ECE 445 / ME 470

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Interactive Projection System on Arbitrary Surfaces

Team #29

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1 Introduction

1.1 Problem Statement

Mainstream smart devices still rely primarily on fixed-size screens as the medium for human-computer interaction, which imposes clear limitations on display area, multi-user collaboration, and natural input methods. Projection technology has the potential to extend interactive interfaces onto a wide range of physical surfaces in the surrounding environment. However, existing projection devices usually provide only one-way visual output and cannot support stable and direct touch interaction on surfaces that vary in shape, size, and material. Prior work has explored the integration of depth sensing and projection to enable multi-touch interaction on arbitrary surfaces. For example, Harrison [1] proposed the OmniTouch system, which used a wearable depth camera and a pico projector to provide touchscreen-like interaction on everyday surfaces such as the user's arm and a tabletop. However, such systems depend on wearable hardware, their interaction region is constrained by the user's pose and range of motion, and they cannot automatically adjust projection angle and direction according to the location of the target surface.

To address these problems, our projectdevelop an interactive projection system that integrates projection display, visual perception, depth-based touch detection, and gesture-based platform control, so that a graphical user interface can be projected onto arbitrary physical surfaces while allowing users to perform direct touch input within the projected region. The initial prototype will be validated on a flat and stable wall surface, and will then be extended to other physical surfaces such as tabletops and sheets of paper in order to evaluate the system's adaptability to arbitrary surfaces.

1.2 Solution Overview

As illustrated in Fig. 1, the system integrates projection, perception, calibration, and control into a unified interaction pipeline. A projector and a depth camera are mounted on a rotating platform. The projector displays a graphical user interface onto the target surface, while the depth camera simultaneously acquires RGB and depth images to detect the user's hand position in real time and determine whether the fingertip is touching the projected surface. The calibration and mapping subsystem uses AprilTag visual fiducial markers to establish the homography between the projector and camera, and uses geometric calibration to align the sensing coordinate system with the projected interface coordinate system, so that the system can update the coordinate mapping when the platform changes its orientation. The detected touch point is transformed into the coordinate system of the projected interface, allowing the system to support direct touch interaction and simple interactive functions on the projection surface.

The system also uses gesture recognition to control the movement and direction of the rotating platform. The system employs the YOLOv8 object detection model together with the MediaPipe hand tracking algorithm in order to improve the robustness of hand detection and the accuracy of fingertip localization. The embedded control module is based on an STM32 microcontroller and is responsible for coordinating data communication, platform actuation, and power management across the subsystems. The overall system architecture is designed from the outset with extensibility to different surfaces in mind, including variation in surface size, spatial pose, and adaptive interface layout.

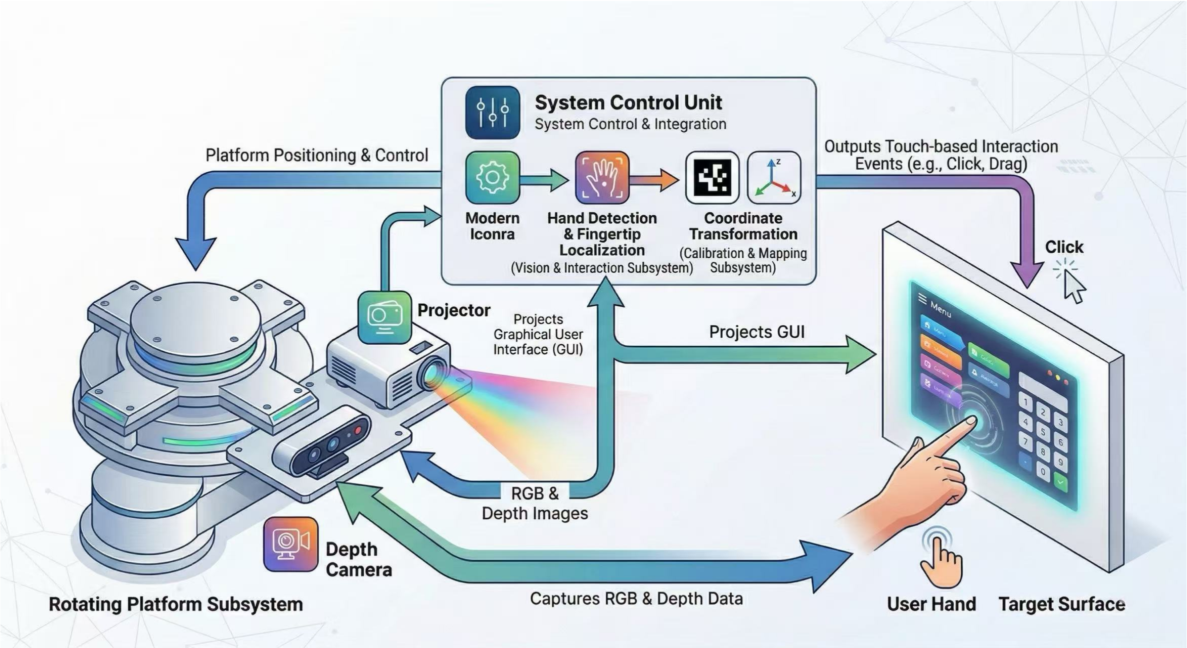

Figure 1: Overall system architecture of the interactive projection system.

