorX<10 && errorX >-10){
    Stop();
    Serial.println("stop");
    delay(5);

   } else {
    Run();
    Serial.println("Run");
    delay(25);

   }
}

void Run(){
  // Function for running the motors
   digitalWrite(LMForward, HIGH);
   digitalWrite(RMForward, HIGH);
  }

void Stop() {
  // Function for stopping the motors
   digitalWrite(LMForward, LOW);
   digitalWrite(RMForward, LOW);
}
```

4 Implementation

Front View:



Back View:



4.1 Description

- **ArUco Board Detection:** Utilizes a camera connected to a mobile device to capture barcode images. Image processing with a Python library like OpenCV is used to identify the barcode's position.

- **Error Calculation:** Measures the error by determining the distance between the detected barcode position and the desired cart position.

- **Bluetooth Communication:** Establishes a Bluetooth connection between a laptop or mobile device and an Arduino Uno. This facilitates the transmission of calculated error or correction coordinates to the Arduino for further action.

- **Arduino Motor Control:** Develops Arduino code to receive correction coordinates via Bluetooth. Control logic is implemented to adjust the cart's motorized wheels based on the received coordinates, with motor driver circuits interfacing with the motors.

- **Feedback Loop:** Maintains a continuous loop that involves capturing barcode images, computing errors, and sending correction commands to the Arduino to keep the cart at the desired position.

- **WiFi Connection:** Ensures that both the mobile device and laptop are connected to the same WiFi network, enabling seamless communication between them.

- **<u>Testing and Calibration:</u>** Rigorously tests the system and calibrates it to ensure precise position correction. Fine-tunes control algorithms and sensor settings as necessary for optimal performance.

- **<u>Power Supply:</u>** Ensures a reliable power supply for the Arduino and motorized components to ensure the effective operation of the system.

5 Design Analysis and Evaluation

5.1 Novelty

The novelty of this project lies in its unique combination of technologies and approaches to solve the problem of precise cart positioning:

- **<u>ArUco Marker Integration:</u>** The project uses ArUco markers, a specialized type of marker in computer vision, for position detection. This choice is innovative and less common than traditional barcodes, making it suitable for specific applications.

- **<u>Bluetooth-Controlled Precision:</u>** Utilizing Bluetooth communication to control the cart's motorized wheels in real time adds a novel layer of precision and responsiveness to the system.

- **<u>Continuous Feedback Loop:</u>** Implementing a continuous feedback loop for real-time correction ensures that the cart maintains its desired position with remarkable accuracy, which is a novel approach in many similar projects.

- **<u>Integration of Wireless Technologies:</u>** The project seamlessly integrates both Bluetooth and WiFi connectivity, optimizing data exchange and communication between devices.

Comprehensive Testing and Calibration: The emphasis on rigorous testing, calibration, and fine-tuning of control algorithms and sensor settings underscores the commitment to achieving reliable and accurate results in dynamic environments.

- **<u>Interdisciplinary Approac</u>**<u>h:</u> Combining computer vision, wireless communication, control systems engineering, and robotics, this project takes an interdisciplinary approach to address a real-world challenge, highlighting the versatility of such integration.

- **<u>Adaptability:</u>** The project's flexibility allows it to be customized for various applications that require precise positioning, showcasing its potential novelty across a range of industries.

In summary, the novelty of this project is in its innovative application of ArUco markers, real-time Bluetooth control, and continuous feedback, all within a framework of interdisciplinary integration. It offers a fresh perspective on solving the problem of precise cart positioning in dynamic environments.

5.2 Design Considerations

5.2.1 Considerations to public health and safety

- <u>Accessibility:</u> Ensure the cart is accessible to all individuals, including those with disabilities. T

- <u>Public Education:</u> Educate the public about the technology and safe interaction with the cart.

- Environmental Impact: Assess and mitigate the cart's environmental impact, including energy consumption and emissions.

