Robotic Arm for Handheld Device Reading - Head Up

University of Toronto
Department of Electrical and Computer Engineering

ECE496 Design Project Proposal

Project ID: 2025143
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Executive Summary

With the widespread integration of smartphones into daily life, users increasingly operate their devices while sitting or reclining on sofas and other relaxed seating. Devices are typically held at lap or chest level for a long duration of time, resulting in severe neck strain known as the “tech neck”. Existing ergonomic solutions, such as static stands, neck-mounted holders, and posture reminder software applications, have achieved limited success in usability. They either restrict movement, cause discomfort during extended use, or require users’ constant effort of holding the device. Consequently, there remains a need for a dynamic, user adaptive solution that can maintain a healthy viewing posture during casual, sofa-based smartphone use.

This proposal introduces Head Up, an intelligent, sofa-based smartphone support system designed to hold smartphones to eye level and dynamically maintain a healthy viewing position. The proposed system integrates a four-degree of freedom (4-DOF) robotic arm with a weighted base for stability, a secure phone clamp, and an embedded camera that tracks the user’s head posture. Using this input, the arm adjusts the screen angle (-20° to +10°) and distance (25-40 cm distance) to maintain ergonomic alignment.

The system also incorporates a wireless handheld controller equipped with a touchpad and a set of control buttons. The controller serves two parallel functions: (1) to enable intuitive interaction with the user’s smartphone (e.g., cursor movement, scrolling, and selection), and (2) to providing a manual override mode for direct control of the robotic arm (e.g., lock/unlock position, auto-align/manual mode, and position control).

The design targets low-latency (< 100 ms) and high-accuracy (≥ 98%) wireless communication within an indoor range of 10 m, supporting both Android and IOS devices. Upon completion, Head Up will deliver a functional prototype that demonstrates real-time, posture adaptive control and improved comfort for sofa-based smartphone use.

1. Introduction

This proposal presents the design and development plan for our project “Head Up,” a smart robotic arm with a remote control system aimed at reducing neck strain during sofa-based smartphone use. This proposal starts with introducing the background and motivation that led to this project, then outlines the problem statement and project goal, followed by a detailed requirements specification that includes core functions, objectives, and constraints. It also includes a system block diagram to illustrate the system’s architecture, with a risk assessment that identifies potential challenges and mitigation strategies. The proposal concludes with a summary of the project’s anticipated contributions and impact.

2. Background and Motivation

Smartphone use has become deeply integrated into everyday life, with people often spending several hours each day on their devices, especially while sitting on a sofa or couch, and holding their phones at lap or chest level. This positions the screen below the eye height and causes the neck to flex forward into what is commonly referred to as forward head posture, or “tech neck.” Research in ergonomics has shown that “the weight seen by the spine dramatically increases when flexing the head forward”[1]. “An adult head weighs about 10 to 12 pounds in a neutral position but can place forces of up to 60 pounds on the neck as the tilt angle of the neck increases”[1]. When sitting on a sofa or couch, people often remain in this forward-tilted position for extended periods. Spending prolonged periods like this is strongly associated with discomfort and chronic neck pain.

There are some products in the market designed to help address the posture issue, such as static phone stands, neck-mounted holders and posture-monitoring apps. However, these products have not been widely adopted for sofa use. Static stands can effectively elevate the phone to eye level, but they require the user to remain in a fixed position, which is unrealistic when people naturally recline, shift, or stretch while sitting on a couch. Neck-mounted holders can also reduce strain by bringing the phone closer to eye level, but they are uncomfortable when used for a long period of time and often too bulky for casual settings. Posture-monitoring apps encourage awareness of poor posture, but they only provide reminders and cannot physically adjust the viewing angle to correct it in real time.

The limitation of these approaches is that they are either too inflexible or too inconvenient for people who want to use their phones comfortably while relaxing on a sofa. What is needed instead is an adaptive and user-friendly solution that can maintain a neck-friendly viewing angle without requiring constant effort from the user. Such a system would fill the gap between passive tools, which only provide limited or static support, and the need for a dynamic, posture-friendly option that adapts to casual phone use while sitting on a sofa or couch.

