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Artful Accessibility- Individuals with Mobility Disabilities in Art Exhibition

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Abstract
With a growing focus on accessibility in cultural sites following the UN Convention on the Rights of Persons with Disabilities, there is a need to make museum experiences more inclusive. Innovative technologies are emerging to ensure all visitors, including those with mobility disabilities, can fully engage with exhibitions. This project introduces a system designed to enhance the experience for individuals with mobility challenges in art exhibitions, using advanced technology to provide an inclusive and seamless experience for all. Our project introduces a system for art exhibitions that adjusts the height of paintings and wall-mounted exhibits to the eye level of visitors with mobility disabilities. Utilizing computer vision algorithms, proximity sensors, and a height-measuring camera, the system detects a visitor's presence and adjusts artwork height in real-time using motors. This approach ensures an inclusive and accessible viewing experience, aligning with ADA standards and enhancing visitor engagement by dynamically adapting to different heights and mobility needs.
Keywords
Cultural heritage experience, Adaptive design, Museum experience, Human-centered computing, Accessibility, Accessibility systems, Dynamic Adjustment, Machine learning (ML), IOT (Internet of Things).

1. Introduction
In recent years, cultural and heritage sites, particularly museums, have increasingly acknowledged and accommodated the diverse needs of their audiences. This shift is underscored by a growing recognition of the importance of inclusivity, especially for individuals who may require support to access and fully enjoy these sites. As museums transition from mere presenters of objects to providing immersive experiences. Emphasizes that no individual should be excluded from experiencing the benefits of the museum, highlighting the importance of accessibility for all citizens [2]. The significance of inclusivity is further underscored by international agreements, such as the UN Convention on the Rights of Persons with Disabilities, which emphasizes the pivotal role of assistive and digital technologies in the lives of people with disabilities [1]. Consequently, museums strive to be more responsive to the varied needs of their visitors, including those with mobility, hearing, visual, and cognitive disabilities. Technology has emerged as a vital tool in creating authentic and accessible museum experiences, bridging the gap for individuals who were previously unable to access certain artifacts and sites independently [4]. However, developing technological solutions for individuals with disabilities necessitates a nuanced approach, considering the diverse range of disabilities and specific conditions that may impact how individuals engage with museum activities. Studies have highlighted the challenges faced by individuals with disabilities, such as those who use wheelchairs or have visual impairments, when visiting art museums. These challenges span from physical obstacles encountered outside the exhibition to difficulties experienced within it, including issues with exhibit heights and positioning [2]. Considering these challenges, our current work addresses the specific needs of individuals with mobility disabilities within art exhibitions. While certain accommodations, such as ramps and elevators, provide greater accessibility, the positioning of exhibit objects remains a crucial aspect that often goes unnoticed. Ensuring that exhibits are displayed at appropriate

heights, allowing both wheelchair users and standing individuals to view them comfortably, is essential for fostering inclusivity in museum spaces [3] (see Figure 1). This book explores our efforts to develop innovative solutions to enhance the accessibility of art exhibitions, with the main goal of providing a seamless and enriching experience for all museum visitors, regardless of their mobility limitations. We propose a novel system designed to adjust the height of artwork displays to accommodate visitors' needs, whether they are seated in a wheelchair or standing. Our system includes a proximity sensor, a camera to detect the visitor's height, and a controller that activates motors to adjust the display's height dynamically. This approach ensures that all visitors can have an enriching and equitable museum experience regardless of their mobility limitations. By incorporating these adaptive technologies, we aim to provide a seamless and enriching experience for all museum visitors, regardless of their mobility limitations. We are working on this project in a professional manner, exploring and developing the concepts and solutions proposed in our supervisor's article to create a robust and effective system for enhancing museum accessibility.

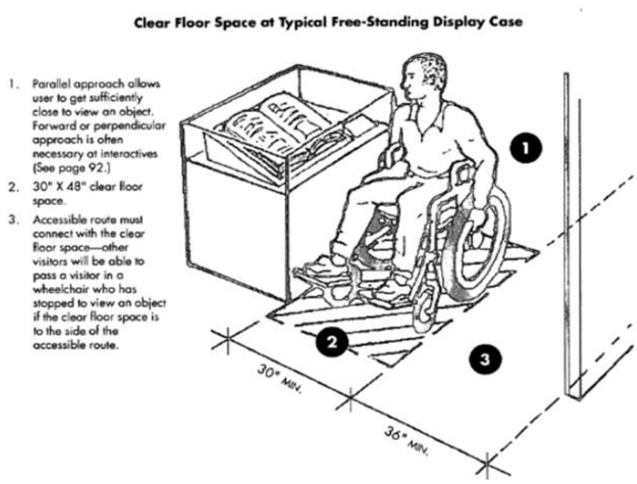

Figure 1: The ADA (Americans with Disabilities Act) Standards for positioning Freestanding display cases [5].

2. Background and Related Work

2.1 The Hecht Museum

The Hecht Museum at the University of Haifa was inaugurated in 1984. It was the initiative of the late Dr. Reuben Hecht, founder of the "Dagon Silos" in the port of Haifa and a founding member of the University of Haifa Board of Governors [Hecht Museum]. The museum hosts a diverse collection of exhibits, including ancient artifacts, archaeological findings, and a notable assortment of art pieces, such as paintings and sculptures. The museum's exhibitions span various historical periods and cultures, offering visitors a rich and educational experience. The decision to focus on the Hecht Museum for this project is strategic due to its unique position within the University of Haifa. This location facilitates and promotes collaborative efforts between the academic community and the museum. Such collaborations can enhance research opportunities, provide access to a broad range of expertise, and support the development and implementation of innovative accessibility solutions. The integration of the museum within the academic

Figure 2: Hoards and Genizot as Chapters in History.

environment ensures that the project benefits from interdisciplinary insights and resources, making it an ideal setting for advancing accessibility in art exhibitions.

2.2 Addressing Diverse Visitor Needs

Museums are increasingly recognizing the need to cater to the diverse needs and expectations of their visitors. They are striving to address a broader spectrum of visitor needs, typically focusing on four main categories: audio, visual, cognitive, and mobility limitations [6,8]. Each of these areas requires specific adjustments and accommodations to ensure a fully inclusive experience for all visitors, regardless of their abilities or challenges [8]. Audio limitations affect visitors who are deaf or hard of hearing. Museums address these needs through solutions like captioning for audio content, sign language tours, and induction loop systems [7,10]. However, challenges remain in providing equal access to audio-based exhibits and tours [7]. Visual limitations impact visitors who are blind or have low vision. Museums tackle this through tactile exhibits, audio descriptions, and large-print materials [11,12]. Yet, making visual art fully accessible to those with sight impairments remains a complex challenge [12]. Cognitive limitations encompass a wide range of challenges, including learning disabilities and neurodivergent conditions. Museums respond with simplified texts, multi-sensory exhibits, and quiet spaces [13,14]. The difficulty lies in catering to the diverse spectrum of cognitive needs without oversimplifying content for all visitors. Mobility limitations, often at the forefront of accessibility efforts, affect visitors with physical disabilities or movement restrictions [4,15]. This category requires a multifaceted approach to ensure full participation in the museum experience. Focusing on mobility limitations is crucial as it represents a prevalent need among museum visitors. Ensuring that visitors with mobility impairments can fully engage with and enjoy art exhibitions aligns with broader inclusivity and accessibility goals championed by museums worldwide [1,5]. By addressing mobility needs, museums promote a more inclusive environment where everyone can participate fully in the cultural and educational experiences offered [4,8]. To enhance accessibility for visitors with mobility challenges, museums are implementing various solutions, both technological and physical [15,16]. In our current work, we decided to concentrate on the specific needs of mobility disability at the museum itself with an emphasis on art exhibitions.

2.2.1 Technological/Physical Solutions for People with Mobility Impairment in Museums

As a part of our development process, we have examined existing technological and physical solutions for People with Mobility Impairment in Museums. The objective of this review was to gather comprehensive information and gain a thorough understanding of what is suitable and unsuitable for individuals with mobile impairment.

Virtual tours: offer an opportunity to explore inaccessible areas remotely. However, they lack the immersive and sensory experience of in-person visits [17]. For instance, while MoMA's virtual tour of Van Gogh's "Starry Night" utilizes high-resolution images and 3D models via photogrammetry [MoMA], it cannot replicate the physical presence and tactile engagement of viewing the artwork firsthand in a museum setting [18].

Accessible maps: such as those used at Colonial Williamsburg and Old Sturbridge Village, help visitors navigate museum spaces more effectively [16]. These tools are invaluable for planning routes but may not always reflect real-time changes or temporary obstacles [16].

