A SECOND YEAR MINI PROJECT REPORT ON

Face Tracking Robotic Arm

BACHELOR OF TECHNOLOGY

IN

ROBOTICS & AUTOMATION

Ansh Sharma (PRN 22070127011)
Priyanshu Lathi (PRN 22070127048)
Harmanaya Sharma (PRN 22070127023)

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Under the Guidance of

Dr. Javed Sayyad, Supervisor
Assistant,
Department of Robotics and Automation
Symbiosis Institute of Technology, Pune
and
Dr. Ramesh B T, Supervisor
Assistant/Associate/Professor,
Department of Robotics and Automation
Symbiosis Institute of Technology, Pune

SYMBIOSIS INSTITUTE OF TECHNOLOGY
SYMBIOSIS INTERNATIONAL (DEEMED UNIVERSITY), Pune-412115

Academic Year
2023-2024

BUDGET OF THE PROJECT

Sr. No.	Description of part with Specification	Quantity (no's)	Price/item (₹)	Total cost (₹)
1.	ROBOTIC ARM WITH 2 DEGREE OF FREEDOM (PLA 3D PRINTED)	1	1200	1200
2.	MG995 SERVO MOTORS	2	300	600
3.	ZEBRONICS WEB CAMERA WITH 3P LENS & BUILT-IN MICROPHONE 640*480	1	600	600
4.	ARDUINO UNO R3	1	900	900
5.	JUMPER WIRES (PACK OF 20)	1	15	15
6.	LITHIUM ION BATTERY 3.7V 2000MAH	3	63	189
			TOTAL	3504

ABSTRACT

The project “Face Tracking Robotic Arm” is an adoption of smart robotics and computer vision to control and position the robot arm to detect faces in real time. Through using OpenCV, cvzone, NumPy, PyFirmata and PySerial libraries, Arduino Uno microcontroller and MG995 servo motors this project demonstrates how all these converge for precise and fast action based on detected face positions.

The direction of human faces movement is followed by the PID-controlled python robot equipped with an algorithm that in real-time with OpenCV, the system automatically finds face and tracks by help of OpenCV detects the face position and automatically corrects it. The smooth communication of the program and the coordinating movement of the robot towards the face coordinates is achieved by integration of both PyFirmata and PySerial libraries.

The system’s performance and reliability are proven to be highly dependable because of its extensive inspecting and adjusting process for testing it under various conditions. The effectiveness, enhanced resolution, and stability of face-tracking robot arm system is demonstrated. Not only is it possible to establish an independent robot using embedded systems and DIY electronics by this venture, but it also reveals that robotics is an interdisciplinary area involving computer vision, control theory and the like, without any significant effort.

The aim for the future will be to build this venture into a platform that will support more research in robotics, human-robot interaction, and assistive technologies. Adding extra sensors could enhance perception of the surrounding and we can develop our motion planning algorithms which would make the arm move smoothly, whereas machine learning techniques can be used to improve the robot’s face recognition.

The existing interconnections between software and hardware have been successfully utilized in demonstrating the “Face Tracking Robotic Arm” project as smart systems that can be interactively applied across various industry sectors.

CHAPTER-1
INTRODUCTION

1.1 OVERVIEW OF THE PROJECT

The convergence of computer vision and robotics technology has created new opportunities for the creation of intelligent systems that can interact with their surroundings in a more natural and flexible way. This intersection is embodied by the "Face Tracking Robotic Arm" project, which combines proportional-integral-derivative (PID) control algorithms, OpenCV for computer vision, and Arduino-based robotics to create a system that can track human faces in real-time and control a 3D printed robotic arm made of PLA filament.

The main idea behind this project is the growing demand for smart and interactive robotic systems in many application areas such as surveillance robotics, human-computer interaction, and virtual assistants. By detecting and following human faces in real time using Arduino board and PID algorithm for accurate motion control in the robot together with computer vision helps to enable a very useful tool to a robotically-controlled arm. Despite being at a nascent stage, it goes far beyond accomplishing a particular job.

The objective of this project is to build and conceive a working prototype of a face tracking robotic arm based upon off-the-shelf hardware components, open-source software libraries and a 3D printed PLA structure. Leveraging the flexibility and affordability of the 3D printing technology, the project demonstrates the possibility of fabricating lightweight and tailored robotic components for a variety of applications.

Through this report, we present a detailed outline of the project's hardware setup, software implementation, literature review, methodology. By documenting our design process, challenges faced, and lessons learned, we aim to contribute to the growing body of knowledge in the fields of robotics, computer vision, and human and robot interaction. This project serves as a demonstration to the potential of integrating cutting-edge technologies with accessible manufacturing methods to create advanced and practical solutions for real-world challenges.

1.2 OPENCV

OpenCV (Open-Source Computer Vision Library) is a cornerstone in computer vision worldwide, giving a comprehensive package of instruments and algorithms for image processing, machine learning, and real-time vision applications. The "Face Tracking Robotic Arm" project embodies OpenCV by providing real-time face detection and tracking that can be used for further enhancement of robot intelligence and collaboration.