3. Problem Statement

Sofa-based smartphone viewing frequently induces excessive cervical flexion; prevailing solutions lack active repositioning. We introduce Head Up, a cross-platform, wireless support that maintains eye-level alignment to mitigate postural load.

4. Project Goal

The goal of this project is to create a posture-friendly solution that reduces neck strain by enabling more comfortable and sustained smartphone use while sitting on a sofa or couch.

5. Requirements Specification

Requirements Specification defines what our design must do for the primary purpose, and what should do. Beyond functional expectations, this section also includes the external limitations that the design must be met.

5.1 Requirements

The following Table 1 is specifying what the design must achieve to be considered as a possible solution. Detailed justification for each requirement can be found in **AppendixB.**

Table 1. Requirement Specifications for Head Up

ID	Specification	Description
Hardware Functionality Side		
REQ-1	Remote smartphone control: cursor, click, scroll	The design shall provide remote interaction with the paired smartphone.
REQ-2	Range 10m[2]	The system shall provide reliable wireless connection between controller and mobile device as well as controller and robotic arm within normal indoor range.
REQ-3	Robotic arm adjustment: 4 degrees of freedom [Justification in appendixB]	The system shall support flexible positioning of the mounted smartphone.
REQ-4	Stable load support: standard smartphone mass (0~300 g) [3]	The system shall hold and support a smartphone securely without tipping or instability.

Software Functionality Side		
REQ-5	Manual override: directional control(up, down, left, right) and lock, unlock functionality	The design shall provide a manual control interface that allows the user to directly control the robotic arm's movements.
REQ-6	Auto-align Angles: 20° below horizontal to 10° above horizontal [4] [5] [6] Distance: 25~40 cm [7] [8]	The system shall adjust the holder so that the screen remains aligned with the user's ergonomic viewing position.
REQ-7	Command processing latency ≤ 100 ms [9]	The system shall process and transmit control inputs from the handheld controller to the main processor within ≤ 100 ms, ensuring that the overall user interaction feels instantaneous under normal operating conditions.
REQ-8	Mechanical response latency ≤ 20 ms [10][11][12]	The robotic arm shall initiate and visibly begin movement within ≤ 20 ms after a valid actuation command is issued.
REQ-9	Command accuracy: = 98% [13]	The system must correctly interpret and execute user commands.
REQ-10	Mode switching capability	The system shall allow users to switch between automatic alignment mode and manual control mode.

5.2 Objectives

In this subsection, Table 2 presents the objectives of our project, which describe the desirable qualities that the design should ideally achieve, and each is paired with a method of measurement to indicate how success can be evaluated.

Table 2. Objectives with metrics for Head Up

ID	Specification	Description
OBJ-1	Command accuracy: > 98 % correctness [REQ-9]	Optimize beyond baseline requirement [REQ-9] for reliability.
OBJ-2	Responsive interactions: minimize latency [REQ-7, REQ-8]	Optimize latency to achieve a smoother response.

5.3 Constraints

Table 3 outlines the constraints that apply to our project. These constraints are external factors that the system must comply with, including safety, environment, and platform compatibility.

Table 3. Constraints of Head Up

ID	Specification	Description
CON-1	Compliance with consumer electronics safety standards	Must meet regulations for overheating, battery safety
CON-2	Compatibility with Android and IOS	Must support standard mobile platforms
CON-3	Use approved and legal wireless standards	Must use safe, certified communication methods
CON-4	Safe physical operation: no unintended contact with user	Must avoid collision with the user and couch during normal operation.

6. System Block Diagram

The system block diagram Figure 1, presents the architecture of Head Up and how subsystems of hardware, middleware, and software combine to fulfill the requirements of this sofa based smartphone ergonomics.