Augmented Reality (AR) and Virtual Reality (VR) technologies: have been explored by museums to create immersive and engaging environments for visitors, including those with mobility impairments [15,19]. These technologies offer personalized experiences, allowing users to interact with exhibits in new ways. The use of VR has shown promise in providing an inclusive experience by enabling visitors to engage with exhibits regardless of physical limitations [19]. However, challenges such as high costs, potential discomfort like motion sickness, and user-friendliness issues can limit their accessibility and overall inclusivity [18,19]. These factors need careful consideration when implementing VR solutions in museums to ensure they benefit all visitors. For example, the Smithsonian National Museum of Natural History has implemented a virtual tour interface [19], as can be seen in Figure 3, allowing remote exploration of exhibition areas. This interface features an interior view of the museum with a navigational map overlay, enabling users to explore different wings and exhibits from anywhere [17]. Such applications demonstrate how digital technologies can enhance accessibility and offer alternative ways to engage with museum content, potentially overcoming physical barriers and expanding the reach of cultural institutions [16,17].

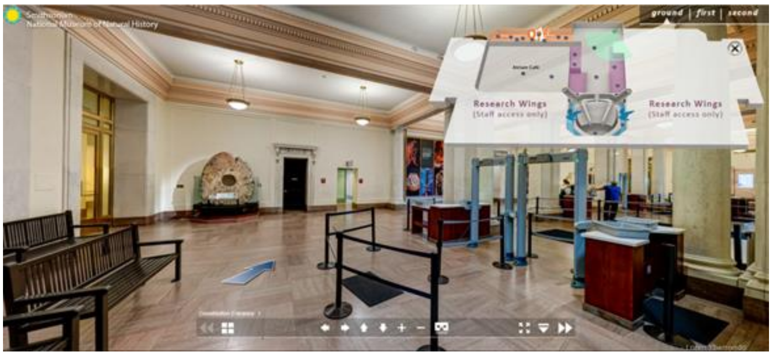

Figure 3: virtual tour of the Smithsonian National Museum of Natural History [Smithsonian Museum]

In addition to these technological solutions, museums also focus on physical aids to improve mobility access [4]. One such solution is the provision of adjustable seating. For instance, the National Gallery of Art in Washington, D.C. offers adjustable seating options in several of its galleries, allowing visitors to sit at varying heights while viewing exhibits [4]. This approach helps visitors view exhibits more comfortably by allowing them to adjust their seated position to suit their needs [7]. However, adjustable seating is not without its limitations. The static nature of artwork placement means that even with adjustable seating, some pieces may remain positioned too high for optimal viewing from a seated position [4]. This challenge particularly affects wheelchair users, for whom the artwork's height remains a constant issue regardless of seating adjustments [4,5]. Furthermore, the practicality of adjustable seating for wheelchair users presents another challenge. Transferring from a wheelchair to adjustable seating can be cumbersome and, in some cases, unfeasible due to personal mobility limitations [4]. This limitation highlights the need for a more comprehensive approach to accessibility that considers the diverse needs of all visitors with mobility impairments [15]. These examples underscore the complexity of creating truly inclusive museum spaces [4]. While progress has been made in addressing mobility limitations through both technological and physical solutions, challenges persist [4,16]. A balanced approach that combines technological innovations with thoughtful physical accommodations is essential to creating an inclusive and engaging museum experience for all visitors [15]. By continuously improving and integrating various accessibility measures, museums can work towards meeting the diverse needs of their visitors, fostering an environment of inclusivity and equality where art and culture can be appreciated by everyone.

3. Expected Achievements

Our project addresses a critical need in art exhibitions by introducing an innovative system designed to enhance accessibility for individuals with mobility disabilities. The system proposes real-time adjustment of the height of paintings and wall-mounted exhibits based on visitors' face levels. This adaptive technology utilizes advanced computer vision algorithms to detect and respond to visitors' presence, ensuring that artworks are optimally positioned for viewing [20]. The system integrates proximity sensors, a height-measuring camera, and a microcontroller linked to two motors capable of handling paintings weighing 5 to 10 kg [18]. Upon detecting a visitor, the system automatically adjusts the artwork's height to align with their face level, providing an inclusive viewing experience. Once the visitor moves away, the artwork returns to its original position, maintaining the integrity of the exhibition layout, as shown in Figure 4.

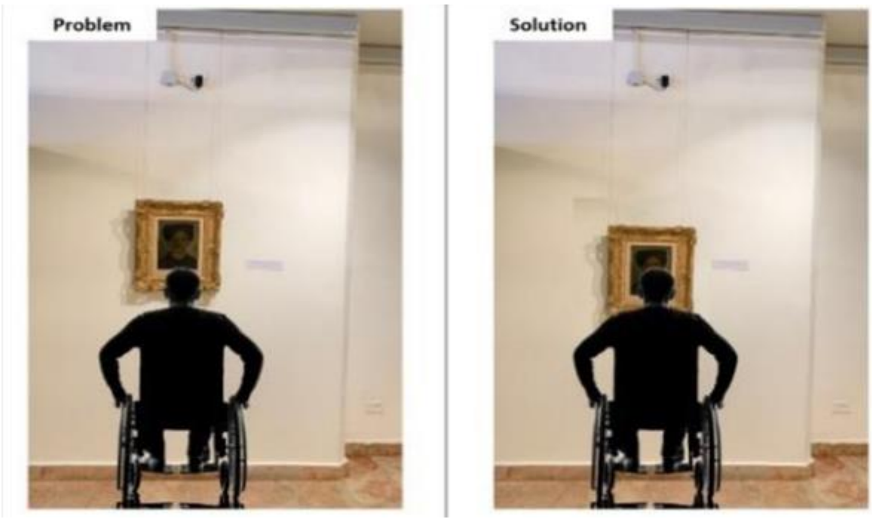

Figure 4: Adjustment of the painting's height in the art wing at Hecht Museum [9].

3.1 Successful Criteria

Our project's success hinges on achieving several critical goals. Firstly, the system must accurately detect visitors and swiftly adjust artwork heights in real time to match their face levels, ensuring a seamless and enjoyable viewing experience. This requirement aligns with our commitment to enhancing accessibility in line with ADA standards and other relevant accessibility guidelines [5,7], ensuring that all visitors, including those with mobility disabilities, can fully engage with and appreciate the exhibits [6]. Additionally, all system components, such as motors and sensors, must be robust and reliable enough to continuously support artworks with minimal maintenance in a public museum setting [8]. By meeting these criteria, our project not only aims to enhance accessibility but also demonstrates the potential for transformative and inclusive museum experiences through innovative technological solutions.

4. Engineering Process

4.1 Process

Our project begins with defining the problem, gathering requirements, evaluating alternatives, selecting the most suitable solution, testing, implementation and evaluation. The development process for our innovative system, which adjusts artwork height in real-time, ensures that each phase of development is driven by a deep understanding of user needs and continuous improvement. Our system aims to create a more authentic experience, potentially bringing users closer to previously inaccessible artifacts and sites. By accommodating visitors of varying heights and mobility statuses, our system adheres to ADA standards and other accessibility guidelines, setting a new standard for interactive and equitable cultural experiences. This innovative approach enhances visitor engagement and fosters a more dynamic and visitor-centric exhibition environment, addressing the challenges identified by Poria et al. [6] regarding the accessibility of art museums for people with mobility disabilities. Implementing this combined approach promises to significantly enhance accessibility and inclusivity in museum settings, aligning with the growing recognition of the need to cater to diverse audiences in cultural and heritage sites [4,21]. By integrating technology to facilitate accessibility, our project contributes to the broader goal of creating more responsive and inclusive museum experiences.

4.1.1 Key elements of our approach include

In developing our innovative system for adjusting artwork height in real-time to enhance accessibility for wheelchair users in art exhibitions, we follow a methodical approach designed to address key challenges and ensure effective solutions.

- **Problem Definition and Requirement Gathering:** Our initial objective is to clearly define the accessibility challenges faced by wheelchair users in art exhibitions. To achieve this, we combine primary data collection with extensive research, encompassing academic papers, industry reports, case studies, and online resources. This comprehensive approach grounds our understanding of existing knowledge and best practices [6,21]. Regular consultations with our project supervisor, Dr. Julia Sheidin, and the Mechanical Engineer provide invaluable insights, refining our understanding and validating our findings (sub-section 4.1.2).
- **Evaluation of Alternatives:** Our next step involves identifying and assessing various technological solutions to address the identified challenges. We review existing technologies such as adjustable seating, digital guides, and assistive devices to evaluate their efficacy and limitations in museum environments (sub-section 4.1.3).
- **Solution Selection:** With the data gathered, we analyze and select a solution that integrates advanced technologies. This includes proximity sensors, cameras, microcontrollers, and motors capable of adjusting artwork height based on real-time face detection, ensuring seamless integration and operational alignment within museum settings (sub-section 4.2).
- **System Development and Testing:** Our focus then shifts to developing a robust and reliable system. Agile development practices guide system components' construction, testing, and refinement, including a cloud-based face detection program, microcontroller systems, motors, and proximity sensors. This iterative approach ensures that the system meets high performance and reliability standards (sub-section 6).