In recent years, the hybrid computer vision functionality integrated into robotic systems brought in the epoch of change with human-like perception and reaction. OpenCV, being a library of such algorithms like facial feature detection, object recognition and motion analysis, is the main tool that robots use to do that.

Figure 1: OpenCV & Python

The motivation behind integrating OpenCV into the "Face Tracking Robotic Arm" project stems from its unparalleled capability to process visual data in real-time, making it ideal for applications requiring dynamic interaction with the surrounding environment. By harnessing the power of OpenCV's face detection and tracking algorithms, the project aims to create a robotic arm capable of autonomously tracking human faces with precision and responsiveness.

The primary objective of this project is to demonstrate the seamless integration of OpenCV with Arduino-based robotics to create an intelligent system capable of real-time face tracking and interaction. By leveraging OpenCV's robust feature detection algorithms and intuitive API, the project seeks to showcase the potential of computer vision in enhancing the capabilities of robotic systems for various applications, including human-robot interaction, surveillance, and assistive technologies.

In this report we present a detailed exploration of how OpenCV was involved in the Face Tracking Robotic Arm project such as its implementation, performance evaluation, and prospects for future research and development. The main purpose of documenting our experiences and lessons learned from connecting OpenCV to real robot is to help advance smart robots as well as encourage more creativity within computer vision and related areas.

1.3 PID (PARTIAL, INTEGRAL, DERIVATIVE)

The PID controller is a control system for use as one of the phenomena that maintains consistency with the output through dynamic output in response to external inputs. PID controller as a part of the project titled " Face Tracking Robotic Arm " has been given a task of making sure that specific movements by the robotic arm are triggered immediately once its location is identified through facial recognition software. This is achieved by the controller by incorporating three main components which are:

1. Proportional (P) term: The proportional component depends only on the difference between the set point and the process variable. This difference is referred to as the Error term. The proportional gain (Kc) determines the ratio of output response to the error signal and responds with immediate corrective action based on magnitude of error.

2. Integral (I) term: The integral component accumulates the error term over time. Therefore, even with a small error term, the integral component will steadily increase. Because the integral response will continue to rise over time unless the error is zero, the outcome is to

drive the Steady-State error to zero. The Steady-State error is the total difference between the process variable and the set point.

3. Derivative (D) term: When the process variable rises quickly, the derivative component causes the output to decrease. The derivative response fluctuates in direct proportion to the rate of change of the process variable. It offers damping action to reduce oscillations and overshoot in the system's reaction, improving responsiveness and stability.

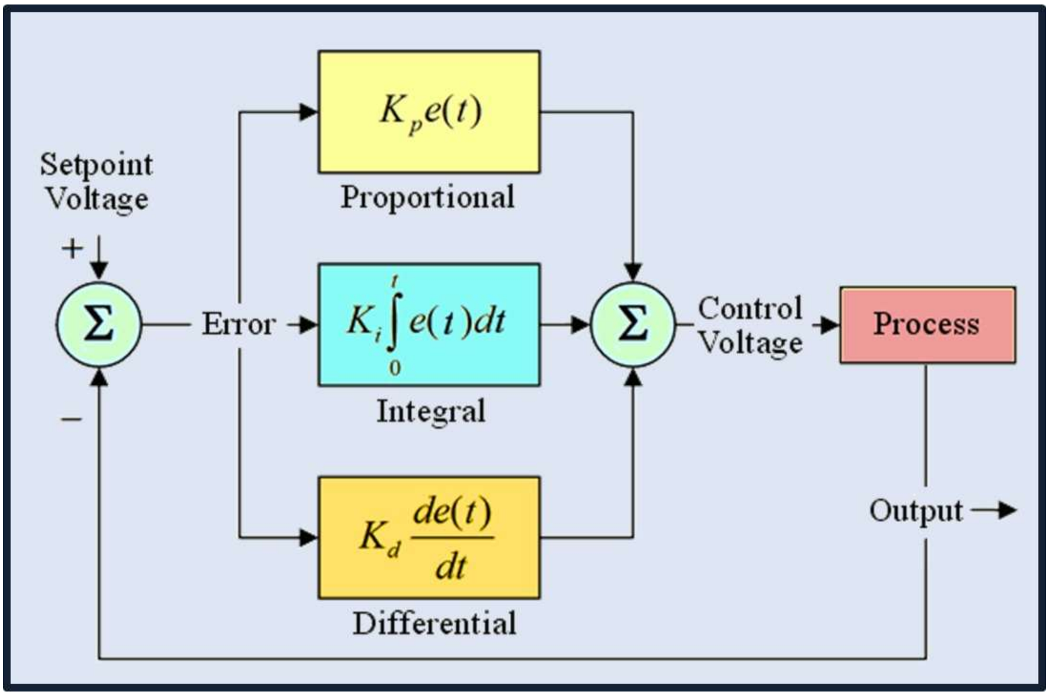

Figure 2: PID Working

By bringing together these three components, the PID controller monitors the system's behaviour, by adapting to the system’s behaviour, disturbances and changes ensuring consistent performance.

