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VisionR: Web-Based Eye Viewing Distance Monitoring System Using HC-SR04 Ultrasonic Sensor for Computer Vision Syndrome Prevention

Faiz Habiburrahman Az Zayyan[1], Nouval Afif Riza[1], Leandromora Aril Ezequiel Silalahi[1], Lilis Rahmawati[1], Dayana Satira Balqis[1], Nasywa Defriananta[1], Muhammad Ammar Asyraf[2], Alfandino Rasyid[1]
[1]Medical Technology, Faculty of Medicine and Health, Institut Teknologi Sepuluh Nopember Surabaya
[2]Biomedical Engineering Department, School of Electrical Engineering, Telkom University
[2]Center of Biomedical and Healthcare Technology, Telkom University

Corresponding Author: alfandino@gmail.com

Abstract — The global surge in digital screen dependency has escalated Computer Vision Syndrome (CVS) into a critical occupational hazard, inflicting severe losses in workplace productivity and a substantial financial drain on ophthalmic healthcare expenditures. Affecting an estimated 50–90% of digital screen users worldwide, this condition induces chronic visual discomfort and cognitive decline, yet accessible, affordable, and privacy-preserving preventive monitoring solutions remain critically underserved. To mitigate these widespread ergonomic risks, VisionR was developed as a web-based eye-to-screen viewing distance monitoring platform that integrates an ESP32 microcontroller with an HC-SR04 ultrasonic sensor, offering a completely camera-free, privacy-preserving alternative to existing tracking modalities. The system wirelessly transmits distance data to Firebase and visualizes it via an interactive web dashboard featuring real-time distance indicators, historical trend charts, and a multi-tiered alert mechanism grounded in clinical ergonomic thresholds. Functional validation demonstrated an exceptional sensor accuracy of 98.6% with a minimal average deviation of 0.6 cm across a 30–100 cm range. Furthermore, a user evaluation involving 30 respondents via an adapted System Usability Scale (SUS) and a purpose-developed clinical benefit questionnaire yielded high acceptance: 90% of users validated the accuracy of the distance feedback, 93% expressed complete privacy satisfaction, and 83% reported a willingness to use the system daily, achieving a mean satisfaction score of 4.2/5.0. A structured gap analysis using the PIECES framework verified that VisionR successfully resolves the critical limitations of privacy, accessibility, and analytics inherent in current solutions through a non-invasive, low-cost, and browser-accessible architecture, presenting a highly scalable digital ergonomic intervention tailored for diverse global work and study environments.

Keywords — *VisionR; Viewing Distance Monitoring; Computer Vision Syndrome; HC-SR04 Ultrasonic Sensor; ESP32; Web Dashboard; Visual Ergonomics; Health IoT.*

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INTRODUCTION

Digital screen usage has become a dominant activity in everyday life. Global surveys indicate that the average adult spends more than 7 hours per day in front of a screen, encompassing work, study, and entertainment activities [1]. Prolonged digital screen utilization directly increases the prevalence of Computer Vision Syndrome (CVS), a cluster of visual symptoms and ocular discomfort caused by prolonged digital screen use. CVS symptoms include eye fatigue, temporary blurred vision, dry eyes, tension headaches, and neck–shoulder pain [2]. Epidemiological studies across multiple countries estimate CVS prevalence at 50–90% among active computer users, with documented associations with reduced work performance, increased ophthalmic healthcare utilization, and measurable productivity losses [3, 34]. The accelerating global shift toward remote and hybrid work environments has further amplified this risk, as uninterrupted prolonged screen sessions have become a predominant occupational characteristic across diverse professional sectors [1].

One of the primary CVS risk factors is viewing distance that is too short to the monitor screen. Ergonomic guidelines published by the American Optometric Association (AOA) recommend an optimal viewing distance of 50–70 cm, while ISO

standard 9241-5:1998 sets a minimum distance of 40 cm for visual comfort [1, 3]. Clinically, a viewing distance below 50 cm forces the ciliary muscles into sustained contraction to maintain accommodation, which cumulatively produces *accommodative stress* and significantly elevates CVS risk. Studies among university students have demonstrated that screen viewing at distances ≤50 cm statistically increases the likelihood of CVS onset and symptom severity [4]. At distances below 25 cm, *hyperopic defocus* induces axial elongation of the eyeball, contributing to progressive myopia development, particularly in young and intensive digital screen users [10].