- **Implementation and Evaluation:** Our system is deployed in a real-world museum setting upon completion of development. Here, we closely monitor its operation and collect feedback from users and museum staff to evaluate its impact on accessibility and visitor engagement. This phase allows us to make necessary adjustments to optimize performance and enhance user satisfaction (will take place during phase B of the capstone project).

Following this structured and iterative process, our goal is to deliver a solution that significantly enhances the museum experience for individuals with mobility disabilities. Through thoughtful design and rigorous testing, we aim to ensure that all visitors can fully enjoy and engage with the cultural and artistic treasures on display.

4.1.2 Problem Definition and Requirements Specification

Museums often face challenges in providing equal access for visitors with mobility disabilities due to traditional displays that do not accommodate varying face levels, affecting the viewing experience. To address this, we propose an automated system that dynamically adjusts the height of wall-hung artworks, enhancing accessibility while adhering to ADA standards [5] and the Smithsonian Guidelines for Accessible Exhibition Design [7]. The system's development involves defining functional requirements for its behaviors and interactions, and non-functional requirements for reliability, scalability, usability, and security [23]. Meeting these requirements is crucial for creating a high-quality, inclusive art viewing experience in line with established accessibility guidelines.

Functional Requirements (FR):

1. Visitor Detection and Measurement:
   - The system should use computer vision for detecting visitor's face [20].
   - The system should detect a person in a wheelchair.
   - The system should utilize proximity sensors to detect visitor presence [16].

2. Artwork Adjustment:
   - The system should control the motorized vertical movement of the artwork.
   - The system should accommodate paintings of various weights.
   - The system should adjust artwork height to match the average face level of adult wheelchair users.
   - The system should return artwork to its original position after the visitor departs.

3. System Communication and Calibration:
   - The system should ensure reliable Wi-Fi communication between cloud-based software and the microcontroller, facilitating real-time updates and adjustments [16].
   - The system should support calibration for accurate height adjustments and face detection [9].

4. Accessibility Compliance:
   - The system should adhere to ADA standards for accessible design in public accommodations [5].
   - The system should maintain appropriate clear floor space in front of each adjustable artwork for wheelchair access.

- The system should ensure that all controls comply with accessibility standards.

Non-Functional Requirements (NFR):

1. System Performance and Reliability:
   - Ensure consistent operation with minimal failures.
   - Maintain real-time responsiveness with low latency in height adjustments.
   - Optimize power consumption for energy efficiency.

2. Scalability and Compatibility:
   - Design the system to accommodate multiple exhibits and different types of artworks, with modular components and scalable architecture [15].
   - Ensure integration with existing museum infrastructure.

3. Security and Maintainability:
   - Implement secure Wi-Fi communication and data protection measures.
   - Ensure ease of system maintenance and updates.

4. Usability and Durability:
   - Maintain high precision in face detection and height measurement using high-quality sensors and calibration techniques [8].
   - Utilize components capable of withstanding regular museum use, including robust construction and resistance to environmental factors [8].

4.1.3 Evaluation of Alternative Solutions

In our evaluation of alternatives, we weighted all aspects of the solution (See table 1), which each aspect has a different unit of weight (Low to High). This approach allowed us to generate a broad range of ideas, some of which were unconventional. Through we refined and improved upon these concepts. As a result, we have identified three primary alternatives for comparison.

- **Alternative 1: Measuring Height from Bottom Up Using Streaming Video Camera:** This method employs a streaming video camera to measure the visitor's height from the bottom up. Visitor engagement is medium as the system attempts to adjust automatically. The development complexity is high, requiring sophisticated image processing and computer vision algorithms. Interactivity is also medium, with automatic height adjustment based on video analysis. Accessibility is rated as medium, as the system adjusts based on visual data. The cost is high due to the need for powerful processing CPU capabilities. Disadvantages include accuracy issues caused by variations in lighting and visitor posture, and the high CPU power required to run the computer vision program effectively (See section 4.1.4 about microcontrollers).

- **Alternative 2: Fixed Points with Sensors for Height Detection**
  This approach uses sensors placed at fixed points on the wall to detect the visitor's height. Visitor engagement is medium, with height adjustment based on sensor data. The development complexity is medium, involving the installation and calibration of

multiple sensors. Interactivity is also medium, featuring automatic height adjustment based on sensor readings. Accessibility is rated medium, offering some level of automated adjustment. The cost is medium, as sensors must be strategically placed and calibrated. Disadvantages include the difficulty of finding sensors that can reliably detect distances of 1 to 2 meters and potential inaccuracies or blind spots if visitors are not correctly positioned relative to the sensors (See section 4.1.4 about sensors).

- **Alternative 3: Fully Automated Height Adjustment System with Computer Vision for Face Detection**
  This method employs a camera and computer vision to detect the visitor's faces, automatically adjusting the artwork height. Visitor engagement is high, as the system provides a seamless and personalized experience. Development complexity is also high, involving advanced technology, integration with cloud services, and precise motor control. Interactivity is high, offering a smooth and engaging experience for visitors. Accessibility is rated high, providing optimal accessibility for all users, particularly those with mobility disabilities. The cost is high due to the complexity and advanced nature of the system. Advantages include the system placing the painting at an initial height and then lowering it slowly until it detects the visitor's face, ensuring accurate height adjustment (Conditionally, if detected, the person is in a wheelchair). This method overcomes many of the accuracy and CPU power issues faced by Alternative 1, as well as the sensor placement challenges of Alternative 2.

The table below summarizes the three main alternatives, categorized by key factors:

Category	**Alternative 1: Person's height calculation**	**Alternative 2: Fixed Point Sensors**	**Alternative 3: Computer Vision for Face Detection**
Solution	CV (Computer Vision) height calculating ML algorithm	Fixed sensors (Top-Bottom) on the wall	Computer vision ML face detection and adjusts to faces level
Visitor Engagement	High	Medium	Medium
Development Complexity	High	Low	Medium
Interactivity	High	Medium	Medium
Accessibility	Medium	Medium	Medium
Cost	High	High	Medium

Disadvantages	Accuracy issues, high CPU power	Potentially inaccurate in some cases	Visitors must keep staring at the camera until the process is done.

Table **1** - overview the alternatives

By evaluating these alternatives, we can determine the best solution that balances technological feasibility, development complexity, visitor engagement, interactivity, and overall accessibility. Based on this assessment, our project will proceed with the fully automated height adjustment system (Alternative 3), which provides the highest level of accessibility and visitor engagement, ensuring an inclusive and enriching museum experience for all visitors.

4.1.4 Evaluation of System's Components

In designing our system for dynamically adjusting the height of museum artworks, selecting the appropriate components is crucial for ensuring functionality, reliability, and efficiency. The system consists of several key components, including the camera, microcontroller, sensors, and motors. Each component was carefully evaluated, with two options considered for each and one selected based on its advantages for our specific application.

1. **Microcontroller:** The ESP32 with Wi-Fi capabilities and the Raspberry Pi were the options considered. The ESP32 is known for its low power consumption, integrated Wi-Fi and Bluetooth, and extensive library support for IoT applications. However, it lacks the computational power to handle complex image-processing tasks like face detection. The Raspberry Pi, with its more powerful CPU, can run sophisticated machine learning algorithms directly on the device, eliminating the need for cloud-based processing. Given the requirements of our system, we opted for the Raspberry Pi because it can handle face detection locally, reducing latency and dependence on external servers and thereby enhancing the system's overall efficiency and responsiveness. [ESP32, Raspberry Pi]
2. **Camera:** We evaluated the Raspberry Pi Camera Module v2 and the ESP32-CAM for the camera component. The Raspberry Pi Camera Module v2 provides an 8MP resolution and seamless compatibility with Raspberry Pi microcontrollers, making it a robust choice for capturing detailed video streams. The ESP32-CAM, while compact and integrated with Wi-Fi and Bluetooth, offers a lower resolution and might require more external components for image processing. We chose the Raspberry Pi Camera Module v2 due to its superior video quality and ease of integration with Raspberry Pi microcontrollers, ensuring more reliable and detailed face detection for our application, which is critical for accurately adjusting the artwork's height. [ESP32-CAM, Raspberry Pi Camera v2]
3. **Sensor:** For the sensor, we compared the ITR 20001 proximity sensor and the HC-SR04 ultrasonic sensor. The ITR 20001 is a reflective optical sensor suitable for short-range detection and has a straightforward integration process. The HC-SR04, an ultrasonic sensor, offers longer-range detection and better accuracy over larger

distances. We chose the HC-SR04 ultrasonic sensor because our application benefits from its ability to detect visitors from a greater distance, ensuring that the system can anticipate the need for height adjustment as a visitor approaches. This longer-range detection improves the system's responsiveness and accuracy in identifying the presence of visitors directly in front of the painting [HC-SR04 , ITR 20001].