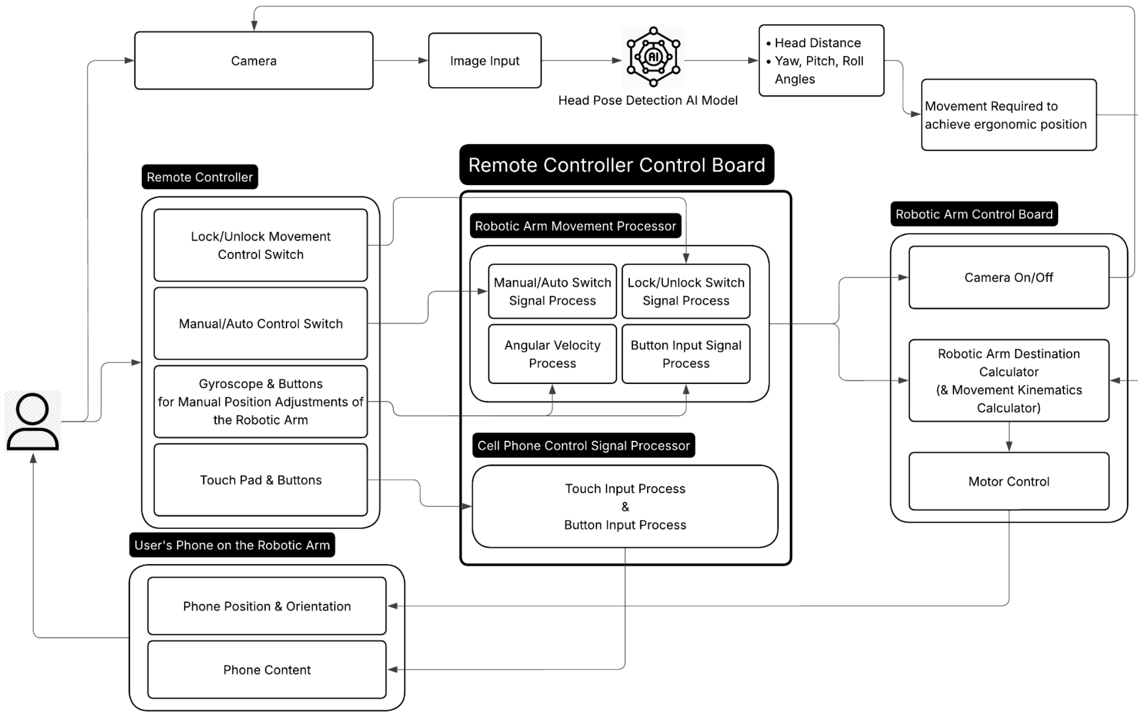


Figure 1. System Block Diagram of HeadsUp

The robotic arm offers four degrees of freedom (REQ-3) to accommodate flexible positioning of the smartphone, while maintaining stable support of the load up to 300 g (REQ-4). Wireless modules ensure stable indoor communication of the remote controller, the robotic arm, and the smartphone (REQ-2, CON-3).

The AI subsystem takes webcam input to recognize the head position of the user (REQ-6, OBJ-1), and the system aligns automatically within ranges of ergonomics of -20° to +10° tilt and 25-40 cm distance (REQ-6). This system works together to achieve low latency and accurate commands.

The remote controller allows the manual interaction with a smartphone and controlling position such that the system can be used even without posture detection by the AI (REQ-5, REQ-10). The modules collectively fulfill the requirements (CON-1, CON-2, CON-4) for safety, compatibility, and ergonomically correct operation, supporting the project's goal of reducing "tech neck" (OBJ-2).

7. Risk Assessment

Risk assessment identifies the major uncertainties that could limit the system's ability to meet its requirements and objectives. For Head Up, the two highest-priority risks concern AI posture detection reliability and system integration complexity. By identifying these risks early, the team can implement mitigation strategies that preserve the project's essential goals and provide alternate paths to partial success should challenges arise.

7.1 AI User Posture Detection

The accuracy of posture detection is central to the adaptive alignment feature (REQ-6, OBJ-1). However, webcam head and posture detection faces challenges such as variable lighting, diverse user appearances, and limited processing power. These factors create a high likelihood of reduced detection precision, potentially failing to meet the ≥98% requirement (REQ-9) and undermining the objective of achieving a smooth, responsive user experience.