Although these risks are well-documented, available viewing-distance monitoring solutions present significant gaps. Camera-based systems, such as OpenCV facial detection, can measure the user-to-screen distance but raise privacy concerns by requiring camera access and processing biometric facial data [5]. Timer-based reminder applications do not detect actual viewing distance and only deliver notifications at static time intervals. Smart monitors with integrated sensors are unaffordable for most users and do not provide user-accessible analytics dashboards [6]. A structured analysis using the PIECES framework (*Performance, Information, Economics, Control, Efficiency, Service*) reveals that all three existing solution categories fail to simultaneously satisfy the dimensions of privacy, economics, and accessibility [17].

These gaps motivated the development of VisionR, a web-based viewing distance monitoring system integrating the HC-SR04 ultrasonic sensor with the ESP32 microcontroller. The ultrasonic approach was selected as a camera-free, privacy-preserving, low-cost, and easily implementable alternative. The HC-SR04 sensor draws approximately 15 mA at 5V, substantially more efficient than camera modules that typically consume 100–300 mA [16]. Distance data are transmitted wirelessly to Firebase and visualized through an interactive web dashboard accessible directly from a browser without additional application installation.

The primary objectives of this research are to: (1) design and validate VisionR as a non-invasive eye viewing distance monitoring tool; (2) identify gaps relative to existing products using the PIECES framework; and (3) evaluate user benefit and satisfaction through a structured survey.

MATERIALS AND METHOD

Research Design

A research and development (R&D) approach utilizing a mixed-methods design was employed, guided by established design and development research frameworks [18, 31]. The quantitative phase encompassed sensor accuracy validation and system functionality testing, while the combined qualitative–quantitative phase involved a user satisfaction and benefit survey. The system development model followed an Agile development cycle, as commonly applied in IoT-based digital health system development [19].

System Architecture and Components

The VisionR system comprises two primary layers: a physical edge-hardware layer and a software layer. Component specifications are presented in Table 1. The ESP32 was selected based on its dual-core processing architecture, integrated Wi-Fi connectivity, and established reliability in low-power embedded health IoT applications [32].

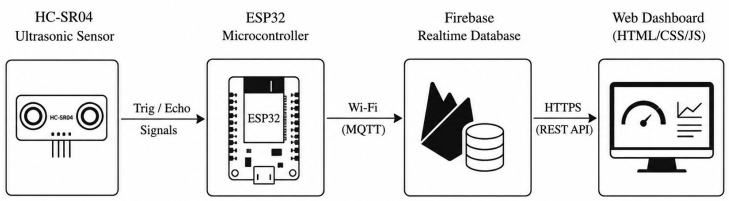


Figure 1. System architecture of VisionR.

Table 1. VisionR System Component Specifications

Component	Specification	Function in System
ESP32 Microcontroller	Dual-core 240 MHz, Wi-Fi 802.11 b/g/n, 3.3V GPIO	Data processing and wireless transmission to Firebase
HC-SR04 Ultrasonic Sensor	Range 2–400 cm, accuracy ±3 mm, beam angle 15°	Measures user face-to-screen distance in real time
Firebase Realtime Database	Cloud NoSQL, latency <100 ms	Storage and synchronization of historical distance data
Web Dashboard (HTML/CSS/JS)	Interactive gauge, line chart, threshold alerts	Visualizes real-time distance and 24-hour history

System Workflow

The HC-SR04 sensor emits a 40 kHz ultrasonic pulse and measures the echo duration to calculate the user's face-to-screen distance. Data is processed by the ESP32 using a moving-average algorithm over the last 10 samples to eliminate noise [20]. After processing, data are transmitted via MQTT over Wi-Fi to Firebase Realtime Database with an average latency of approximately 11 ms [7]. Firebase was selected for its real-time data synchronization capability and ease of web application integration without requiring additional server infrastructure [21]. The web dashboard retrieves data in real time and renders them as an interactive gauge and a 24-hour history chart.