1.3 High-Level Requirements

The interactive projection system shall satisfy the following high-level requirements.

1. The system shall project a stable and clearly visible interactive interface onto at least one physical surface and remain operational during demonstration.
2. The system shall detect direct touch input within the projected region and correctly trigger at least one basic interactive response on the projection surface.
3. The touch localization accuracy shall be sufficient to support basic interface operations such as region selection or simple object interaction, with mapping error not exceeding plus or minus ten projected pixels.
4. The system shall demonstrate extensibility to arbitrary surfaces by supporting interaction on at least one additional surface beyond a wall.
5. The complete prototype shall support a demonstrable application scenario with direct touch interaction on the projected interface, in order to verify that the full interaction loop from projection display to touch feedback has been successfully implemented.

2 Design

2.1 Block Diagram

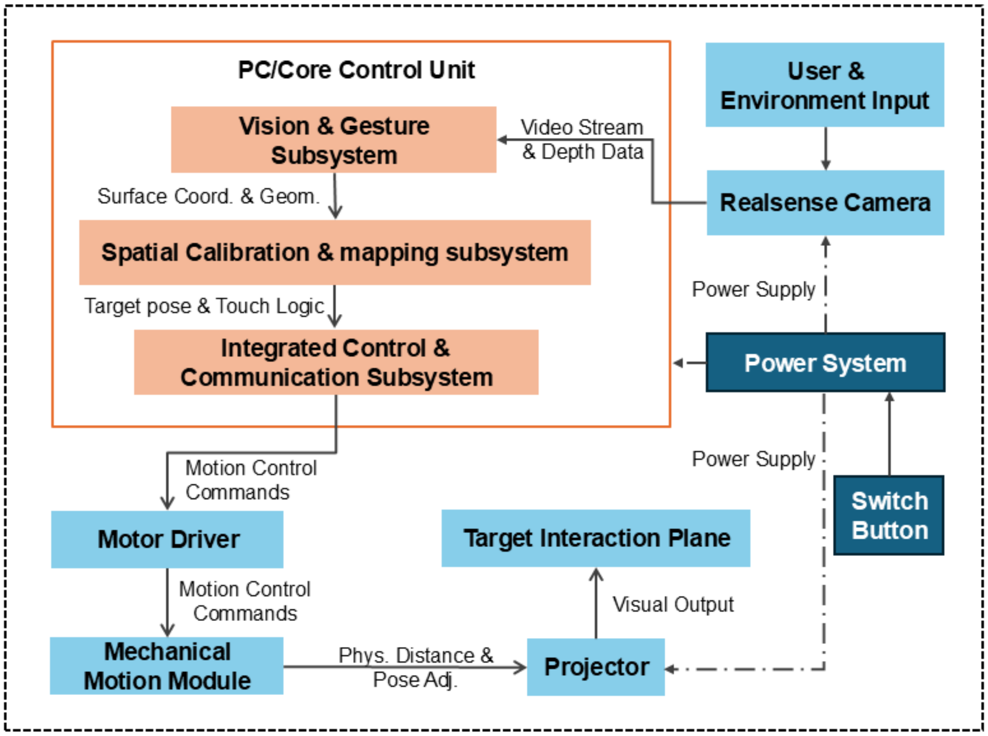

Figure 2: System Block Diagram

The system's overall architecture is illustrated in the block diagram (Figure 2). It demonstrates the complete data and control flow from environmental perception to physical execution. The system consists of the following primary modules:

- **User & Environment Input**: Real-world interaction planes and user gestures are captured by the RealSense camera, which transmits video and depth streams to the PC/Core Control Unit.
- **PC/Core Control Unit**: This acts as the central processing hub, comprising the Vision & Gesture Subsystem, Spatial Calibration & Mapping Subsystem, and Integrated Control & Communication Subsystem. It processes surface geometry, calculates touch logic, and issues motion commands.
- **Output Execution**: The Motor Driver receives motion control commands and actuates the Mechanical Motion Module. This adjusts the physical distance and pose of the Projector, casting the visual output onto the Target Interaction Plane.
- **Power System**: Provides stable power supply to the RealSense camera, core control unit, and the switch button to ensure reliable operation across all subsystems.