The PID controller in the project "Face Tracking Robotic Arm" adjusts its motor's placement based on real-time coordinates detected on one's face (Darmitzoglou, 2017). The PID controller generates control signals that track face very accurately and smoothly (Darmitzoglou, 2017) through persistently monitoring error between desired face position and its actual position (Priyankara et al., 2016). This study would aim at comparing the performance of these four algorithms. To compare the performance, ellipse fitting, statistical approaches, and their combination were the techniques utilized by the PSE ED-based face detection algorithm.

Moreover, the idea of open and closed-loop systems is fundamental to understand the operation of PID controllers:

- Open-loop system: In an open-loop system, the control action is only determined by the input command; feedback is not provided by the system's output. Because it is unable to adapt to errors or disturbances, this technique is less accurate and robust in real-world applications.

- Closed-loop system: In contrast, a closed-loop system incorporates feedback from the system's output to dynamically modify the control action. By routinely comparing the actual output to the intended setpoint, closed-loop systems actively regulate system behaviour. This enables the system to retain target performance while adjusting for uncertainties and disturbances.

In the context of PID control, the basic underpinning for achieving precise and steady control of dynamic processes is utilization of closed-loop systems that are capable of accurate tracking and response to changing conditions.
In this report, we sought to unveil the principles as well as implementation strategies of PID control within the "Face Tracking Robotic Arm" project with particular emphasis on how it improves system performance and responsiveness. We seek for further knowledge and use of control theory in robotics and automation by disseminating our insights and knowledge gained by applying PID control in robotic motion control.

1.4 ARDUINO UNO R3

In these changing dynamics of technological world, the Arduino Uno R3 is one of the most essential developments of embedded systems and Do It Yourself electronics. The board is best suited to carry out a wide range of projects, from simple LED experiments to complex robotics because it offers both technical competence and accessibility. Arduino Uno R3 is the primary brain and commander for many complex processes in various fields and industries through communication with extra hardware and software modules which make a system smarter and interactive.

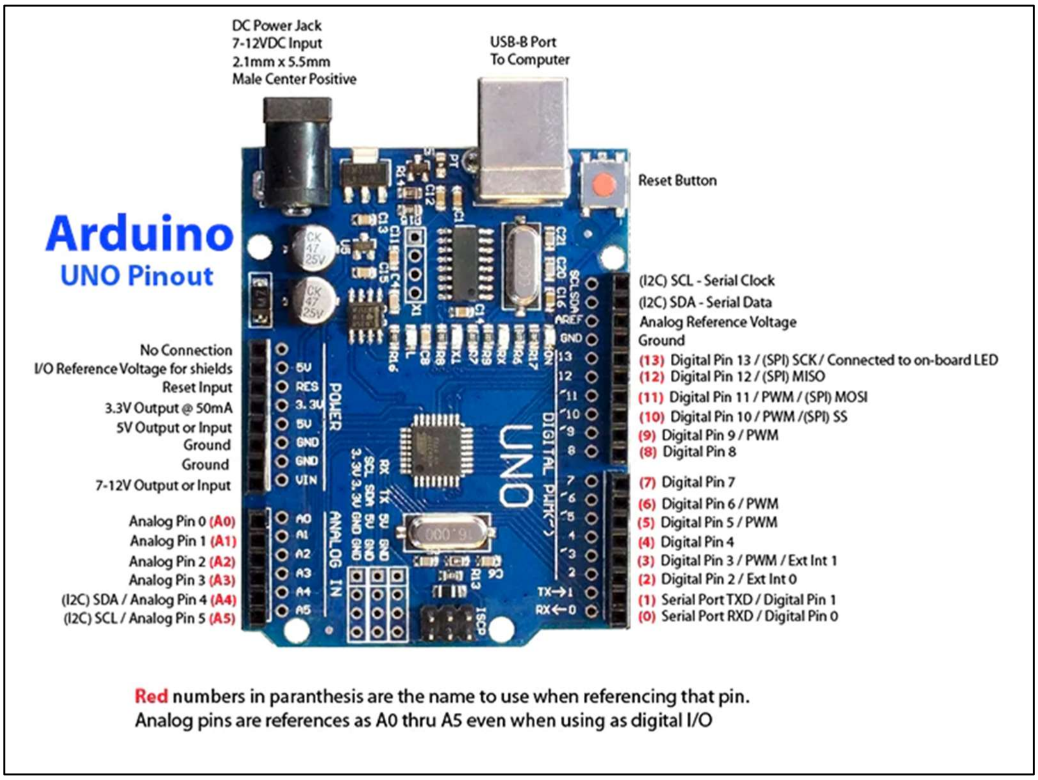

Figure 3: Arduino UNO R3

The main element and foundation of Arduino Uno R3 is ATmega328p which is a single-chip microcontroller. A key feature of Arduino is that is has a user-friendly interface which makes it easy for users and beginners to navigate and operate through. Integrated with a variety of digital and analog input/output pins, serial communication and pulse width modulation (PWM), the Arduino Uno R3 has a plethora of features. Moreover, the robust core greatly helps with the integration of new projects and applications.