4. **Motor:** The motor options considered were the NEMA 17 stepper motor and the MG995 servo motor. The NEMA 17 stepper motor is known for its high torque, precision control, and ability to handle significant loads, making it ideal for applications requiring fine-grained adjustments. The MG995 servo motor, while providing good torque and speed, is less precise in its movements compared to stepper motors. Given the need for precise height adjustments to ensure optimal visibility of the artwork, we selected the NEMA 17 stepper motor. Its precision and ability to handle the weight of the paintings (5-10 kg) make it the most suitable choice for our system, ensuring reliable and accurate height adjustments StepperOnline. [NEMA 17, MG995]

4.1.5 System's technologies

- **C Programming for Microcontrollers:** In our project, C programming serves as the foundational language for orchestrating the intricate control of microcontroller devices like the Raspberry Pi or ESP32. This involves interfacing with a variety of components critical to our system, including proximity sensors, cameras for real-time image processing, and electric motors responsible for adjusting painting heights. According to [Skill-Lync], C's low-level capabilities and direct hardware access are essential for implementing precise control algorithms that manage the dynamic movement of artworks based on visitor interactions. The article highlights that C provides "efficient and predictable performance" and "fine-grained control over system resources", which are crucial for developing real-time systems. By harnessing C's efficiency and capability to interact directly with hardware, we ensure responsive and accurate adjustments of painting heights, tailored in real-time to optimize viewing experiences for museum visitors, particularly those in wheelchairs.

- **Python for Face and Wheelchair Detection:** Python plays a crucial role in our system by handling advanced image processing tasks, particularly for object detection using real-time camera data. Leveraging Python's robust libraries, such as OpenCV and YOLO [25], we implement algorithms that identify and track the position of a visitor's face relative to the artwork. This capability allows our system to determine the optimal viewing height dynamically. According to [Skill-Lync], Python's extensive library support, including powerful tools like OpenCV, "facilitates the development and benchmarking of complex computer vision models". The article emphasizes that Python's "flexibility and ease of use in implementing and testing algorithms" make it particularly effective for handling complex tasks such as real-time face detection, ensuring accurate face-level detection even in varying lighting and environmental conditions within museum settings.

- **Networking for Communication Between Microcontroller and Cloud Server:** Networking forms the backbone of our system's data management and remote monitoring capabilities. By establishing communication protocols between the microcontroller (e.g. Raspberry Pi, ESP32) and a cloud server, we enable seamless data exchange and remote-control functionalities. This architecture allows us to collect and transmit real-time sensor data, including visitor interactions and painting adjustments, to a central server for analysis and monitoring. Networking protocols such as MQTT or HTTP are employed to ensure secure and efficient data transmission, facilitating responsive system adjustments and centralized management of multiple installations across different museum locations [MQTT].

4.2 Product (Solution Selection)

4.2.1 Solution

Our proposed system is designed to autonomously adjust the height of paintings to optimize visibility for visitors, particularly those in wheelchairs. The system integrates a proximity sensor to detect the presence of a visitor, initiating the operation of an electric motor. This motor lowers the painting until a camera detects the visitor's faces, ensuring accurate positioning for optimal viewing. Upon detecting a visitor approaching the painting, the system activates the electric motor, which begins lowering the painting along retractable cords. Simultaneously, a camera captures real-time images to identify the visitor's face level (in condition detected a person in a wheelchair). Using this data, the system calculates the precise distance required to position the painting at the optimal height relative to the visitor's seated position. The calculated adjustment, in terms of both direction and distance, is then transmitted to the motor control system, facilitating seamless and precise repositioning of the artwork. Once the painting aligns with the visitor's face level, as determined by the camera, the motor halts movement, ensuring the artwork remains stationary until the visitor moves away. This approach not only enhances accessibility for wheelchair users by customizing the viewing experience to their face level but also exemplifies a sophisticated integration of sensor technology and motor control mechanisms within museum environments. By automating the height adjustment process based on real-time visitor interaction, our system aims to foster inclusive and engaging experiences for all museum patrons. The system is controlled by a microcontroller hidden in or behind the frame, which processes the data and commands the motor accordingly (see Figure 5 illustrates the proposed system).

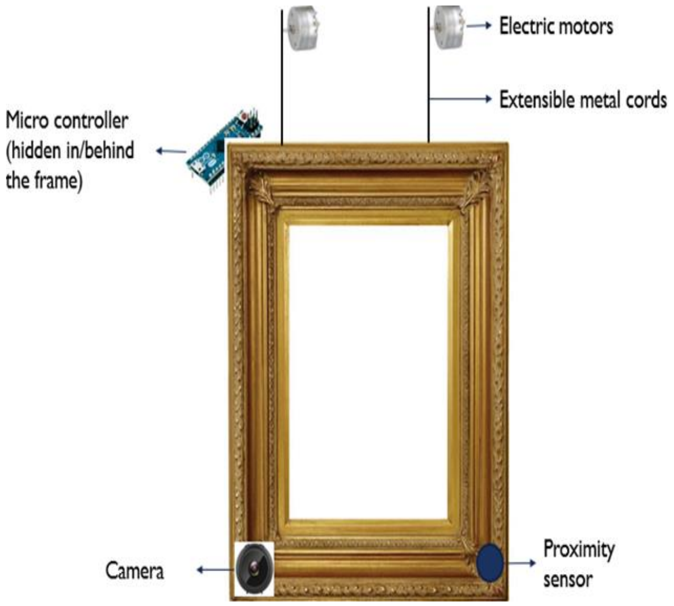

Figure 5: The proposed system [9].

4.2.2 System Diagrams

Sequence diagrams are crucial for visualizing and detailing interactions between objects over time, helping to clarify system behavior and facilitate communication among stakeholders. They are useful for design, documentation, and testing, ensuring a shared understanding of system dynamics [24]. We've chose sequence diagram over activity because we wanted to display how our system's components communicate with each other and illustrate the role of each component.