2.2 Vision & Interaction Subsystem

This subsystem is responsible for real-time environment perception, hand gesture capture, and transforming gesture commands into Pan-Tilt-Zoom motion control and touchscreen operations.

2.2.1 Hardware Support

The visual sensing unit utilizes a RealSense depth camera. It employs depth maps to filter background noise and accurately calculate the physical distance between the finger and the projection plane.

- **Requirement 1**: The camera must maintain a stable 30 FPS depth stream output at 640×480 resolution to ensure the PTZ response has no perceptible latency.
- **Requirement 2**: The PC processing unit must support the concurrent execution of YOLOv8 detection and MediaPipe 21-landmark extraction.

2.2.2 Hand Detection & PTZ Control

The system controls the Yaw and Pitch of the projector's PTZ mount through gesture recognition to achieve position adjustment of the projected image.

Requirements	**Verification**
1. High PTZ control sensitivity.	1. Drive PTZ rotation via hand movement; calculate the fit between instructions and encoder feedback data.
2. Short response time from gesture initiation to PTZ startup.	2. Use a high-speed camera to record the frame difference between the start of the hand gesture and the physical rotation of the PTZ.

2.2.3 Virtual Touch Mapping & Interaction

The system defines the projection surface as a "virtual touchscreen". By calculating the Z-axis depth of the index fingertip (Landmark 8) in space, a "touch" event is triggered when the distance to the projection plane is less than a threshold d.

- **Coordinate Transformation**: Use a Homography matrix (H) to map the finger pixel coordinates detected by the camera to the logical coordinate system of the projection plane.
- **Interaction Logic**:
  - **Opening Files**: Maintain the "touch" state with the fingertip at the target icon location.

  - **Keyboard Input**: Divide the projected virtual keyboard area into a coordinate grid; a character input is triggered when the fingertip lands within a specific grid cell.

Requirements	Verification
1. Small click offset error on the projection plane.	1. Click a designated bullseye on the projected screen; record the Euclidean distance between the actual trigger coordinates and the target.
2. Low depth misjudgment rate.	2. Conduct 50 near-distance waving tests; record the number of unintended click triggers.

2.2.4 Gesture Recognition Logic

The system distinguishes between **Adjustment Mode** and **Interaction Mode** based on hand shape features:

- **PTZ Adjustment Mode**: When a “five-finger open” or specific grip gesture is detected, the PTZ moves in sync with the hand.
- **Touch Mode**: When a “single index finger extended” gesture is detected, the system enters high-precision fingertip tracking to simulate touch clicks.

Requirements	Verification
1. High accuracy in interaction state switching.	1. Continuously switch between “PTZ Control” and “Virtual Typing” 50 times each; calculate the recognition accuracy.
2. Shield the impact of intense lighting changes on the projection plane from fingertip localization.	2. Perform touch operations on a projection surface playing high-contrast dynamic video; observe fingertip jitter.

2.3 Robotic Arm & Projection Subsystem

This subsystem acts as the physical execution unit, responsible for bridging the digital interface with the physical environment. By integrating spatial perception algorithms with mechanical kinematics, it enables the system to autonomously project a calibrated interface onto arbitrary surfaces with customizable dimensions.

2.3.1 Target Surface Recognition and Autonomous Alignment

To achieve projection on arbitrary surfaces, the system first employs the YOLOv8 object detection model to identify potential projection targets (e.g., a blank canvas, a desktop, or a piece of paper) within the RGB stream. Once the bounding box of the target surface is locked, the system extracts the corresponding 3D point cloud from the RealSense depth data to compute the surface's centroid and normal vector. The core control unit then calculates the inverse kinematics to drive the mechanical motion module, adjusting its pitch and yaw to align the projector's optical axis as orthogonally to the target surface as possible, thereby minimizing severe optical distortion at the hardware level.

2.3.2 Dynamic Scale Control for Arbitrary Projection Sizes

To project an interface of any desired size onto a target canvas, the system dynamically controls the throw distance. The optical projection size is strictly proportional to the physical distance between the projector lens and the target surface. When a user defines a target UI size, the system calculates the required throw distance using the projector's intrinsic throw ratio. The mechanical base or robotic arm then translates along the Z-axis (depth axis) to reach this specific distance. Finally, digital scaling and cropping are applied at the software level for fine-tuning, ensuring the projected image perfectly fits the user's size requirements.

2.3.3 Arbitrary Surface Adaptation and Distortion Correction

Not all physical surfaces are perfectly flat or orthogonal to the projector. When projecting onto complex or tilted arbitrary surfaces, the depth camera continuously maps the surface topography. If the surface is planar but tilted, the system applies an automatic keystone correction using the depth gradient. For slightly irregular surfaces, the visual processing unit utilizes the 3D depth map to generate a pre-distortion mesh. This digital pre-distortion inversely warps the output image so that, when cast onto the physical surface, the final UI appears visually flat and geometrically correct to the user's eye.