The key features of the Arduino Uno R3 include:

- Atmega328P Microcontroller: With ATmega328p at its core, the Arduino Uno R3 has a clock speed of 16MHz and 32KB flash memory. This is what defines its rated speed and the working memory which is able to use for conducting mathematical operations and control algorithms.
- Digital and Analog I/O Pins: The Arduino Uno R3 has 14 digital input and output pins (including 6 PWM output pins), as well as 6 analog input pins, making it easy to have many connecting options.
- USB Interface: The USB interface integration allows for effortless communication between Arduino Uno R3 and the host computer/device. Hence, making it easier to post a program and perform serial communication as well.
- Open-Source Platform: Since, the Arduino Uno R3 is an open-source platform, it enlivens it network through open-source libraries, tutorials and projects which cultivate collaboration and innovation among the makers.

The project "Face Tracking Robot Arm" is implemented on an Arduino Uno R3 which is responsible for managing real-time face detection, servo motor controls, as well as auxiliary peripheral tool management.By combining the adaptability and accessibility, the project aims to demonstrate how Arduino can be utilized to create smart robotic systems.

1.5 PYTHON LIBRARIES USED IN PROJECT

1. cv2 (OpenCV):

OpenCV (Open-Source Computer Vision Library) is an open-source, comprehensive, and versatile software package containing libraries for image processing and machine learning computations. The system under consideration is made up by faces recognition, objects detection, objects tracking, etc. In this "Face Tracking Robotic Arm" project the OpenCV refers to face detection and tracking, a real time webcam feed.

2. cvzone:

cvzone library based on Python and OpenCV are the task-oriented framework in the field of computer vision because most of the tasks in this area is done. The library also simplifies the task of working with OpenCV by providing the necessary modules with common activities like face detection and object tracking bundled in. We will harness the FaceDetector from the cvzone library to implement the face-detection function.

3. NumPy:

NumPy is a core package of scientific computing with Python, where the multi-dimensional arrays and matrix are larger, and moreover, it has some mathematical functions for the working of these arrays, which is now becoming a fad. NumPy in the project provides the core functionality for numerical calculations and array manipulations: in addition, for example, determining intersecting plane coordinates, or analyzing image data.

4. PyFirmata:

PyFirmata is a Python library which is capable of translating the Python program to the Arduino microcontroller boards that thereby create a communication channel. Beside this, Python can work with the Arduino digital and analog pins in relation to sending/getting the command or sensor data. The "Face Tracking Robotic Arm" project feeds to PyFirmata as an interface between the servo motors linked to face's position and the Arduino Uno R3 that serves to perform the required actions.

5. PySerial:

PySerial is a Python library that offers serial communication functionalities, which can be used within Python programs to connect with serial devices like Arduino boards. This enables data to be sent from the program and the respective responses received through a serial port. In this project, PySerial is used to be the intermediary between Python and Arduino to get the message exchange done in the format used by them, for controlling of webcams, servo motors and other equipments.

CHAPTER-2
LITERATURE REVIEW

1. Face Recognition and Tracking Framework for Human–Robot Interaction

Authors: Aly Khalifa, Ahmed A. Abdelrahman, Dominykas Strazdas, Jan Hintz, Thorsten Hempel, and Ayoub Al-Hamadi

Published: 30 May 2022

This paper develops a robust algorithm for face detection and tracking in challenging conditions. Through the application of light convolutional neural networks (CNN), get high results in the real-time of face detection, alignment, and extraction of features. The suggested solution is modular and it can effortlessly be fitted into any industrial applications where humans and robots need to work together.

2. Face Tracking Strategy Based on Manipulability of a 7-DOF Robot Arm and Head Motion Intention Ellipsoids

Authors: Shuai Zhang; Bo Ouyang; Xian He; Xin Yuan; Shanlin Yang
Published: 05 September 2022

In the course of their research, the authors offer a face tracking algorithm using a 7-DOF robot arm. These systems utilize manipulability and head motion intention ellipsoids to facilitate more accurate and faster face tracking compared to non-real-time applications. The study being worked upon here contributes by developing the face tracking robotic systems' capabilities.

3. Live Face Tracking Robot Arm

Authors: Manasa S, Dr. Swetha Rani T, Sneha R, Sonal Jain, Swathi C L
Published: 06-07-2023

In the research paper titled, the authors present a system that combines a robotic arm with computer vision capabilities. The system operates offline and uses an Arduino Uno for embedded control. By leveraging the OpenCV library, the robotic arm achieves precise face tracking and manipulation. Essentially, it can follow and interact with faces in real-world scenarios.