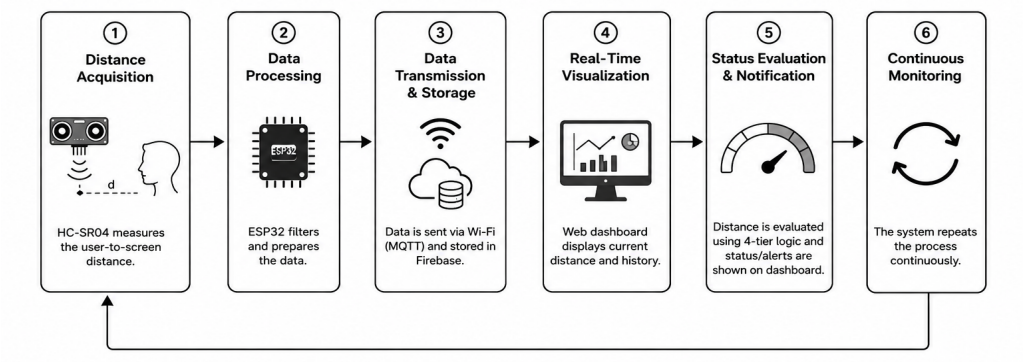
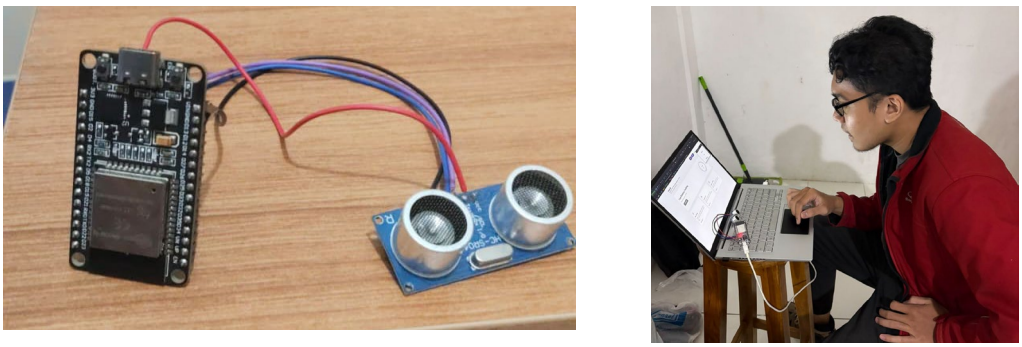


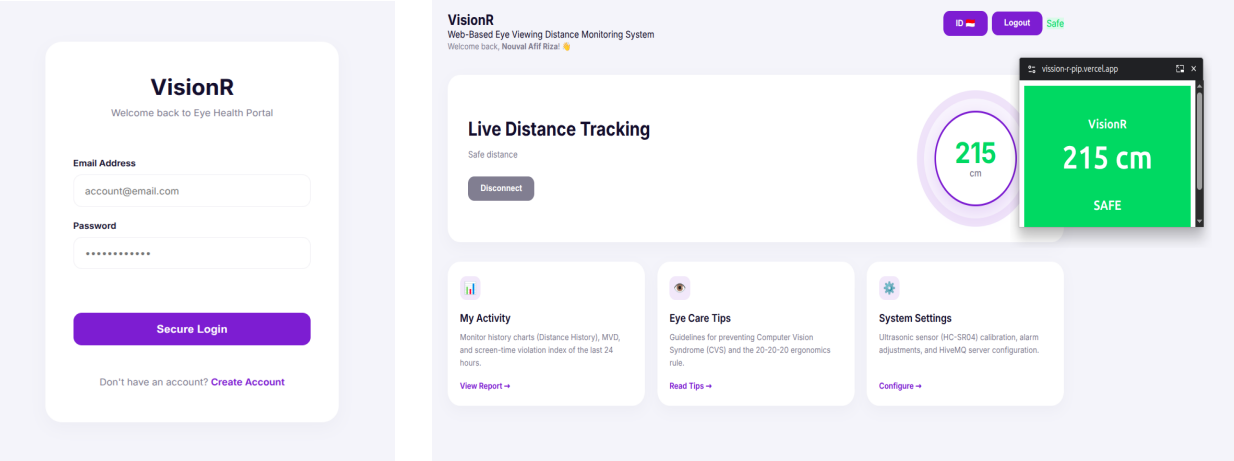
Figure 2. System Workflow



(a) (b)