- Testing and Validation: Conduct rigorous testing in controlled and real-world environments to ensure safety and reliability.

- Continuous Improvement: Monitor and improve the system based on real-world performance and safety incidents.

5.2.2Considerations to environment

- Energy Efficiency: Prioritize energy-efficient design and operation to reduce environmental impact.

- Emissions: Minimize emissions associated with the cart's energy source or propulsion system.

- Sustainable Materials: Use sustainable materials in the construction of the cart to reduce its ecological footprint.

- End-of-Life Recycling: Plan for the recycling or responsible disposal of the cart at the end of its lifecycle.

- Environmental Assessments: Conduct thorough environmental impact assessments to identify and mitigate potential ecological harm.

5.2.3Considerations to cultural and societal needs

- Cultural Sensitivity: Ensure that the cart's design and behavior respect cultural norms and values in diverse communities.

- Accessibility: Make the cart accessible to individuals with diverse needs, including different languages, mobility challenges, and cultural backgrounds.

- Ethical Use: Establish guidelines to prevent misuse of the technology for purposes that may conflict with cultural or societal values.

- Community Engagement: Involve local communities and stakeholders in the development process to address their specific needs and concerns.

- Social Inclusivity: Ensure that the cart promotes social inclusivity and does not inadvertently exclude or isolate any group within society.

- Public Acceptance: Gauge public acceptance and perception of the technology through surveys and feedback to address any societal reservations or misconceptions.

5.3 Limitations of Tools

The project to achieve precise cart positioning using ArUco markers and real-time control involves various tools and technologies, each with its own limitations:

- ArUco Markers:

Limited Detection Range: ArUco markers have a finite detection range, and their size can limit the maximum distance at which they can be detected accurately.
Line of Sight Required: Effective detection often requires an unobstructed line of sight between the camera and the marker, which may not be feasible in complex environments.

- Bluetooth Communication:

Limited Range: Bluetooth has a limited communication range, typically up to 100 meters, which may constrain the operational radius of the cart.
Interference Potential: Bluetooth signals can be susceptible to interference from other devices operating in the same frequency range, potentially affecting communication reliability.

- Camera and Image Processing:

Lighting Conditions: The effectiveness of camera-based systems can be affected by variations in lighting conditions, leading to reduced marker detection accuracy in low-light or highly reflective environments.
Processing Speed: Real-time image processing can be computationally intensive, and there may be limitations in processing speed, potentially affecting the system's ability to respond rapidly.

- Arduino Uno:

Processing Power: The Arduino Uno has limited processing power compared to more advanced microcontrollers, which may limit the complexity of control algorithms and real-time calculations that can be executed.

- Motor Precision:

Mechanical Tolerances: The precision of the cart's motorized wheels may be subject to mechanical tolerances and wear over time, affecting the system's ability to achieve sub-millimeter-level accuracy.

- Battery Life:

Power Supply Constraints: Depending on the power requirements of the system components, the battery life of the cart may be limited, necessitating frequent recharging or replacement.

- Environmental Factors:

Environmental Interference: Factors such as electromagnetic interference, obstacles, or uneven terrain can impact the system's performance and accuracy.

- Cost and Complexity:

Financial Constraints: Implementing and maintaining the required hardware and software components can be costly, limiting the project's accessibility to certain budgets.
Complexity: The integration of multiple technologies and the need for interdisciplinary expertise can make the project complex to design, develop, and maintain.

- Safety Considerations:

Safety Limitations: The system's safety features and fail-safes may have limitations, which need to be carefully addressed to prevent accidents or damage in case of unexpected events.
Addressing these limitations and finding ways to mitigate them is an integral part of developing a robust and reliable cart positioning system.

5.4 Impact Assessment

5.4.1 Assessment of Societal and Cultural Issues

- <u>Cultural Sensitivity</u>: Consider the cart's behavior in diverse cultural contexts to avoid inadvertent offense or discomfort.