To mitigate this risk, the team will follow a staged plan:

1. Implement a head detection model through transfer learning, use established AI models to meet the ≥98% accuracy requirement.
2. Progressively expand to posture classification if resources permit. If not, continue to fine tune the head detection AI.
3. Ensure manual override remains robust, maintaining the essential function of safe smartphone positioning even without AI alignment.

This layered strategy reduces dependence on perfect AI performance, ensuring that core SyRS requirements remain satisfied.

7.2 Full System Integration Complexity

Although individual subsystems, robotic arm, wireless modules, control software may meet their specifications in isolation, the integration of mechanical, electrical, and software components introduces substantial complexity. Timing mismatches, signal interference, or compatibility issues could prevent the system from meeting latency or accuracy targets (REQ-7, REQ-8, REQ-9). The probability of such issues is moderate to high, given the multidisciplinary scope of the project.

To mitigate this risk, the team will follow a staged plan in the early stage of implementation:

1. Start with remote-to-arm control to establish motion reliability (REQ-1, REQ-2, REQ-3).
2. Add smartphone interaction capabilities to demonstrate ergonomic load stability (REQ-4, CON-4).

3. Introduce AI posture alignment once baseline subsystems are verified (REQ-6, OBJ-1).

By defining clear interfaces early, the team minimizes unforeseen conflicts and ensures partial functionality can still be delivered. For example, even if AI integration is incomplete, the system can operate as a stable, remotely controlled robotic stand that meets essential safety and compatibility requirements (REQ-5, CON-1, CON-2).

8. Conclusion

The Head Up system focuses to address the growing problem of "tech neck". The system is designed to provide a simple, adaptive way to support healthier posture during everyday smartphone use. It provides a practical and innovative solution that moves naturally with the body in casual settings, like sitting on a sofa, while encouraging better digital habits without requiring extra effort. The project is designed to be both feasible and efficient by using accessible components to ensure reliable performance without unnecessary complexity. By combining comfort, adaptability, and everyday usability, Head Up not only provides a more comfortable phone use solution for the user, but also addresses a widespread modern challenge: posture-related strain.

References

[1] K. K. Hansraj, “Assessment of stresses in the cervical spine caused by posture and position of the head,” *Surgical Technology International*, vol. 25, pp. 277–279, Nov. 2014. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/25393825/

[2] Z. Xiao, H. Wen, A. Markham, N. Trigoni, P. Blunsom, and C. Chen, “A survey of wireless indoor localization from the device perspective,” *ACM Computing Surveys*, vol. 49, no. 2, pp. 1–31, Jun. 2016, doi: 10.1145/2933232.

[3] A. Cuthbertson, “The weight of the most popular phones of 2019: Apple and Samsung analysis,” *The Next Web*, Dec. 27, 2019. [Online]. Available: https://thenextweb.com/news/weight-most-popular-phones-of-2019-chart-apple-samsung-analysis

[4] Occupational Safety and Health Administration (OSHA), “eTools: Computer Workstations – Workstation Components: Monitors,” [Online]. Available: https://www.osha.gov/etools/computer-workstations/components/monitors

[5] Canadian Centre for Occupational Health and Safety (CCOHS), “Office ergonomics – positioning the monitor,” [Online]. Available: https://www.ccohs.ca/oshanswers/ergonomics/office/monitor_positioning.html

[6] Humanscale, “Positioning your monitor arm,” [Online]. Available: https://ca.humanscale.com/ergonomics/what-is-ergonomics/positioning-your-monitor-arm.cfm

[7] J. Long, R. Cheung, S. Duong, R. Paynter, and L. Asper, “Viewing distance and eyestrain symptoms with prolonged viewing of smartphones,” *Clinical and Experimental Optometry*, 2017, doi: 10.1111/cxo.12453. [Online]. Available: https://explore.eyepromise.com/hubfs/Viewing%20distance%20and%20eyestrain%20symptoms%20with%20prolonged%20viewing%20of%20smartphones.pdf

[8] S. Naipal *et al.*, “Viewing distance, font size and symptoms of eyestrain in non-presbyopic and presbyopic smartphone users,” *Ophthalmic and Physiological Optics*, Oct. 2024, doi: 10.1111/opo.13410.