Requirements	**Verification**
1. Autonomous alignment accuracy: The mechanical module shall align the projector's optical axis with the target surface normal within an angular error of $\leq 5^\circ$.	1. Place a target canvas at various angles. Trigger autonomous alignment. Measure the final angle between the projection axis and the surface normal using an external digital inclinometer.
2. Dynamic scale control accuracy: The system shall be able to automatically adjust the physical distance to project a UI of a specified size with a dimensional error of $\leq \pm 5$ mm.	2. Input a target projection width of 200 mm and 400 mm respectively. After the mechanical module completes adjustment, measure the actual projected UI width with a caliper.
3. Adaptive correction response: The system shall complete surface recognition, pose calculation, and digital pre-distortion matrix updating within 500 ms when the target surface changes.	3. Switch the projection target from a wall to a tilted desk. Record the elapsed time from the frame of the scene change to the frame where the corrected UI is fully rendered.

2.4 Calibration and Mapping Subsystem

The Calibration and Mapping Subsystem is a core component of the interactive projection system. Its function is to establish a unified coordinate reference framework among the projector, depth camera, and rotating platform. This subsystem takes as input the RGB and depth images produced by the depth camera, together with the platform pose information used for projection adjustment. After spatial calibration, coordinate transformation, and touch detection, it outputs the touch position of the user's fingertip in the projected interface coordinate system, together with the corresponding interaction event type. The overall process forms a complete pipeline from physical-space sensing to interface event generation. This subsystem consists of three main modules, namely projector-camera homography calibration, platform pose registration, and touch localization and coordinate mapping.

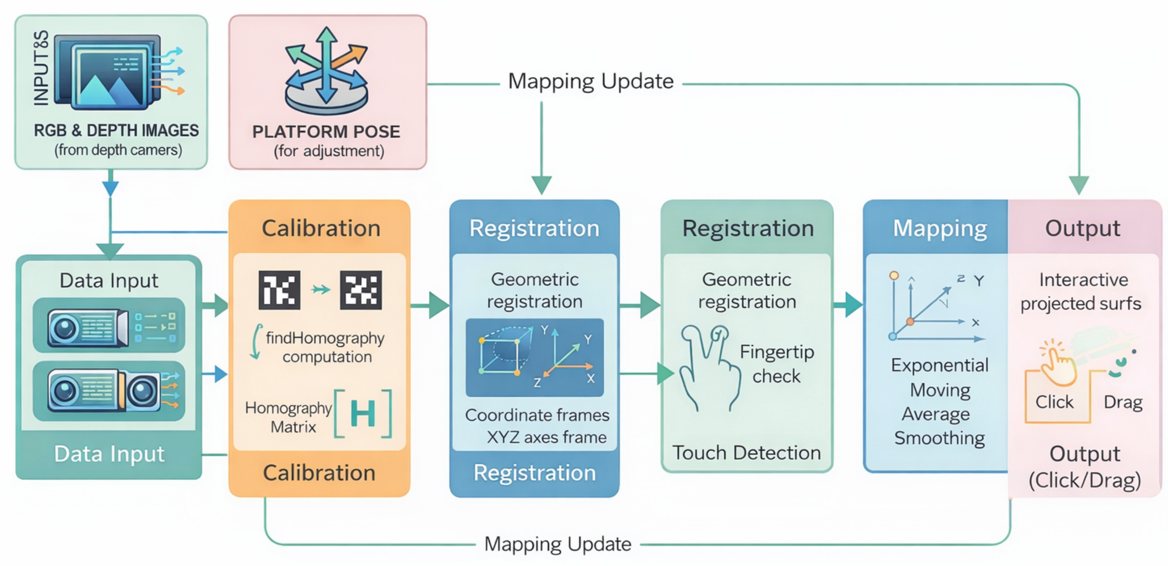

Figure 3: Pipeline of Calibration and Mapping Subsystem.

2.4.1 Projector-Camera Homography Calibration

This module is used to align the projector pixel coordinates with the image pixel coordinates captured by the camera. Since the projector and the camera observe the same target surface from different positions and viewing angles, their coordinate systems cannot be directly matched. Therefore, a geometric mapping must be established between them.

In this design, AprilTags are used as the calibration medium to provide stable and consistent corner detection. During calibration, the projector displays a pattern containing multiple AprilTags onto the target surface, while the camera captures the projected image. The system extracts the corresponding corner points in both the projector coordinate frame and the camera image frame, and then computes the homography matrix H using the OpenCV `findHomography` function. This matrix maps pixel locations from the camera image to their corresponding positions in the projected interface. To ensure robustness, the system enforces a consistent ordering of detected corners and supports recalibration when necessary.