- <u>Community Integration:</u> Assess how the cart can be seamlessly integrated into existing transportation systems and urban planning to benefit society as a whole.

- <u>Accessibility:</u> Ensure the technology is accessible to people of all backgrounds and abilities, promoting inclusivity.

- <u>Ethical Use:</u> Evaluate potential misuse of the technology in ways that conflict with societal values and ethics.

- <u>User Education:</u> Develop educational materials to help users understand how to interact with the cart respectfully and responsibly.

- <u>Local Engagement:</u> Involve local communities and stakeholders in shaping the project to address their specific needs and concerns.

- <u>Public Perception:</u> Monitor public acceptance and perception of the cart to address any societal reservations or misconceptions.

5.4.2 Assessment of Health and Safety Issues

- <u>Pedestrian Safety:</u> Evaluate measures to prevent accidents and ensure the well-being of pedestrians sharing the space with the Human Following Cart.

- <u>Data Privacy:</u> Examine safeguards for protecting user data and privacy, ensuring compliance with relevant regulations.

- <u>Cybersecurity:</u> Assess potential vulnerabilities to hacking or unauthorized access, with a focus on maintaining the system's integrity.

- <u>Emergency Protocols:</u> Establish clear procedures for handling system failures, accidents, or other unexpected situations to minimize harm.

- <u>Accessibility:</u> Ensure that the cart is accessible to all, including those with disabilities, to promote safety and inclusivity.

- <u>Public Education:</u> Develop initiatives to educate the public about the technology's safe interaction and potential benefits.

- <u>Regulatory Compliance:</u> Ensure adherence to local, state, and federal regulations governing autonomous vehicles and public safety.

- <u>Environmental Impact:</u> Assess the environmental implications, including energy consumption and emissions, to minimize the project's ecological footprint.

- <u>Testing and Validation:</u> Conduct thorough testing in various environments to ensure the cart's safety and reliability.

- <u>Continuous Improvement:</u> Implement mechanisms for continuous monitoring, feedback collection, and system improvement to enhance safety over time.

5.4.3 Assessment of Legal Issues

- Regulatory Compliance: Evaluate adherence to local, state, and federal laws and regulations governing autonomous vehicles and technology deployment.
- Liability: Determine liability scenarios in case of accidents or system failures and establish protocols for addressing them.
- Data Privacy: Ensure compliance with data protection and privacy laws to safeguard user information collected by the Human Following Cart.
- Intellectual Property: Assess potential intellectual property issues related to the technology's design and operation, including patents and trademarks.
- Consumer Protection: Examine consumer rights and protections, including warranties, terms of service, and dispute resolution mechanisms.
- Environmental Regulations: Ensure compliance with environmental laws regarding emissions, waste disposal, and sustainability.
- Transportation Laws: Consider transportation-related laws such as traffic regulations and road safety standards when operating in public spaces.
- Accessibility Standards: Adhere to accessibility standards to accommodate individuals with disabilities and avoid legal challenges related to discrimination.
- Ethical and Cultural Sensitivity: Review legal implications related to the technology's behavior and potential cultural or ethical conflicts.
- Contractual Agreements: Establish legally binding contracts with suppliers, partners, and customers to clarify responsibilities and protect interests.

5.5 Ethical Issues

- Privacy Concerns: Potential intrusion into individuals' privacy through data collection and surveillance.
- Safety and Liability: Determining liability in case of accidents or system failures.
- Autonomy and Control: Balancing autonomy with user control over the cart's actions.
- Equity: Ensuring fair access and benefits for all, regardless of socioeconomic status.
- Data Security: Protecting collected data from unauthorized access or misuse.
- Cultural Sensitivity: Addressing cultural norms and values in the cart's behavior.
- Job Displacement: Assessing the impact on employment due to automation.
- Environmental Impact: Minimizing the carbon footprint of the technology.