[9] A. Deber, E. Wigdor, D. M. Lank, and P. O. Kristensson, “How much faster is fast enough? User perception of latency and latency improvements in direct and indirect touch,” in *Proc. CHI Conf. Human Factors Comput. Syst.*, 2015, pp. 1827–1836, doi: 10.1145/2702123.2702300.

[10] T. Laki, A. Gulyás, M. Kovács, D. Szász, and M. Pásztor, “In-network velocity control of industrial robot arms,” in *Proc. USENIX Symp. Networked Systems Design Implementation (NSDI)*, 2022, pp. 403–418.

[11] F. M. G. Larsen, J. Andersen, and O. Ravn, “Measuring and modelling delays in robot manipulators,” *DTU Technical Report*, 2016.

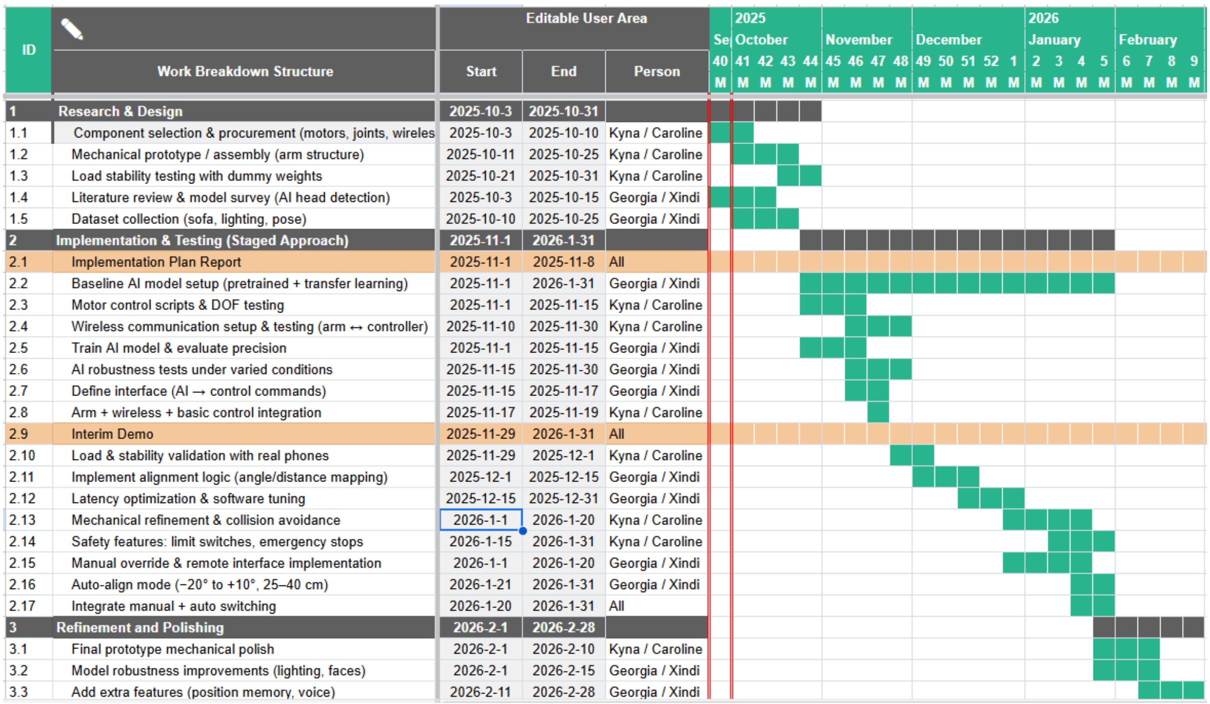
[12] BlackBerry QNX, *Optimizing Robotic Precision: Unleashing Real-Time Performance with Advanced Foundational Software Solutions*, White Paper, 2023. [Online]. Available: https://blackberry.qnx.com/content/dam/resources/blackberry-com/resource-library/en/iot/2023/standard/wp/wp-qnx-optimizing-robotic-precision.pdf

[13] N. Ni and P. Balyan, “Research on mobile user interface for robot arm remote control in industrial application,” *ResearchGate*, Preprint, Oct. 2021. [Online]. Available: https://www.researchgate.net/publication/355538418

Appendices

Appendix A: Gantt Chart

A gantt chart for the team to track project development progress and the overall time line.