4. Understanding and Design of an Arduino-based PID Controller

Authors: Dinesh Bista
Published: 08/12/2016

In his research paper Dinesh Bista investigates the construction and operation of a Proportional, Integral and Derivative (PID) controller based on a microcontroller Arduino platform (the latter). The topic here is the PID algorithm and its practical uses in many areas such as Arduino-based controllers engineering.

CHAPTER-3
PROBLEM STATEMENT & OBJECTIVES

3.1 PROBLEM STATEMENT

Building a face tracking robot, encounters a lot of challenges in the way, sustaining proper movement, tracking being the foremost ones. All these challenges make way for the PID controller, being the most convenient solutions. All the drawbacks like slower tracking, wrong heading and response delays were solved using a PID controller.

In addition, the movement of robot arms is limits compared to the human face which makes it difficult to complete various tracking paths. With the difficulties in control come factors such as lighting conditions, user interaction as well as environment disturbances which pose a high demand for more precision, accuracy as well as flexibility requirements.

Hence, integrating a PID controller is the most suitable solution for the project. Therefore, a great importance is to be put on the controller related issue of precise and stable environment.

3.2 OBJECTIVES

• To create a real-time face tracking system utilizing computer vision algorithms for detecting and tracking faces within a video stream.

• To incorporate a robotic arm governed by PID algorithms, autonomously adapting its position in response to detected face position and coordinates.

• To implement a robust communication protocol between the computer and the Arduino microcontroller to transmit face coordinates efficiently.

• Optimize the PID control parameters to ensure smooth and accurate movement of the robotic arm for precise face tracking.

• Evaluate the performance of the integrated system in terms of tracking accuracy, responsiveness, and overall reliability in various environmental conditions.

CHAPTER-4
METHODOLOGY

4.1 TOOLS REQUIRED:

1. Robotic arm with 2 degrees of freedom (PLA 3D Printed)
2. MG995 Servo Motors
3. Zebronics Zeb-Crystal Clear Web Camera with 3P Lens & Built-in microphone video resolution: 640*480 (30 FPS)
4. Arduino Uno R3
5. Jumper Wires (pack of 20)
6. Lithium-ion batteries 3.7V 2000mAh