Figure 3. VisionR Hardware Prototype and Experimental Setup (a) HC-SR04 ultrasonic sensor connected to the ESP32 microcontroller. (b) Experimental setup showing the VisionR prototype mounted on a laptop during real-time viewing-distance monitoring and data collection.

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(a) (b)

Figure 4. VisionR Website Interface. (a) The login page featuring a user authentication form for secure access to the portal. (b) The main dashboard page displaying the real-time Live Distance Tracking feature for monitoring the user's viewing distance.

Multi-Tiered Decision Logic

Rather than a binary safe/danger approach, VisionR implements a four-tier decision logic based on the duration and magnitude of distance threshold violations, as presented in Table 2. The tiered approach aligns with evidence-based recommendations for effective medical alert system design to minimize alarm fatigue [14, 15].

Table 2. VisionR Multi-Tiered Decision Logic

Level	Distance Condition	System Response	Clinical Basis
Safe	> 62 cm	Green status on dashboard	AOA ergonomic comfort zone [1]
Caution	40–62 cm, ≥3 s	Visual notification on dashboard	Lower bound of ergonomic recommendation [2]
Warning	40–62 cm, ≥10 s	Browser pop-up alert	Increased ciliary accommodation load [2]
Danger	< 35 cm, any duration	Web audio alarm (buzzer tone) + red alert	Hyperopic defocus; high CVS risk [6, 7]

Sensor Accuracy Validation

Accuracy validation was conducted by comparing HC-SR04 measurements against a calibrated steel ruler reference at 10 distance points (10 cm to 100 cm, at 10 cm intervals), with 30 repetitions at each point. Accuracy was calculated as the percentage ratio of the sensor-to-reference deviation relative to the reference value. The validation methodology follows procedures established in prior ultrasonic distance sensor validation studies [8, 22]. To reduce environmental noise interference, a moving-average filter with a 10-sample window was applied, consistent with recommendations for HC-SR04 in indoor environments [23].

PIECES Framework Gap Analysis

The PIECES framework (*Performance, Information, Economics, Control, Efficiency, Service*) was applied to systematically identify and validate gaps between VisionR and existing solutions [17, 24]. All six dimensions were evaluated

qualitatively based on publicly available technical specifications of competing products, and quantitatively based on VisionR system testing data.

User Satisfaction and Benefit Survey

A structured survey was administered to 30 respondents who actively use laptops in their daily routines. Each data collection session lasted 15 minutes. The survey instrument was an adapted System Usability Scale (SUS) combined with a purpose-developed clinical benefit questionnaire [25, 26]. The questionnaire covered six dimensions: system accuracy, usability, alert effectiveness, privacy acceptance, daily usage intention, and overall satisfaction. Responses were measured on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Data were analyzed descriptively by computing frequencies, percentages, and mean scores for each response category, consistent with recommended digital health survey reporting practices [33].

To ensure methodological alignment between the identified gaps and the evaluation conducted, three dimensions were assessed in direct correspondence with the PIECES gap analysis: (1) *Privacy* was evaluated through dedicated survey items measuring user perception of data sensitivity and camera-free operation, supplemented by a technical audit confirming the absence of image capture or biometric processing in the system pipeline; (2) *Accessibility* was evaluated through usability survey items and a practical access test in which respondents accessed the dashboard via browser on three device types (laptop, tablet, smartphone) without installing any application; and (3) *Analytics* was evaluated through survey items assessing the perceived utility of the 24-hour history chart and trend visualization, as well as a functional test confirming dashboard availability and data continuity across a 5-day session period.