ID	Work Breakdown Structure	Start	End	Person
1	Research & Design	2025-10-3	2025-10-31	
1.1	Component selection & procurement (motors, joints, wireles	2025-10-3	2025-10-10	Kyna / Caroline
1.2	Mechanical prototype / assembly (arm structure)	2025-10-11	2025-10-25	Kyna / Caroline
1.3	Load stability testing with dummy weights	2025-10-21	2025-10-31	Kyna / Caroline
1.4	Literature review & model survey (AI head detection)	2025-10-3	2025-10-15	Georgia / Xindi
1.5	Dataset collection (sofa, lighting, pose)	2025-10-10	2025-10-25	Georgia / Xindi
2	Implementation & Testing (Staged Approach)	2025-11-1	2026-1-31	
2.1	Implementation Plan Report	2025-11-1	2025-11-8	All
2.2	Baseline AI model setup (pretrained + transfer learning)	2025-11-1	2026-1-31	Georgia / Xindi
2.3	Motor control scripts & DOF testing	2025-11-1	2025-11-15	Kyna / Caroline
2.4	Wireless communication setup & testing (arm ↔ controller)	2025-11-10	2025-11-30	Kyna / Caroline
2.5	Train AI model & evaluate precision	2025-11-1	2025-11-15	Georgia / Xindi
2.6	AI robustness tests under varied conditions	2025-11-15	2025-11-30	Georgia / Xindi
2.7	Define interface (AI → control commands)	2025-11-15	2025-11-17	Georgia / Xindi
2.8	Arm + wireless + basic control integration	2025-11-17	2025-11-19	Kyna / Caroline
2.9	Interim Demo	2025-11-29	2026-1-31	All
2.10	Load & stability validation with real phones	2025-11-29	2025-12-1	Kyna / Caroline
2.11	Implement alignment logic (angle/distance mapping)	2025-12-1	2025-12-15	Georgia / Xindi
2.12	Latency optimization & software tuning	2025-12-15	2025-12-31	Georgia / Xindi
2.13	Mechanical refinement & collision avoidance	2026-1-1	2026-1-20	Kyna / Caroline
2.14	Safety features: limit switches, emergency stops	2026-1-15	2026-1-31	Kyna / Caroline
2.15	Manual override & remote interface implementation	2026-1-1	2026-1-20	Georgia / Xindi
2.16	Auto-align mode (−20° to +10°, 25–40 cm)	2026-1-21	2026-1-31	Georgia / Xindi
2.17	Integrate manual + auto switching	2026-1-20	2026-1-31	All
3	Refinement and Polishing	2026-2-1	2026-2-28	
3.1	Final prototype mechanical polish	2026-2-1	2026-2-10	Kyna / Caroline
3.2	Model robustness improvements (lighting, faces)	2026-2-1	2026-2-15	Georgia / Xindi
3.3	Add extra features (position memory, voice)	2026-2-11	2026-2-28	Georgia / Xindi

Appendix B: Justification of Requirements

REQ-1 Remote smartphone control: cursor, click, scroll

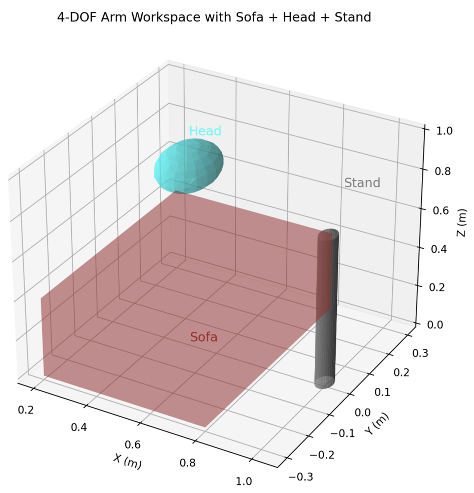
The design should allow the basic interactions for user's smartphone devices. Functions such as cursor movement shown on screen, clicking, and scrolling, are able to cover most of the daily operations, ensuring users to interact with their device without physically touching.