4.2 BLOCK DIAGRAM OF THE PROJECT:

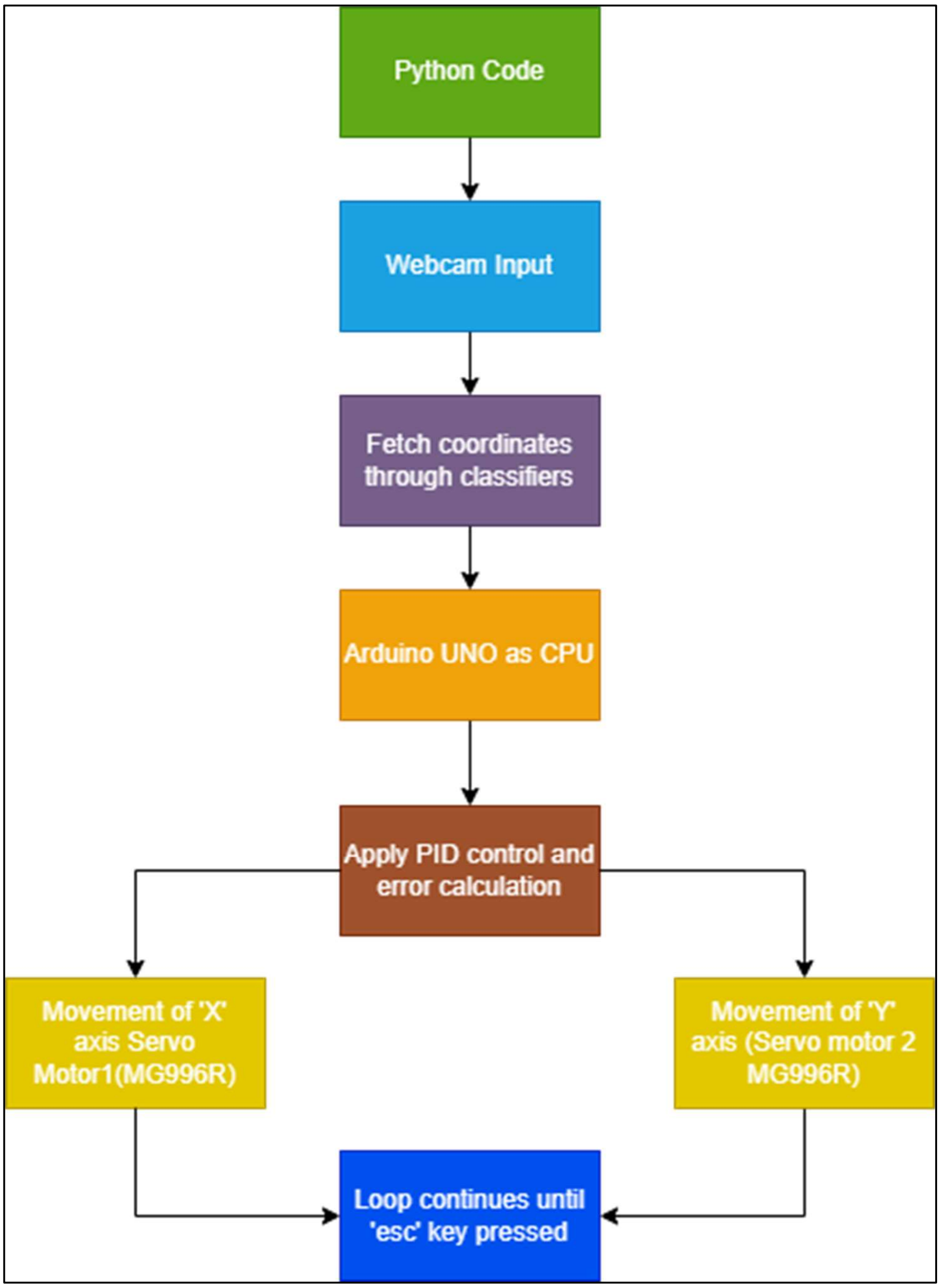

Figure 4: Block Diagram

4.3 PROCEDURE:

1. Setup and Configuration:

- Install necessary software: Install Python, OpenCV, cvzone, NumPy, and PyFirmata libraries.
- Connect Arduino: Connect the Arduino Uno R3 to your computer via USB and upload the StandardFirmata firmware to enable communication between Python and Arduino.

2. Hardware Assembly:

    - Connect Servo Motors: Connect the MG995 servo motors to the Arduino Uno R3 using jumper wires and ensure that the servos are powered on and connected to the correct pins in Arduino (eg pins 9 and 10).
    - Mount Webcam: Mount the webcam at a fixed, stable position facing the region where facial detection will take place. Make sure of providing a view with no disturbances in the surroundings.

3. Python Script Development:

    - Initialize Libraries: Import the necessary libraries like cv2, cvzone, NumPy, Pyserial and PyFirmata
    - Setup Arduino Communication: Setup communication path between the Arduino with PyFirmata to manipulate servo motors.
    - Initialize Face Detection: Use the FaceDetector module from cvzone to initialize face detection capabilities from the webcam feed.
    - Define PID Controller Parameters: Cohort the PID Controller gains by determining their proportionate, integrative and derivative (Kp,Ki,Kd) parameters.
    - Implement PID Control Loop: Develop functions to evaluate the servo positions corresponding to the face coordinates retrieved using PID.

4. Main Loop Execution:

    - Capture Webcam Feed: Constantly capture pictures from the the web cam using OpenCV's VideoCapture at each and every frame.
    - Process Frames for Face Detection: Detect the face using the face detection module in each frame.
    - Calculate Servo Positions: Determine the servo positions based on the coordinated of the face detected.
    - Send Servo Commands to Arduino: Using PyFirmata, move servo motors and send commands.
    - Visualize Tracking Feedback: Debug and monitor the robot using the real-time input on the webcam feed pointing the detected faces.

5. Testing and Calibration:

    - Test System Functionality: Conduct tests on the face tracking robot arm in different conditions like lighting, angles and distance.
    - Calibrate PID Controller: Tune the PID parameters to find the correct trade-off between the system's response and accuracy.
    - Evaluate Performance: Test the system's performance based on face-tracking accuracy, servo motor response and system stability.

6. Integration and Deployment:

- Integrate Components: Connect all software and hardware components to an integrated system, to make it easier for the webcam, Arduino and servo motors to function coherently and in a synchronised manner.
- Deploy System: Place the robot arm in the actual environmenfor user interaction and display.

7. Documentation and Reporting:

- Document System Architecture: Document the hardware introduction, as well as the software implementation and pay particular attention to the system architecture which can be used later.
- Create User Manual: Prepare a user manual detailing the system's operation, setup instructions, and troubleshooting tips.
- Generate Report: Develop a detailed report which effectively outlines the project’s methods, findings and future reccomendations.