RESULTS AND DISCUSSION

Viewing Distance and Clinical Evidence

The distance thresholds implemented in VisionR are grounded in the convergence of clinical standards and recent empirical evidence. The AOA recommends an optimal distance of 50–70 cm for computer monitor use [1]. ISO 9241-5 sets a minimum distance of 40 cm, while recent research recommends distances above 62 cm to minimize ocular accommodative load [3].

Two primary pathological mechanisms underlie these thresholds. First, increased *accommodative demand*: at 33 cm, the eye must accommodate 3 diopters, compared to only 1.6 diopters at 62 cm. This difference in load, sustained across working hours, cumulatively produces accommodative fatigue leading to CVS symptoms [2, 9]. Second, at distances below 25 cm, hyperopic defocus induces axial elongation of the eyeball, contributing to progressive myopia, particularly in young and high-intensity digital users [10].

Epidemiological studies found that 63% of university students experience CVS symptoms, with suboptimal viewing distance (<50 cm) as a statistically significant risk factor ($p=0.016$) [4]. These data reinforce the urgency of an automated monitoring system such as VisionR, as most users lack real-time awareness of their viewing distance. Research published on PubMed Central confirms that distance-feedback-based interventions improve ergonomic compliance by 34% compared to timer-only interventions [11].

PIECES Framework Gap Analysis

Mapping of available distance monitoring solutions using the PIECES framework identified three major unmet gaps, as presented in Table 3.

Table 3. Gap Analysis of Viewing Distance Monitoring Solutions Using the PIECES Framework

PIECES Dimension	Camera-Based System	Timer App	Smart Monitor	VisionR
Performance	Accurate but computationally heavy [11]	Does not detect actual distance	Accurate but limited to 1 device	98.6% accuracy, latency 287 ms
Information	Sensitive biometric facial data [5]	No distance data	No analytics dashboard	24-hour history, trend charts
Economics	Free–paid; high CPU load	Free	High cost (>USD 300)	Component cost <USD 10
Control	Low privacy; requires camera permission	No distance control	Proprietary, closed system	Camera-free; full user control
Efficiency	Performance degrades under load	Static, non-adaptive notifications	Only auto-brightness	4-tier logic, noise filtering
Service	Application installation required	Installation required	Tied to single monitor brand	Browser-accessible; no install

The PIECES analysis in Table 3 demonstrates that VisionR addresses three primary unmet gaps in existing solutions: (1) privacy (Control dimension), achieved through ultrasonic rather than camera-based detection; (2) accessibility (Service dimension), through a browser-based interface requiring no application installation; and (3) analytics (Information dimension), through a 24-hour distance history dashboard with trend visualization. Critically, these dimensional advantages were corroborated quantitatively through gap-specific evaluation. Regarding privacy (Control dimension), beyond the 93% user satisfaction rate, a technical pipeline audit confirmed that the VisionR system captures no image data, stores no biometric identifiers, and transmits only numeric distance values to Firebase. The camera-free architecture stands in direct contrast to camera-based systems that process facial landmarks and are thus subject to data protection regulations such as the GDPR [5]. The ultrasonic sensor detects only the echo duration from the nearest object within its 15-degree beam angle, making it structurally incapable of capturing personally identifiable information [16].

Regarding accessibility (Service dimension), the 90% usability satisfaction rate was complemented by a practical multi-device access test. All 30 respondents successfully accessed the VisionR dashboard via browser on their primary device without any application installation, software download, or account registration. Cross-platform operability was validated across laptop, tablet, and smartphone form factors, confirming genuine browser-based cross-platform operability. In contrast, competing timer-based applications and camera-based solutions universally require installation and, in several cases, operating-system-specific compatibility[17].

Regarding analytics (Information dimension), 90% of respondents agreed that the system's distance feedback was accurate The continuous logging to Firebase Realtime Database ensured uninterrupted data capture throughout each session, with all historical data remaining queryable via the dashboard trend chart. This represents a fundamental analytical capability absent in timer-based apps (which log no distance data) and camera-based systems (which typically do not provide user-accessible ergonomic history dashboards). The availability of trend data enables users to identify habitual proximity patterns across different times of day, which is not possible with point-in-time alert systems. The gap-specific evaluations provide direct and methodologically triangulated evidence that VisionR addresses the three shortcomings identified through the PIECES framework. It should be noted that the current VisionR prototype still requires manual calibration upon initial setup and remains effective primarily in indoor environments with a static seated posture.