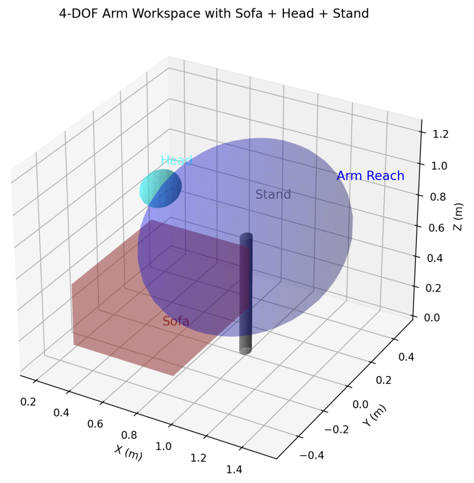
REQ-2 Reliable wireless connection (10 m)

The system should ensure a stable wireless transmission from the remote controller and to the smartphone device and robotic arm. The reliable indoor range as referenced in paper, typically by 10 meters. The distance is sufficient for handling sofa-to-stand scenarios.

REQ-3 Robotic arm adjustment: 4 degrees of freedom

The robotic arm should allow flexible positioning of the smartphone. For a four DOF arm, it can achieve: Base rotation (arm rotates left and right at the base), Shoulder joint (arm moves up and down at the shoulder), Elbow joint (Extends or retracts the reach of the arm), Wrist rotation or tilt (The wrist rotates or tilts up and down), and is considered enough through the following sofa-to-stand scenario simulation script to adapt to different user postures while avoiding unnecessary mechanical complexity. The system should reach all reachable space to be considered as successful. The requirement ensures the design successfully support these movement for users to have a ergonomic viewing in the sofa scenario.





https://github.com/GigiaaaChen/ECE496/blob/main/Code/arm4dof_test.py

REQ-4 Load support: smartphone up to 300 g

According to The Next Web's statistical analysis of the most popular smartphones in 2019, the average device weight was approximately 179.3 g. Combining this with the official specifications of most popular models from 2024–2025: iPhone 15 (171 g), iPhone 15 Pro Max (221 g), Galaxy A15 5G (200 g), and Galaxy S24 Ultra (232 g).

Based on these references, the typical mass range of modern mainstream smartphones can be defined as approximately 170–230 g. The design requirements specifies the design should support cell phone and its phone case.

REQ-5 Manual override mode (movements, lock/unlock controls)

The system shall allow users to manually adjust the robotic arm in four directions (up, down, left, right) as the basic movement. It shall also provide lock/unlock control so that, in either auto or manual mode, the current position can be fixed, and no further commands will cause movement while locked.

REQ-6 Auto-align (angles −20° to +10°, distance 25–40 cm)

The stand should keep the screen aligned within an ergonomic viewing position. Ergonomics guidelines for monitors and phones typically recommend downward gaze of about 15° and viewing distances in the 25–40 cm range. These ranges help prevent neck strain and visual fatigue.

REQ-7 Command Processing Latency ≤ 100 ms

Research indicates that system response times below approximately 100 ms are generally considered as instantaneous reaction for users.

REQ-8 Mechanical response latency ≤ 20 ms

Research in robot command systems shows 95–98% accuracy is considered reliable. Therefore, achieving accuracy of 98% is set as the system requirement.

REQ-9 Command accuracy ≥ 98%

The system must correctly interpret user commands, including the command to smart phone and to robotic arm, with high reliability. A software-control-robotic-arm design presented by Ni and Balyan (2021) achieved a command execution accuracy of about 98%. Our design adopts this result as a reference benchmark and therefore sets 98% as the success criterion for command accuracy.

REQ-10 Switching between manual and auto modes

The system should allow switching between manual and automatic alignment so that users can choose the mode that best suits their needs.