6 Reflection on Individual and Team work

6.1 Individual Contribution of Each Member

- ID 1906069 and 1906097 did the Python part of the project
- ID 1906096 and 1906095 did the Arduino part of the project
- ID 1806068 and 1906098 did the hardware manipulation of the project

6.2 Mode of TeamWork and Diversity

- We were 6 people in our group.
- We formed 3 sub groups of two people.
- One grop did the Python part of the project.
- Another group did the Arduino part of the project.
- And the last group did the hardware manipulation of the project.

6.3 Log Book of Project Implementation

Week	Activity
4th Week	Submitted project proposal
6th Week	Completed working procedure of the project
8th Week	Completed Python part of the project
9th Week	Purchasing necessary equipment
11th Week	Implementing Bluetooth module with Arduino
12th Week	Assembling and testing

7 Communication

7.1 Executive Summary

Effective teamwork and diversity play pivotal roles in the success of any project. Here are instances of how we foster teamwork and diversity in our project:

- Transparent Communication: We established transparent communication channels among team members to ensure everyone is well-informed. We utilized a WhatsApp group to facilitate open sharing of thoughts and ideas.

- Role Clarity: We provided clear definitions of each team member's roles and responsibilities during our initial project meeting. This ensured that everyone comprehended their specific tasks and their contributions to the project.

- Embracing Diversity: To embrace diversity and inclusivity within the project team, we divided our project into four key segments and distributed the workload among team members.

- Encouraging Flexibility: We encouraged team members to think creatively and explore unconventional solutions to challenges, promoting innovation.

In our project, we prioritize transparent communication, role clarity, diversity, and flexibility as essential elements for effective teamwork and project success.

7.2 User Manual

Introduction:

Welcome to the Human Following Cart user manual.
This manual provides essential information for safe and efficient use of the cart.

Getting Started:

Power on the cart according to the provided instructions.
Ensure the cart's sensors are unobstructed.

Operating the Cart:

Stand in front of the cart, and it will autonomously follow you.
Maintain a safe distance to avoid collisions.
Use the provided remote control for manual control if needed.

Safety Guidelines:

Be aware of your surroundings to prevent accidents.
Keep children and pets away from the cart's path.
Use caution in crowded or high-traffic areas.

Privacy and Data:

The cart may collect data for operation. Ensure you are comfortable with this.
Follow data privacy guidelines for the safe handling of collected information.

Maintenance:

Regularly check for debris or obstructions in the cart's wheels and sensors.
Charge the cart's battery as instructed to ensure optimal performance.

Troubleshooting:

Refer to the troubleshooting section for common issues and solutions.
Contact customer support for technical problems not covered here.

Safety and Liability:

Understand liability and safety concerns when using the cart in public spaces.

Regulatory Compliance:

Adhere to local regulations regarding the use of autonomous devices in public areas.

Conclusion:

Enjoy using the Human Following Cart responsibly and safely.

For any questions or assistance, contact customer support.
Remember to follow safety precautions and local laws when using the Human Following Cart, and always prioritize the safety of yourself and others.

8 Project Management and Cost Analysis

Equipment	**Cost**
Arduino Uno	1000
Bluetooth module (HC-05)	200
DC motor (4 pieces)	1600
Wheels	350
LiPo battery	1500
Motor driver	300
PVC board	200
Total	**5150**

9 Future Work

- Safety Enhancements: Improve safety measures like obstacle detection and collision avoidance.
- Advanced Navigation: Develop better urban navigation capabilities.
- User Interaction: Enhance user-friendliness and intuitive interactions.
- Energy Efficiency: Focus on eco-friendly power sources and energy use.
- Data Security: Strengthen data privacy and security.
- Cultural Adaptation: Customize cart behavior for diverse cultural contexts.
- Regulatory Compliance: Stay updated with evolving regulations.
- Community Integration: Explore integration into urban planning and transportation.
- Continuous Improvement: Gather feedback for ongoing enhancements.
- Global Expansion: Consider broader market opportunities while respecting cultural diversity.

10 References

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