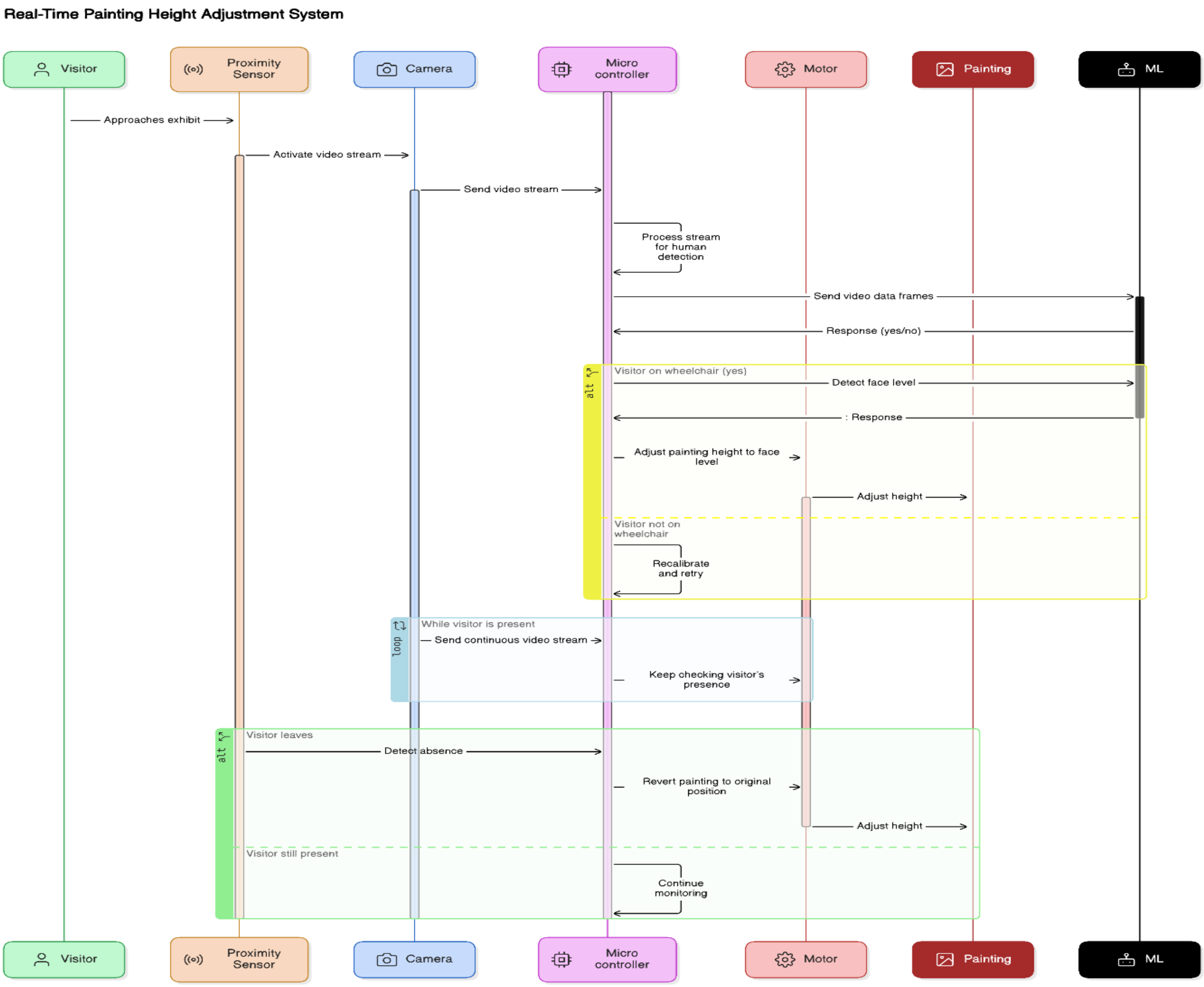

Figure 6 - Sequence Diagram

The real-time painting height adjustment system dynamically adjusts the height of a painting based on the face level of each visitor. The process involves multiple components, including a proximity sensor, camera, microcontroller, motor, and cloud services, working together to ensure optimal viewing conditions. The sequence of interactions begins when a visitor approaches the exhibit and continues through to adjusting the painting's height, maintaining the optimal position, and resetting once the visitor leaves. The following table provides a detailed overview of each step in this sequence:

Step	Component	Action	Description
1	Visitor	Approaches exhibit	The system detects the presence of a visitor approaching the painting.
2	Proximity Sensor	Activate video stream	The proximity sensor activates when a visitor is near, triggering the camera to start streaming video.
3	Camera	Send video stream	The camera begins capturing and sending the video stream to the microcontroller for processing.
4	Microcontroller	Process stream for human detection	The microcontroller receives the video stream and processes it to detect the presence of a human visitor.
5	ML (Machine Learning)	Detect face level and wheelchair status	The system uses machine learning to analyze the video data and determine if the visitor is on a wheelchair.
6	ML	Response (yes/no)	Based on the analysis, the ML model responds to the microcontroller with a "yes" (on wheelchair) or "no."
7	Microcontroller	Adjust painting height to face level	If the visitor is on a wheelchair, the microcontroller sends a command to adjust the painting's height.
8	Motor	Adjust height	The motor receives the command and physically adjusts the painting's height to the visitor's face level.
9	Microcontroller	Recalibrate and retry (if visitor is not on wheelchair)	If the visitor is not on a wheelchair, the system recalibrates and retries to ensure optimal height adjustment.
10	Camera	Send continuous video stream	While the visitor is present, the camera continues sending video streams to monitor their status.
11	Microcontroller	Keep checking visitor's presence	The microcontroller continuously checks if the visitor is still present at the exhibit.
12	Visitor	Leaves	When the visitor leaves, their absence is detected by the system.
13	Proximity Sensor	Detect absence	The proximity sensor detects the absence of a visitor in front of the painting.
14	Microcontroller	Revert painting to original position	Upon detecting the absence, the microcontroller commands the motor to revert the painting to its original height.
15	Motor	Adjust height	The motor adjusts the painting back to its default height.
16	Microcontroller & Camera	Continue monitoring	The system continues monitoring for the presence of new visitors and restarts the process as needed.

Table 2 - overview the Sequence Diagram

4.2.3 System Architecture

The architecture leverages a combination of sensors, microcontrollers, and a cloud-based machine-learning program to achieve precise and responsive adjustments. The main microcontroller acts as the central processing unit of the system. It is responsible for coordinating the motor operations and handling the data received from the camera microcontroller. When a visitor approaches the artwork, the main microcontroller receives a signal from the sensor, thus activating the camera, indicating whether the visitor is with mobility aid (e.g., Wheelchair) and if face level has been detected all via transmitting stream video data to the Cloud. This video stream is transmitted via Wi-Fi to a cloud server for further processing. The video stream from the camera microcontroller is processed by a Python machine-learning program hosted on a cloud server. The machine learning program analyzes the video stream to detect the visitor's face level and calculate the appropriate height adjustment required for the artwork. If the visitor's face level is below the predefined optimal range, the program sends a signal back to the main microcontroller, indicating that an adjustment is needed. Upon receiving a signal from the main microcontroller, the motor is activated to adjust the height of the artwork. The motor operates the retractable metal cords on which the artwork is mounted, allowing it to move up or down to align with the visitor's face level. Once the adjustment is complete and the visitor moves away, the artwork is returned to its initial position.

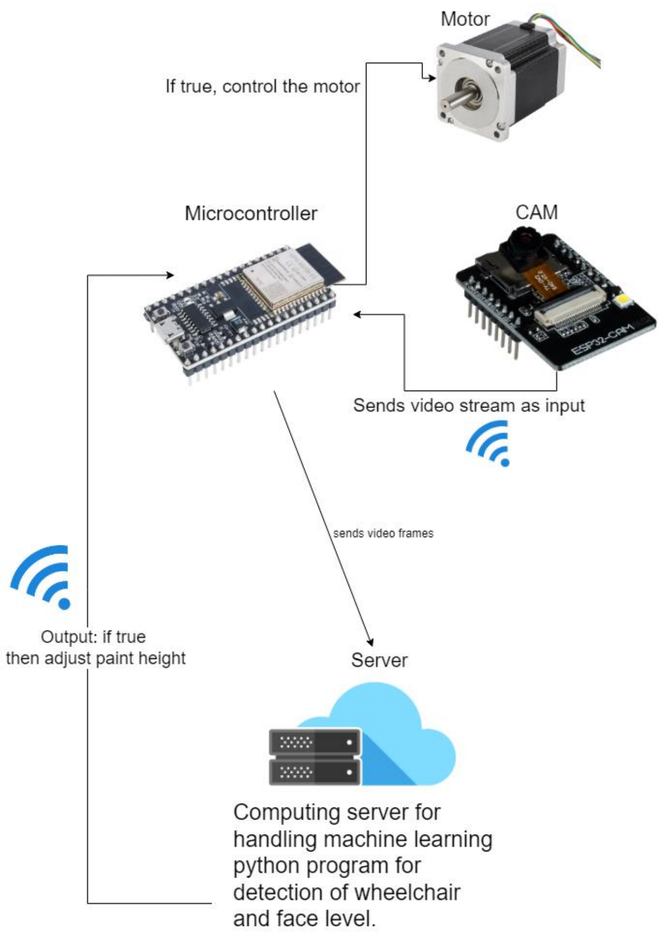

Figure 7- System Architecture Artwork height.

4.2.4 Computer Vision for Object Detection

The decision to prioritize CV-based detection of individuals with visible mobility aids (e.g., wheelchairs) stems from the improved accuracy and objectivity that machine learning models offer. In contrast to other method that require to hardcode the detection of wheelchair height with sensor as mentioned in 4.1.3 - alternative 2, These models can be trained to accurately identify wheelchairs and other mobility aids within a visual field, eliminating the potential for human error or bias in determining who requires adjustments. By automating the detection process, the system can proactively adjust artwork heights without requiring user input, creating a smoother and more inclusive experience for visitors with disabilities. Furthermore, CV-based detection can adapt to changing situations in real-time. If multiple individuals are present, the system can quickly assess and prioritize those with mobility aids, ensuring that their needs are met promptly. We have come to conclusion to use utilize Computer Vision (CV) model YOLO (You Only Look Once) for object detection. Specifically, version YOLOv4-Tiny. YOLOv4-Tiny is a compact and efficient version of the YOLOv4 object detection model, designed for real-time applications on devices with limited computational resources. It retains the high speed of YOLO while sacrificing some accuracy for faster processing, making it ideal for applications like detecting wheelchairs and human faces. In such a project, YOLOv4-Tiny's reduced architecture allows for rapid inference and low latency, making it suitable for edge devices, such as Raspberry Pi. Its ability to detect multiple objects, including wheelchairs and faces, with sufficient precision enables practical deployment in environments like hospitals, care facilities, and public spaces for accessibility enhancements and safety monitoring.