Requirements	**Verification**
1. Coordinate mapping error after calibration shall be $\leq \pm 5$ projected pixels.	Place 10 known test points on the projection surface; compute RMS error between mapped and expected positions.
2. AprilTag calibration shall complete within 5 seconds.	Measure elapsed time from projection start to calibration success; average over 10 trials.
3. Calibration shall remain stable for 30 minutes under fixed setup.	Evaluate mapping error every 5 minutes over 30 minutes; ensure deviation does not exceed 2× initial error.

Figure 4: An Image of Projector

2.4.2 Platform Pose Registration

The Platform Pose Registration module addresses the problem of maintaining correct coordinate mapping when the projector and depth camera change their orientation together with the rotating platform. Because the platform may move upward, downward, or change direction during interaction, the spatial relationship between the sensing system and the target surface may also change. As a result, the system must be able to update the coordinate mapping after platform motion without repeating the entire calibration procedure.

This system uses geometric registration to maintain the relationship between the camera coordinate frame, the projector coordinate frame, and the current platform pose. Specifically, the system combines the calibrated projector-camera relationship with the platform orientation information and updates the projection geometry accordingly. During operation, when the platform changes its position or direction under gesture control, the system updates the corresponding mapping so that the projected interface remains spatially consistent. This design improves both system continuity and real-time performance.

Requirements	**Verification**
1. Platform pose registration error shall be ≤ 5 mm equivalent at the projection surface.	Measure projected reference points before and after platform adjustment and compare the resulting spatial deviation using external measurement.
2. Coordinate update latency after platform motion shall be ≤ 200 ms.	Record time from platform stop to updated coordinate output; average over 20 trials.
3. Pose registration update shall complete within 30 seconds during reconfiguration.	Measure total time from platform adjustment to updated registration output.

2.4.3 Touch Localization and Coordinate Mapping

The Touch Localization and Coordinate Mapping module is responsible for converting the user's physical touch on the target surface into an interaction event in the projected interface. This module takes as input the aligned RGB and depth images together with the homography matrix H provided by the calibration module, and outputs the touch location in projector coordinates as well as the corresponding interaction event type. Depth information is used as the basis for touch detection in order to support direct surface interaction.

During operation, the system first extracts the reference depth of the target surface from the calibrated projection region. MediaPipe is then used to detect hand landmarks in real time from the RGB image, and the fingertip of the index finger is selected as the touch candidate. The system queries the depth value at that location and compares it with the surface reference depth. When the depth difference is smaller than a predefined threshold, the system determines that a valid touch has occurred. The detected point is then mapped into the projector coordinate system using the homography matrix. To improve interaction stability, the mapped coordinates are smoothed using an exponential moving average filter, and simple touch-based interaction events are identified based on the temporal change of the touch state.

Requirements	**Verification**
1. Touch localization error shall be $\leq \pm 10$ projected pixels.	Perform 50 touches on known UI targets; measure pixel deviation from target centers.
2. Touch detection latency shall be ≤ 100 ms.	Use a high-speed camera to measure delay from contact to system response.
3. Touch interaction recognition accuracy shall be $\geq 90\%$.	Perform 100 touch interaction trials; compute correct detection ratio.
4. Hover false trigger rate shall be $\leq 5\%$.	Hold finger 3–5 cm above the surface for 30 seconds; record unintended triggers.

Figure 5: An Image of Depth Camera.

2.5 Control & Integration System

The Control and Integration System is responsible for coordinating data flow and control signals among the perception, calibration, and actuation subsystems. Unlike the previous modules that focus on sensing and computation, this subsystem provides the execution framework that connects high-level interaction logic with physical system response.

2.5.1 System Coordination Architecture

The system adopts a hierarchical control architecture that separates high-level processing from low-level execution. The PC-based unit performs gesture recognition, spatial mapping, and interaction decision-making, and generates control commands based on the computed results. These commands are transmitted to the embedded control unit, which interprets them and generates control signals for the actuation subsystem.

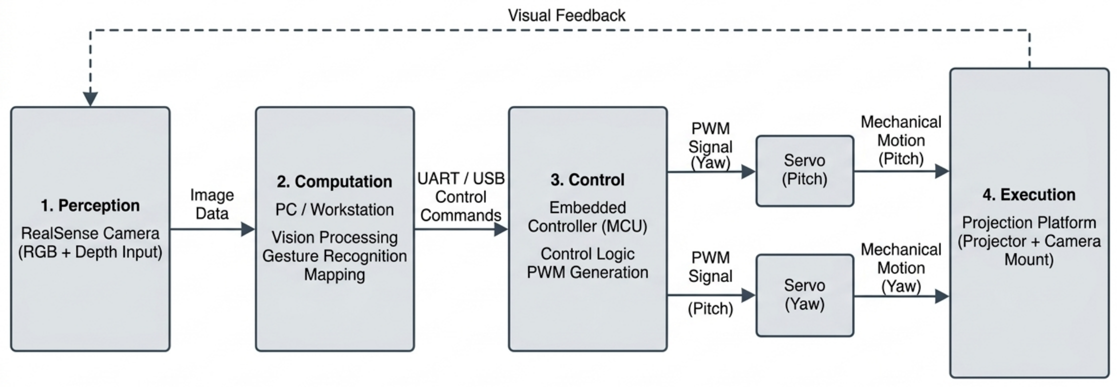

Figure 6: System-level control and integration architecture showing the data flow from perception to actuation and the corresponding feedback loop.