4.4 FLOWCHART OF THE PROJECT:

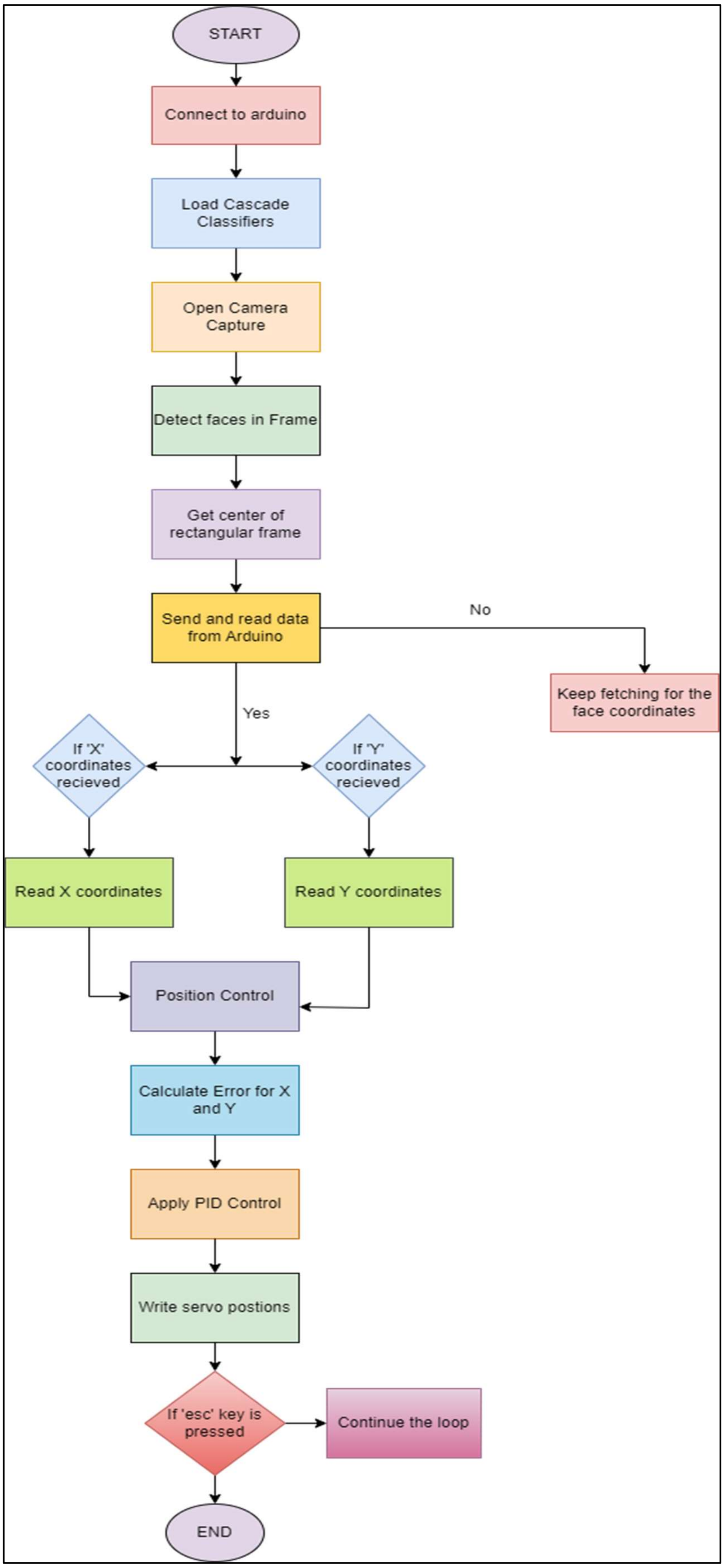

Figure 5: Flowchart

CHAPTER-5
RESULTS & DISCUSSION

The "Face Tracking Robotic Arm" project produced promising outcomes confirming the successful merging of computer vision, control theory, and hardware realization for intelligent robotic system that is efficient in locating a human face in real time. By means of stringent examination and evaluation, valuable input was accumulated which helped to identify strong and weak points of the system, as well as opportunities for future improvement.

Figure 6: Project Prototype

Face Detection and Tracking Accuracy:
The system demonstrated high precision capabilities of OpenCV as well as cvzone in terms of real-time face detection and tracking. The FaceDetector module was able to easily detect faces within the camera view, which in turn allowed the system to precisely locate and track facial movements with no lags.

Figure 7: Face Detection

Robotic Arm Control Precision:

The implementation of the PID control algorithm in the system that used the Python language obtained the precise and responsive control of the robot arm movements, which were adjusted according to the coordinates of the detected face. The PID controller was highly effective that it adjusted the positions of the servo motors to match those of a human face, thus achieving smoother and accurate tracking while minimizing overshoot and oscillations substantially.