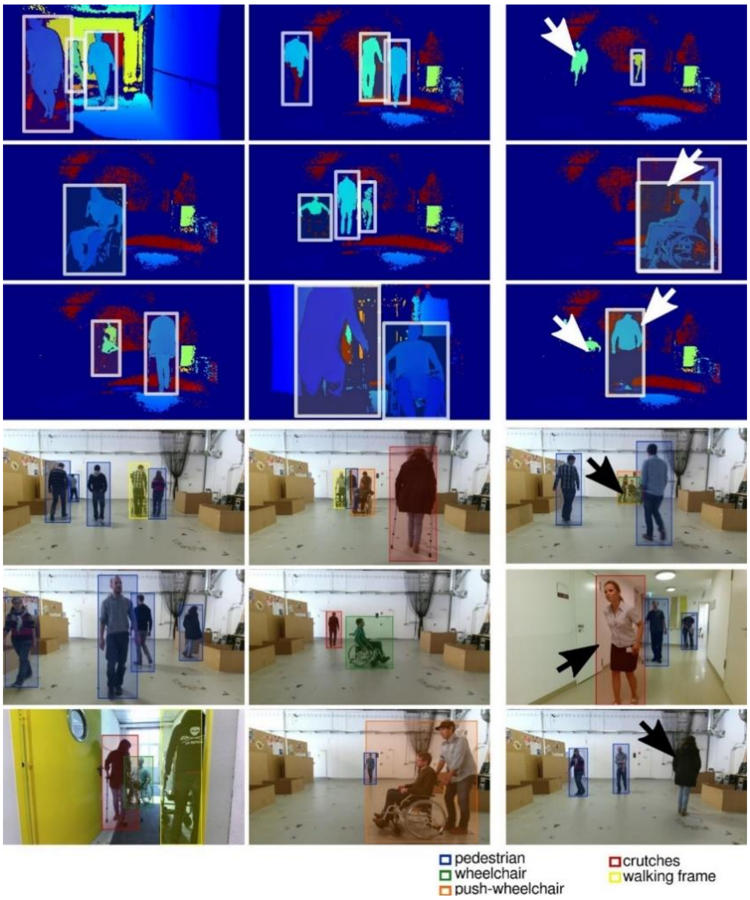

Figure 8- CV for detecting wheelchair in real-time video stream. [source]

4.2.4.1 Brief Background

YOLO is an object detection algorithm that frames the detection task as a single regression problem, directly predicting bounding boxes and class probabilities from an image in one evaluation. Unlike traditional methods that use a sliding window or region proposal approach, YOLO divides the image into a grid and, for each grid cell, predicts a fixed number of bounding boxes, confidence scores, and class probabilities. This unified model allows YOLO to achieve real-time detection speeds with relatively high accuracy by leveraging deep convolutional neural networks (CNNs) for end-to-end learning. YOLO's architecture enables fast, simultaneous detection of multiple objects, making it highly suitable for applications requiring real-time analysis, such as autonomous driving, surveillance, and assistive technologies [YOLO].

4.2.4.2 Implementation

Deploying YOLOv4-Tiny on a Raspberry Pi microcontroller to detect disabled individuals in wheelchairs and their faces, enabling autonomous adjustment of art height for optimal visibility. The implementation leverages YOLOv4-Tiny's efficient deep learning-based object detection capabilities, specifically designed to operate on devices with limited computational resources, like the Raspberry Pi. The model will be trained or fine-tuned to recognize wheelchairs, human faces, and other assistive equipment, using a dataset like the one depicted in the uploaded images, where objects such as pedestrians, wheelchairs, and crutches are accurately detected and classified.

For deployment, the YOLOv4-Tiny model will run on the Raspberry Pi, interfacing with camera modules to capture real-time video feeds. Upon detecting a person in a wheelchair and identifying their face, the system calculates the optimal height for displaying artwork based on the detected face position. The detected data is processed in real-time, allowing the motorized frame or mount holding the artwork to adjust dynamically to the correct eye level. This setup ensures an inclusive and adaptive viewing experience, particularly in environments like museums, galleries, or public spaces where accessibility and engagement for all visitors are crucial. The low power consumption and compact form factor of the Raspberry Pi make it an ideal choice for such an application, balancing efficiency and effectiveness in a cost-effective solution. This project demonstrates how modern deep learning models, even in their lightweight versions like YOLOv4-Tiny, can be adapted for edge devices to solve real-world accessibility challenges.

4.2.4.3 Dataset

For detecting people with wheelchairs and their faces, we need a diverse and comprehensive dataset that includes various scenarios involving disabled individuals in different environments and conditions. Some well-known websites provide large-scale datasets suitable for training YOLOv4-Tiny for this purpose. These datasets include annotated images of wheelchairs, human faces, and other assistive devices like crutches or walking frames.

Here are a few notable sources:

- **COCO (Common Objects in Context)**: COCO is one of the most popular datasets for object detection, segmentation, and captioning. While it does not specifically focus on wheelchairs, it contains images of people in various poses and with different assistive devices. The COCO dataset can be used as a base dataset, and additional images of wheelchairs can be added for fine-tuning the YOLOv4-Tiny model.
    1. **AI Hub from Roboflow**: Roboflow provides various datasets for computer vision applications, including some that focus on accessibility devices like wheelchairs. These datasets are often curated from different sources and come pre-annotated with labels such as "wheelchair," "pedestrian," "face," etc. The platform also allows for easy dataset augmentation, which can help improve the robustness of the YOLOv4-Tiny model on real-world data [Robobflow] (see figure 9).

2. **Wheelchair Detection Dataset from Kaggle**: Kaggle is another excellent source for datasets, often contributed by the community. It offers specific datasets for detecting wheelchairs, sometimes along with other accessibility-related categories like walkers or canes. These datasets are ideal for training and validating YOLOv4-Tiny in environments with high variability, such as crowded public spaces or indoor settings. [Kaggle]
3. **Custom Dataset Creation**: In addition to these sources, creating a custom dataset tailored to the specific requirements of your project is highly recommended. This involves collecting images from environments where the system will be deployed (e.g., hospitals, galleries, or care facilities) and manually annotating them to include wheelchairs, faces, and other relevant objects. This custom dataset ensures that the model is optimized for the actual conditions it will encounter.

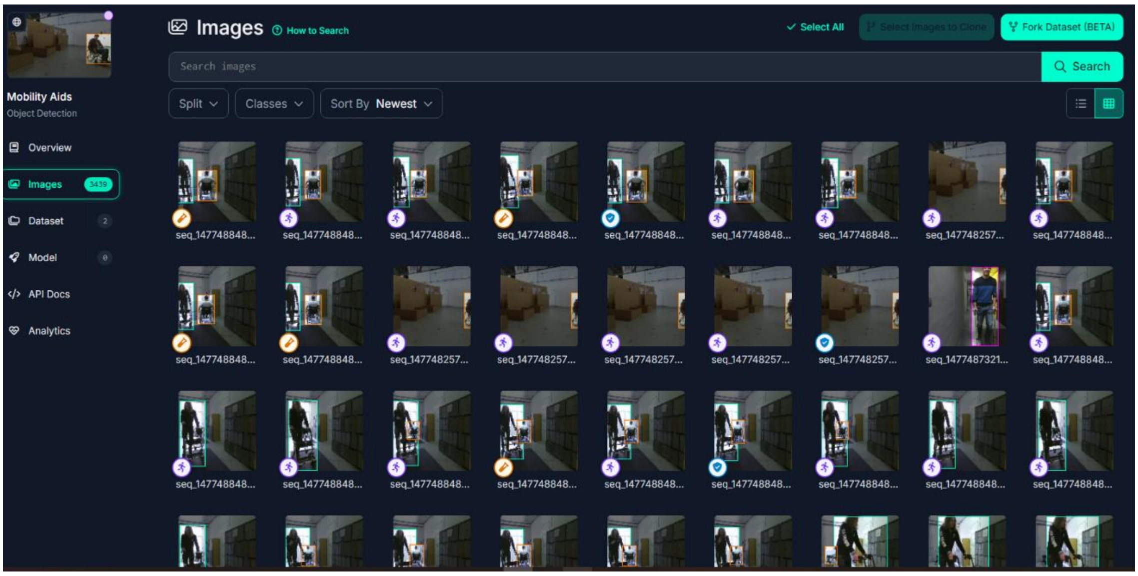

Figure 9- Mobility aid wheelchair dataset [Robobflow].