As shown in Fig. 6, the system consists of four main stages: perception, computation, control, and execution. The perception module captures real-time image data, which is processed on the PC for gesture recognition and spatial mapping. Control commands are then transmitted to the embedded controller, which generates PWM signals to drive the servo motors for pitch and yaw adjustment of the projection platform.

This design enables modular operation while maintaining coordinated behavior across subsystems. The architecture also highlights the separation between high-level computation and low-level control, improving system modularity and scalability.

Requirements	**Verification**
1. The system shall complete a full control loop from gesture detection to actuation output without interruption.	Perform continuous interaction for at least 5 minutes, including cursor movement and triggering actions; verify that no control interruption occurs.
2. Command transmission between PC and embedded controller shall achieve a success rate of at least 99%.	Send 1000 consecutive commands under normal operation; record the number of correctly received and executed commands.
3. The system shall maintain correct execution order of control commands.	Transmit ordered commands with sequence identifiers and verify that execution order matches transmission order.

2.5.2 Embedded Control and Hardware Implementation

The embedded control unit is implemented using a microcontroller-based system integrated on a custom-designed PCB. This PCB serves as the hardware interface for communication, control signal generation, and power distribution.

The design includes control logic, actuation interfaces, power regulation circuits, communication ports, and debugging interfaces. Special consideration is given to power stability and signal integrity to ensure reliable operation.

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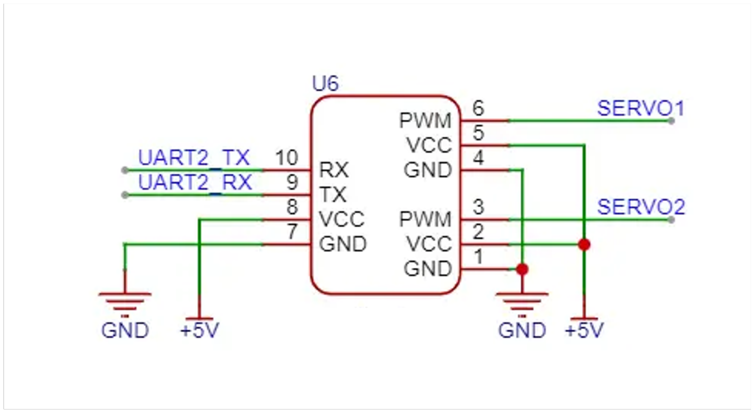

Figure 7: Control circuit for servo-based actuation subsystem. The MCU generates PWM signals to drive two servo motors for pitch and yaw motion.

The actuation subsystem is implemented using high-torque servo motors (MG996R in the current prototype), driven by PWM signals from the embedded controller. A regulated 5V supply is provided to ensure stable operation of the servo motors.

Figure 8: High-torque servo motor (MG996R) used for pitch and yaw actuation in the projection platform

Requirements	Verification
1. The embedded control unit shall operate continuously without unexpected reset or system failure.	Run the system continuously for at least 30 minutes and monitor for abnormal reset or system interruption.
2. The power supply shall maintain stable voltage under load conditions.	Measure voltage at key power nodes under operation; ensure voltage variation is within $\pm 5\%$.
3. The communication interface shall maintain stable data transmission.	Transmit continuous data packets for at least 5 minutes; record communication errors or packet loss.

2.5.3 Communication and Real-Time Coordination

A structured communication mechanism is used to transmit control commands and system states between the PC and the embedded controller. The communication protocol is designed to be lightweight and reliable, ensuring effective command delivery.

The overall interaction loop consists of perception, decision-making, communication, and actuation. The system prioritizes responsiveness by minimizing unnecessary processing overhead and ensuring efficient coordination among subsystems.

Requirements	Verification
1. The system shall maintain responsive interaction during operation.	Perform continuous interaction tasks; measure delay between user action and system response; ensure average delay is below 100 ms.
2. Communication reliability shall be maintained under continuous operation.	Send at least 1000 consecutive commands; verify that the error rate remains below 1%.
3. The system shall maintain stable performance under varying conditions.	Test under different lighting conditions and platform orientations; verify that interaction performance does not degrade significantly.
4. The system shall support continuous operation without noticeable lag.	Operate the system continuously for at least 10 minutes with frequent interactions; observe whether any lag accumulation occurs.