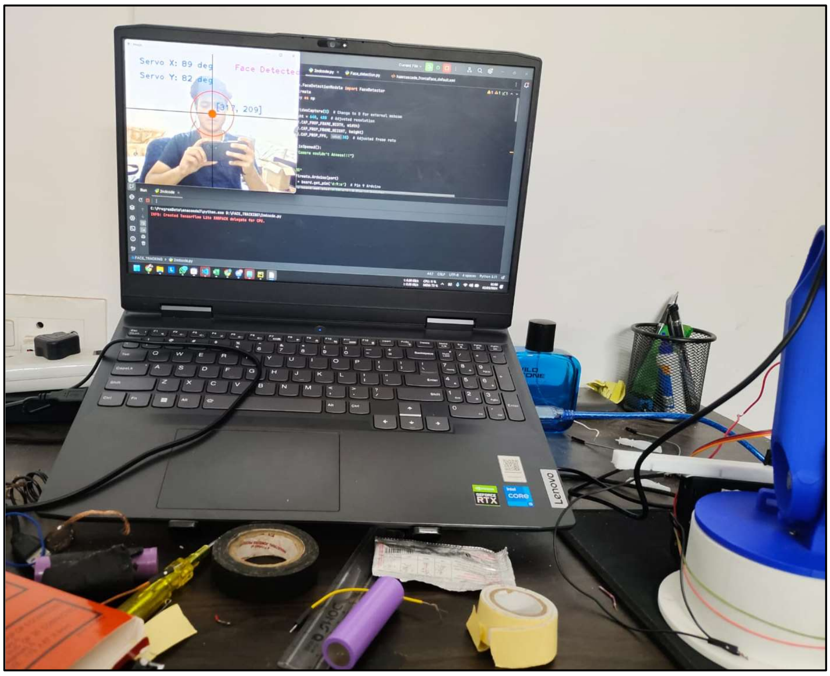

Figure 8: Control Precision

System Responsiveness and Stability:
The use of PyFirmata and PySerial libraries granted Python and Arduino communication interfaces which allowed real-time control and coordination of the robotic arm movements. The system responded promptly to the changes in the target's position and quickly adjusted the angle of the servo motors to conform to the target.

5.1 FUTURE ENHANCEMENTS & CONSIDERATIONS

Although the project reached its main goals, the nascent stages of a face detector and robotic arm tracking presented a comparison, some improvements and optimizations were identified in the future, which include:

• Environment Perception: The addition of sensors, for example, ultra sound and infrared sensors will enable the robot to perceive its surroundings.

• Motion Planning: The utilization of the latest motion planning algorithms ensures that the movements are smooth and precise. In this regard, the robotic arm could progress from a cartesian machine to something that undoubtedly simulates the movement of the human body.

• Machine Learning Integration: Implementation of machine learning techniques and algorithms can be used to improvise the face recognition in environments where there are disturbances.

5.2 APPLICATIONS

- Assistive Technologies: This can be then used as part or a whole of the assistive technologies for individuals who are restricted mobility. It could be designed to recognize faces of people and, consequently, perform operations like light switch on/off, TV settings adjustment, or statues fetching.

- Surveillance and Security: In surveillance systems, it can be deployed as a robotic arm to observe and follow people within a specific area of the system. It helps them track any randomly acting visitors or intruders in real-time and then send immediate alerts.

- Human-Robot Interaction Research: Scientists may use the system also for the patterns of communication between a human and a robot. It may be a place where social robotics experiments can be conducted, and ways of how a relationship between humans and robots can be changed in different environments are tested.

- Education and STEM Outreach: The jet wanted project can be utilized to train students in robotics, computer vision, and control theory. It can lead to an immersion of STEM subjects into the school curriculum through conducting experiments and building projects.

- Art Installations: To achieve this, artists and creators should integrate the face-tracking robotic arm into their installations and/or performances. It can feature as an interactive and dynamic element to artworks and react on the viewers' movement and presence in real-time.

- Gaming and Entertainment: This may be achieved through gaming devices or virtual reality environment. It comes as a way of enriching the experience since it lets you inter with virtual characters through facial expressions and gestures.

- Personalized Services: Whether it is in retail or hospitality, the robotic arm could give personal attention to a person, facilitated by the facial recognition. It may welcome customers, help with product recommendations or guide then to appropriate parts of an establishment.

- Medical and Healthcare: It can be tailored to be used in diagnostics and healthcare. It may help doctors in tracking patients' faces during telematic consultations and/or rehabilitation sessions.

- Industrial Automation: In the factory, the robotic arm can be used for jobs that require quality control, assembly, or material handling. It allows to increase the level of a job's effectiveness and productivity by automatically following human operators or by checking the products on assembly lines.

CHAPTER-6
CONCLUSION

The "Face Tracking Robotic Arm" project, which is a smart convergence of Arduino based robotics, computer vision, and control theory is to be developed into a real-time human face tracking system with interactive features. Via the use of OpenCV, cvzone, NumPy, PyFirmata, and PySerial libraries, as well as the Arduino Uno R3 microcontroller and MG995 servo motors, we have occurred to show the feasibility of those technologies to provide correct information and enable the robot arm to track the face position in time.

Finally, the system that we united OpenCV for human face detection in real time and a PID control algorithm developed by Python utilizes the movement of motors driving the robotic arm to control the position of its movement on the basis of the human movement. Furthermore, two libraries cooperation that is PyFirmata and PySerial to relieve the signals smoothly from Python to Arduino to the dedicated motors network that move at once depending on the obtained coordinates.

The effectiveness and stability of our face-tracking robotic arm system was proven through in-depth testing and calibration in different scenarios which showed its precision, sensitivity, and regulation to different levels. Besides, the project is a demonstration of the fact that embedded systems and DIY electronics could be used in the creation of smart robotic systems and the whole field of robotics is a multidisciplinary one, integrating elements of computer vision, control theory and hardware.

Steering towards the future, this project offers the opportunity to explore and initiate innovative works in robotics, human-robot interaction and assistive technologies. These future enhancements could comprise of the incorporation of further sensors for environment recognition, advanced motion planning algorithms for more fluent trajectory of the robotic arms, and the integration of machine learning for better face recognition rates.

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