By leveraging these datasets, you can train a robust and accurate YOLOv4-Tiny model capable of detecting people with wheelchairs and their faces in real-time, facilitating the adjustment of art height for better accessibility and engagement. Combining different datasets and applying data augmentation techniques can help overcome challenges related to lighting, occlusions, and diverse backgrounds, ensuring reliable performance in various scenarios.

4.2.4.3 Training

Training YOLOv4-Tiny for detecting wheelchairs and human faces involves several key steps:

1. **Data Preparation**: Start by gathering a diverse and annotated dataset that includes images of wheelchairs, human faces, and relevant contexts. Ensure the dataset is well-balanced to avoid bias and includes various environments, angles, and lighting

conditions. Data augmentation techniques such as flipping, scaling, and rotation can help improve model generalization.

2. **Model Configuration**: Set up the YOLOv4-Tiny configuration files, which define the architecture, number of classes (e.g., wheelchair, face), anchor boxes, and other hyperparameters like batch size, learning rate, and number of iterations. The YOLOv4-Tiny model is much lighter than the full YOLOv4, making it suitable for edge devices like the Raspberry Pi.
3. **Training Process**: Use a framework like Darknet, PyTorch, or TensorFlow to train the model. The training involves forward and backward passes through the network, where the model learns to minimize the loss function, which combines localization loss (for bounding boxes), confidence loss, and classification loss. The model's weights are updated iteratively based on the calculated gradients.
4. **Evaluation and Fine-Tuning**: Evaluate the model's performance using metrics such as MAP (mean Average Precision), precision, recall, and F1 score. If the results are unsatisfactory, fine-tune the model by adjusting hyperparameters, increasing training data, or employing techniques like transfer learning with pre-trained weights.
5. **Deployment**: Once trained, the optimized YOLOv4-Tiny model is exported for deployment on the Raspberry Pi microcontroller, enabling real-time detection of wheelchairs and human faces for dynamic art height adjustment.

5. Challenges and Limitations

5.1 Crowded Museum and Multiple visitors

5.1.1 Sensor in a Crowded Museum

The main use of sensors is to idle the system (saving power) until detecting incoming object. Sensors might struggle to function accurately in a crowded museum environment, leading to frequent miscalculations or false detections. We will be taking two approaches to attempt to solve the issue. Firstly, using the approach marking the area's floor where the interested person for the artwork to stand. Thus, the distance will be fixed for the sensor to detect and not detect anything further. The second approach is utilizing CV to detect people with mobility aids (wheelchairs specifically). Even though the sensor might detect randomly, then passing people; if the condition isn’t met, it will go back to an idle state.

5.1.2 Multiple Visitors Camera Detection

When multiple visitors are in view, detecting the person on the wheelchair becomes challenging .

Suggested Solutions:

- **Priority Settings:** Implement CV to prioritize certain users (e.g., those with visible mobility aids) if the system detects multiple visitors.

- **User Feedback System:** Incorporate a feedback mechanism where users can indicate if they need the painting lowered, ensuring the system responds to actual needs.

While a user feedback system may seem intuitive, it presents several drawbacks in this context. Not all visitors may be aware of the feedback mechanism or feel comfortable using it, which could lead to missed opportunities to provide necessary adjustments. Additionally, waiting for user feedback introduces a delay in the adjustment process, which can negatively impact the visitor's experience. Implementing a feedback loop also disrupts the seamless automation that CV-based detection offers, adding an additional layer of complexity that could potentially introduce errors or malfunctions. By prioritizing CV-based detection of individuals with mobility aids, the system can leverage the accuracy and efficiency of machine learning to provide a truly automated and inclusive experience for all museum visitors. While user feedback may have its merits in other contexts, it is not the most suitable solution for addressing the challenges of multiple visitor detection in this scenario.

5.2 Power Supply

We must ensure a consistent and reliable power supply for the motor, sensors, and microcontroller. The challenge is to maintain continuous power to these critical components, as any disruption could impact the system's functionality and reliability. We propose several solutions:

- **Uninterruptible Power Supply (UPS):** Utilizing a UPS can provide a buffer against power interruptions by supplying continuous power when the main source fails. This ensures that the system remains operational during outages or fluctuations, particularly in environments where reliability is essential, such as museums. A UPS would prevent sudden shutdowns that could disrupt the functionality of the motor and sensors, maintaining consistent operation and protecting the system from potential damage caused by power loss.
- **Low-Power Components:** Selecting energy-efficient components is crucial for reducing overall power consumption. By incorporating low-power components, the system will consume less energy, which can help in several ways. Energy-efficient components reduce the strain on the power supply, leading to more stable operation and less heat generation. This contributes to the reliability of the system by lowering the risk of overheating and potential electrical failures. Additionally, using low-power components aligns with sustainability goals by minimizing energy consumption and reducing operational costs. This is especially relevant in a museum setting, where long-term cost-efficiency and environmental impact are important considerations.

5.3 Measurements of the Artwork

Problem: Accurate knowledge of the artwork's dimensions is essential for proper height adjustment.

Suggested Solution: Manual Input Options: Provide a manual input option for curators to enter dimensions if automated tools are unavailable or impractical. In addressing the challenge of accurately measuring artwork dimensions for our project, we have opted to implement manual input options as our solution. This choice is based on practical considerations that ensure flexibility and reliability in obtaining and updating the necessary dimensions for each piece of artwork. Manual input parameters provide a straightforward method for curators and museum staff to input precise dimensions directly into the system. This approach allows for immediate updates or corrections as needed, ensuring that the height adjustment mechanism can operate with accurate data at all times. By empowering staff with the ability to input measurements manually, we mitigate potential delays or inaccuracies that could arise from relying solely on automated tools or databases. Moreover, manual input options enhance the system's adaptability to various artwork types and conditions that may not be easily captured by automated measurement tools. This flexibility ensures comprehensive coverage of the museum's collection, including artworks that may have unique dimensions or irregular shapes requiring specific adjustments.

5.4 Mechanical Engineering Expertise

The problem is designing and implementing mechanisms for adjusting the height of paintings requires specialized mechanical engineering knowledge, which may not be within the expertise of the project team.

Consultation with Mechanical Engineers: Engage with mechanical engineering experts or consultants with the necessary skills and experience in designing and integrating mechanisms for height adjustment. Collaborating with these professionals will ensure that the mechanical aspects of the project, such as selecting appropriate motors and pulley systems and ensuring structural integrity, are handled effectively. The decision to seek assistance from mechanical engineers stems from recognizing that precise and reliable height adjustment mechanisms require specialized knowledge in mechanical design and engineering. This expertise is crucial for selecting and integrating components that can withstand the demands of continuous use in a museum environment while ensuring smooth and accurate adjustment of painting heights. By consulting with mechanical engineers, the project team can benefit from their technical insights and practical experience in designing mechanisms tailored to the specific requirements of the height adjustment system. This collaboration not only mitigates the risk of design flaws or mechanical failures but also enhances the overall reliability and performance of the system. Moreover, involving mechanical engineers ensures compliance with safety standards and best practices in mechanical design, thereby safeguarding against potential hazards or operational inefficiencies. Their expertise will be instrumental in optimizing the functionality and longevity of the height adjustment system, ultimately contributing to a successful implementation within the museum setting.

Suggested questions to consult a mechanical engineer supervisor:

1. Do you have an alternative solution or any improvements/changes to our selected solution?
2. Do you agree with the system components we have chosen? Especially the motors?
3. Do you think we need to use the standard battery to power supply the system or attach a cable to provide the power via a plug?
4. What do you think about the suggestion of adding a counterweight to help ease the pressure on motors while going downwards?
5. Do you have another idea instead of ropes? For example, a digitally adjustable mount stand.

6. Evaluation /Verification Plan

To ensure the system operates correctly and as intended, we will evaluate it through the following steps:

1. Execute the testing plan.
2. Have the system used by two representative users: a caregiver and a patient.

6.1 Testing Plan

A verification plan is a strategic document outlining the methods and procedures to ensure that a system meets its design specifications and requirements. It serves to identify and correct issues early, helping to deliver a reliable and functional final system [ChipVerify].

Our artwork height adjustment system is designed to meet its specifications and enhance accessibility for visitors with mobility disabilities. This plan outlines a structured approach to evaluate the system's performance, reliability, and safety before full-scale implementation.