2.6 Tolerance Analysis

The performance of the interactive projection system is influenced by various sources of error arising from mechanical, sensing, calibration, and control subsystems. This section analyzes how these uncertainties affect system accuracy and evaluates the system's tolerance to such variations.

2.6.1 Mechanical Tolerance

Mechanical inaccuracies in the rotating platform, including angular deviation and structural misalignment, may lead to displacement of the projected interface on the target surface. Even small angular errors can result in noticeable shifts in projection position, especially at larger projection distances.

To mitigate this effect, the system incorporates continuous calibration and mapping updates, which compensate for minor mechanical deviations during operation.

2.6.2 Calibration Tolerance

Errors in projector-camera calibration may arise from imperfect detection of calibration markers and numerical approximation in homography estimation. These errors directly affect the mapping accuracy between camera coordinates and projector coordinates.

The system tolerates small calibration deviations by applying smoothing techniques and allowing periodic recalibration when necessary.

2.6.3 Sensing and Interaction Tolerance

Uncertainty in fingertip localization and depth measurement introduces variability in touch detection. Noise in depth sensing and slight hand motion can cause fluctuations in detected touch positions.

To reduce the impact of these variations, the system applies filtering methods to stabilize the interaction point and uses threshold-based detection to avoid false triggering.

2.6.4 Control and Communication Tolerance

Delays and uncertainties in command transmission and execution may affect system responsiveness. Communication latency and timing mismatch between subsystems can lead to slight delays in actuation.

The system is designed to tolerate moderate delays by ensuring that control commands are processed efficiently and that interaction feedback remains consistent under typical operating conditions.

2.6.5 Overall System Tolerance

By combining calibration, filtering, and coordinated control strategies, the system maintains acceptable interaction performance despite the presence of multiple sources of uncertainty. The overall design emphasizes robustness, allowing the system to operate reliably under realistic conditions where perfect accuracy cannot be guaranteed.

3 Cost and Schedule

3.1 Cost Analysis

Part	**Cost (RMB)**
RealSense depth camera	450
Portable projector	400
Two PTZ servos	300
STM32 control board and PCB components	180
Power supply and voltage regulation modules	100

Table 1: Estimated cost

The cost shown in Table 1 represents the estimated hardware expense of the prototype system. The major cost is concentrated in the RealSense depth camera, the portable projector, and the PTZ servos, since these components directly support RGB-D sensing, interface projection, and platform motion control. The remaining cost is associated with the STM32 control board, PCB components, and power modules required for system integration.

Since this project is intended for prototype validation rather than product deployment, the listed cost reflects the minimum set of hardware needed to demonstrate the complete interaction loop. In future iterations, the total cost may be reduced through component substitution or more integrated hardware design.

3.2 Schedule

Week	**Jie Xu**	**Zibo Dai**	**Yuqi Tang**	**Jing Weng**
3/30–4/5	Set up Ultralytics environment; research YOLOv8 efficiency on RealSense.	Determine PTZ motor models; design projector PTZ bracket.	Research calibration algorithms; derive Homography Matrix H.	Determine STM32F103ZET6 master and protocols (UART/CAN).
4/6–4/12	Integrate YOLO v8 and Media Pipe; implement hand/fingertip tracking.	3D printing and assembly of PTZ bracket; install motors and drivers.	Develop QR-based auto-calibration; achieve coordinate transformation.	Design power management; ensure stable supply for motors and circuits.
4/13–4/19	Develop gesture recognition for PTZ control.	Write PTZ PID control code; implement angle adjustment logic.	Develop touch logic using Z-axis depth to detect surface contact.	Write motor drivers; establish UART link between PC and PTZ system.
4/20–4/26	Optimize vision algorithm latency.	Test PTZ deadzone; verify gesture-to-angle mapping.	Develop virtual keyboard with grid-based input.	Complete PCB soldering and debugging; perform signal tuning.
4/27–5/3	Improve accuracy under environmental interference.	Perform safety analysis; optimize image stabilization during rotation.	Test click offset and double-click success rate.	Integrate code and achieve full interaction loop.
5/4–5/17	Prepare demonstration application scenarios.	Draft mechanical structure and safety sections of final document.	Organize calibration data; prepare final acceptance report.	Prepare final presentation.

4 Discussion of Ethics and Safety

4.1 Ethical Considerations

This project follows the principles outlined in the IEEE Code of Ethics and the ACM Code of Ethics [2][3], with particular attention to public welfare, privacy protection, honest representation of system capabilities, and responsible use of computing technologies.