Our verification plan encompasses three key methods, each targeting a specific aspect of the system's performance:

1. **Face-Level Detection Accuracy and Wheelchair Detection:** Our system employs advanced camera technology and computer vision algorithms to accurately detect visitors' face levels, including those using wheelchairs. To evaluate the system's accuracy, we will conduct tests with participants of varying heights and mobility statuses, ensuring that wheelchair users are specifically included in our testing process. This involves capturing each participant's face level, processing the images through our proprietary algorithm, and comparing these results against manual measurements. Additionally, we will assess the system's ability to accurately detect and account for the height of wheelchair users by analyzing how well the system adapts to different wheelchair configurations and positions. By evaluating the variance between algorithm-detected and manually measured face levels, we can quantify the system's precision for all user groups. Recent research underscores the potential of computer vision tools to enhance cultural image accessibility [20], directly supporting the objectives of our face-level detection system. This comprehensive approach ensures a thorough assessment of our system's performance, offering valuable insights for further optimization and ensuring inclusivity for all visitors.

2. **Artwork Height Adjustment Response Time**: Our system utilizes motors to adjust the height of artwork based on the detected face level of visitors. We aim to measure the response time from the initial detection to the completed adjustment across multiple attempts and scenarios involving participants of varying heights. This ensures that our system can promptly and accurately adjust the display to enhance accessibility. The significance of swift response times in interactive systems is well-documented, emphasizing that delays can greatly affect

user satisfaction and engagement. Research in performance engineering and model-based simulations highlights the necessity for quick and efficient response times, with benchmarks often aiming for adjustments to be completed within a few seconds to maintain user interest and ensure a seamless experience [SpringerLink]. Informed by industry standards and research, we work to provide a smooth and responsive experience for museum visitors with mobility, ensuring that our system meets the high expectations of modern interactive environments.

3. **Single Artwork Pilot Test:** Testing the system with a single artwork before scaling up to a full exhibition is crucial for ensuring its reliability and effectiveness. This initial small-scale testing is essential for identifying and resolving issues early, ensuring overall system effectiveness [7]. By focusing on one piece, you can fine-tune the accuracy of height adjustments, ensuring precise and intended accessibility without the complexity of managing multiple artworks. This concentrated approach facilitates easier monitoring of response times, detection of mechanical issues, and overall performance evaluation, allowing for early identification and resolution of problems. It also minimizes the risk of damaging multiple pieces or disrupting the exhibition if issues arise, providing a controlled environment for troubleshooting. Additionally, observing user interactions and system performance with one artwork yields valuable insights for refining the system before broader implementation.

6.2 Usability Evaluation by Users

To ensure the success and efficacy of the Painting Automated Height Adjustment System at The Hecht Museum, a comprehensive Evaluation and Verification Plan has been developed. This plan is designed to assess the system's effectiveness in enhancing accessibility for visitors with mobility impairments and ensuring a high-quality experience. The plan is detailed in Table 3 and includes key metrics, methodologies, and benchmarks to evaluate both the impact and performance of the system, aligned with best practices in system evaluation [26].

Objective	Metrics
Visitor Engagement	The time spent by a visitor using the system to view the painting should be at least 5 minutes to ensure that the system effectively supports visitor engagement, a key aspect of accessibility [27].
User Impact Assessment	User surveys will be conducted to evaluate the educational value of the system with questions focused on the clarity of information and learning outcomes, and feedback will be collected from museum tour guides [28]. Additionally, the System Usability Scale (SUS) score should exceed 85, indicating high user satisfaction [29].

Technical Performance	The Mean Time to Failure (MTTF) of the system should be 20 minutes to demonstrate the system's reliability over extended periods of use [30]. System load times must be under 5 minutes to maintain efficient performance. This metric aligns with Avizienis et al.'s concepts of system reliability and performance [30], which underscore the importance of dependable and secure computing.

Table 3 - Verification Plan

The Evaluation and Verification Plan for the Painting Automated Height Adjustment System at The Hecht Museum employs a structured approach to assess the system's functional effectiveness and user experience. Guided by established metrics and methodologies, the plan focuses on enhancing visitor engagement by ensuring a minimum interaction time of 5 minutes per visitor, supported by insights from Duarte et al. [27]. As recommended, user impact is evaluated through surveys and feedback, aiming for a high System Usability Scale (SUS) score [28]. Operational efficiency and reliability are monitored using statistical analysis of system performance, including Mean Time to Failure (MTTF) and load times, aligned with standards from [30,31]. This comprehensive approach not only aims to improve accessibility for visitors with mobility impairments but also underscores the system's reliability and performance within museum environments.

7. Future work and Improvents

While the current phase of our project focuses on the core functionality of adjusting artwork height for wheelchair users, there are several opportunities for future work that could significantly enhance and expand the system's capabilities:

1. **Scaling the System for Multiple Artworks**: One potential extension is to implement the IoT system across multiple paintings within a museum or gallery setting. This would involve creating a centralized maintenance and management web application, accessible only to authorized museum staff. The application would enable them to monitor and control the height adjustments of all artworks equipped with the system, ensuring that each artwork is optimized for accessibility and visitor engagement.
2. **Maintenance and Monitoring System:** The proposed web application combines real-time monitoring and visitor interaction analytics to enhance museum operations. It tracks critical system parameters such as battery levels, connectivity status, and system health to ensure preemptive maintenance and issue alerts for servicing needs, minimizing downtime. Simultaneously, the system analyzes visitor engagement with artworks using sensors or computer vision technology. This includes measuring viewing durations, visitor types (e.g., persons with mobility limitations), and response times. These insights provide valuable data for optimizing artwork placement, adjusting display heights based on visitor proximity, and highlighting popular pieces, improving overall visitor experience and system

efficiency. (See Figure 10 for a sample dashboard that displays real-time data for Artwork 1, including detection history, system stats, and engagement metrics).

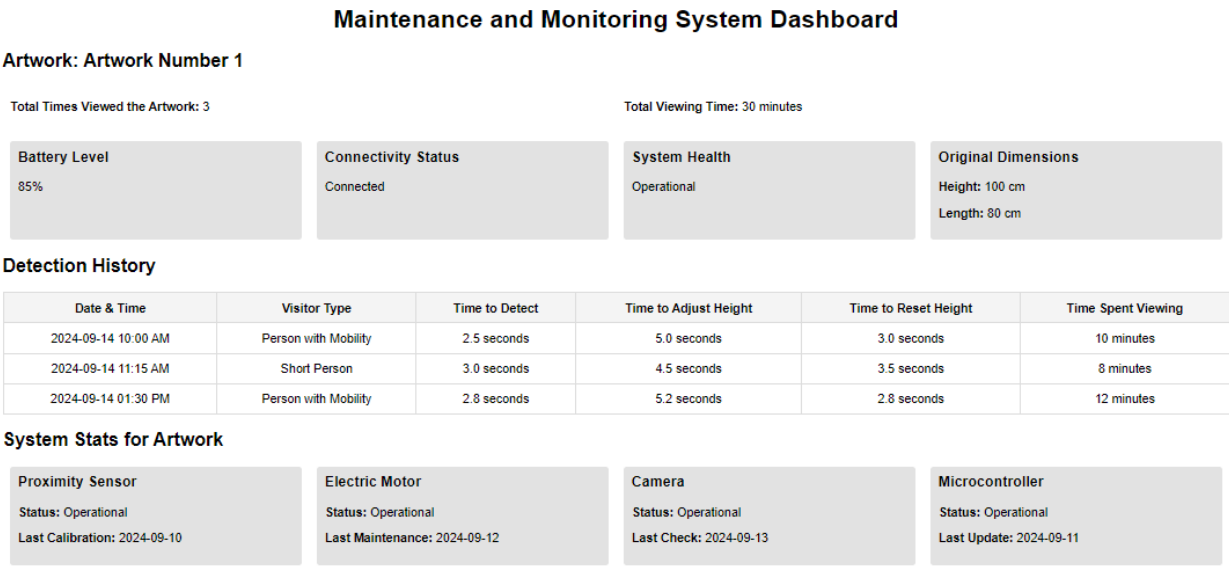

Figure 10- Maintenance and Monitoring System (fake Data for example).

3. **Adaptive Height Adjustment Based on User Feedback**: Future iterations of the system could incorporate machine learning algorithms that adjust artwork height dynamically based on user feedback or detected patterns in visitor behavior. For instance, if data shows that most wheelchair users prefer a slightly lower height for better visibility, the system could learn and adjust automatically over time, enhancing the user experience.
4. **Integration with Existing Museum Systems**: Another area for future development is integrating our IoT system with existing museum management and accessibility systems. This would create a more cohesive and streamlined user experience and allow for better coordination between different services within the museum.

By implementing these future improvements, the project could significantly elevate its impact, providing museums and galleries with a sophisticated tool to enhance accessibility, engagement, and overall visitor experience.

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