Alignment with Professional Ethical Codes. The IEEE Code of Ethics emphasizes prioritizing the safety, health, and welfare of the public, as well as protecting privacy and being honest about system performance [2]. Similarly, the ACM Code of Ethics requires computing professionals to avoid harm, respect privacy, and provide transparent and accurate descriptions of system behavior [3]. These principles are directly relevant to this project, which involves real-time sensing, projection, and human interaction in physical environments. The system is therefore designed to minimize unintended risks and avoid misleading users about its capabilities.

Privacy and Data Handling. The system uses vision-based sensing to detect surfaces and user interactions, which may unintentionally capture information about users or their surroundings. To address this concern, data collection is strictly limited to what is necessary for surface detection and touch localization. The sensing region is constrained to the interaction area whenever possible to avoid capturing irrelevant environmental information. Data is processed primarily in real time and is not persistently stored unless required for calibration or performance evaluation. Any recorded data is used solely for system development purposes and is not used for identity recognition, behavioral analysis, or any secondary application. These measures align with the principle of minimizing data collection and protecting user privacy [3].

Honesty and Transparency of System Capabilities. Both IEEE and ACM ethical guidelines emphasize the importance of honesty and transparency in technical work [2][3]. Although the goal of this project is to enable interaction on arbitrary surfaces, the current implementation is a prototype and does not guarantee consistent performance across all surface types, lighting conditions, or geometries. Therefore, the system will not be presented as universally robust. Known limitations, such as sensitivity to lighting variation, surface reflectivity, and calibration error, will be clearly communicated during demonstrations. In addition, the system is not intended for safety-critical or decision-critical applications. This ensures that users are not misled by overstated claims.

Responsible Use and Misuse Prevention. The system is designed for low-risk interactive applications such as projected user interfaces and demonstration scenarios. However, misuse may occur if the system is applied in inappropriate contexts. To mitigate this, the system is restricted to controlled environments during testing and demonstration. It is not intended for use in security-sensitive, financial, medical, or industrial control applications. Furthermore, users should not rely on the system in situations where incorrect interaction recognition could lead to significant consequences.

Use in Shared Physical Spaces. Since the system projects interactive content onto real-world surfaces, it may affect shared environments. To ensure responsible use, projection and interaction are limited to authorized surfaces and controlled spaces. The system will not be used to overlay information onto private or sensitive surfaces without permission. Demonstrations and testing are conducted in a manner that avoids disrupting others in the surrounding environment. This reflects the ethical responsibility to respect others and minimize unintended impact in shared spaces.

4.2 Safety Considerations

This project is a low-voltage, indoor interactive system involving projection, sensing, and embedded control. The primary safety considerations arise from electrical components, optical exposure from the projector, mechanical setup, and operational procedures during testing and demonstration. The system is designed to minimize risk through careful hardware selection, stable installation, and controlled usage.

Electrical Safety. The system operates using low-voltage electronics powered by standard regulated power supplies and manufacturer-provided adapters. All wiring is insulated and connections are secured to prevent accidental short circuits or loose contacts. Power is disconnected before any rewiring or hardware adjustments are performed. During extended operation, components such as the projector and control hardware are monitored to ensure that temperature remains within safe operating limits. No exposed conductive elements are present in the user interaction area.

Optical and Projection Safety. The projector is positioned such that its primary light beam does not directly enter the user's eyes during normal operation. Brightness is adjusted to ensure sufficient visibility while avoiding excessive glare. Users are instructed not to look directly into the projector lens. When testing on reflective or glossy surfaces, additional care is taken to avoid unintended reflections toward users. If depth or vision sensors with active illumination are used, they are operated within manufacturer-specified conditions to ensure safe exposure levels.

Mechanical and Setup Safety. All hardware components, including the projector, sensing module, and control system, are mounted on stable support structures to maintain consistent geometry during operation. Mechanical fixtures such as stands or clamps are checked and secured prior to calibration and demonstration. The system is first tested on stable, flat surfaces before being extended to other objects. Cables are routed and secured to prevent tripping hazards or accidental disconnection. If the physical configuration of the system is disturbed, recalibration is required before further operation.

Operational Safety and Testing Procedure. The system is developed and tested in a staged manner, beginning with controlled validation on a wall and then extending to additional surfaces such as desks or paper. Before each demonstration, a basic checklist is followed, including verification of power connections, system alignment, calibration accuracy, and cable placement. During operation, the system can be manually paused or reset if tracking becomes unstable or unexpected behavior occurs. All testing and demonstrations are conducted in supervised indoor environments, and the prototype is not deployed in crowded or uncontrolled public settings.

References

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[2] IEEE. "Ieee code of ethics." Accessed: 2026-04-01. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.

[3] Association for Computing Machinery (ACM). "Acm code of ethics and professional conduct." Accessed: 2026-04-01. [Online]. Available: https://www.acm.org/code-of-ethics.