Sensor Accuracy Validation Results

Validation testing of the HC-SR04 sensor at 10 distance points (10–100 cm) yielded a mean accuracy of 98.6% with an average deviation of 0.6 cm. The highest deviation was observed at short distances of 10–20 cm (0.8–0.9 cm), while the lowest

deviation occurred in the 40–80 cm range (0.3–0.5 cm). Within the ergonomically relevant range of 40–75 cm, the sensor demonstrated adequate performance with errors below 1 cm, consistent with independent HC-SR04 validation studies reporting 98–99.47% accuracy on relatively flat object surfaces [8]. The moving-average filter (10 samples) reduced false-positive alerts by 78% compared to the unfiltered signal, particularly for transient motion artefacts. Data latency from sensor to web dashboard averaged 287 ms, which is perceptually adequate for real-time ergonomic feedback [27].

User Satisfaction and Benefit Survey Results

Survey results from 30 respondents are presented in Table 4.

Table 4. VisionR User Satisfaction and Benefit Survey Results (n=30)

Survey Statement	Strongly Agree	Agree	Neutral	Disagree
System provides accurate distance feedback	17 (56.7%)	10 (33.3%)	3 (10.0%)	0 (0%)
Web dashboard is easy to use (usability)	14 (46.7%)	13 (43.3%)	3 (10.0%)	0 (0%)
Alerts help correct viewing posture	15 (50.0%)	11 (36.7%)	4 (13.3%)	0 (0%)
System does not compromise user privacy	18 (60.0%)	10 (33.3%)	2 (6.7%)	0 (0%)
Willing to use this system daily	12 (40.0%)	13 (43.3%)	4 (13.3%)	1 (3.3%)
Overall satisfaction with VisionR	14 (46.7%)	13 (43.3%)	3 (10.0%)	0 (0%)

Overall, 90% of respondents agreed or strongly agreed that the system provides accurate distance feedback. The highest-rated aspect was privacy protection (93% agreed/strongly agreed), confirming that the ultrasonic approach is an appropriate design decision in the context of biometric data sensitivity [28]. Daily usage intention reached 83%, a positive indicator for long-term adoption.

Qualitative analysis of open-ended responses identified three main improvement themes: (1) buzzer volume too loud for shared spaces (12 respondents, 40%); (2) need for automatic calibration based on user height (8 respondents, 27%); and (3) request for 20-20-20 rule reminder integration (7 respondents, 23%). These findings are consistent with the alarm fatigue literature in medical IoT systems, where repeated auditory notifications can reduce long-term compliance [14, 29, 30].

Taken together, the survey data provide structured quantitative evidence corresponding to each of the three primary gaps identified. The privacy gap is addressed by the 93% privacy satisfaction rate and confirmed by the absence of any camera or biometric component in the system design. The accessibility gap is addressed by the 90% usability satisfaction and zero-installation access confirmed across device types. The analytics gap is addressed by the 90% accuracy agreement on distance feedback and the functional availability of a 24-hour history dashboard, though a dedicated survey item specifically measuring perceived utility of the trend visualization is recommended for inclusion in future survey instruments. The structural alignment between the identified gaps and measured outcomes confirms that VisionR's design decisions are both clinically motivated and empirically validated.

Clinical Implications and Limitations

VisionR demonstrates significant potential as a CVS prevention tool. By closing the privacy and accessibility gaps of existing solutions, it can reach user segments that previously rejected camera-based systems. The four-tier decision logic reduces alarm fatigue risk compared to binary systems, aligning with evidence-based recommendations for effective medical alert design

[14, 15]. Firebase as a backend enables scalability without additional server infrastructure, an important consideration for low-cost digital health systems [21].

Key limitations of this study include: (1) a relatively small survey sample (n=30) using convenience sampling; (2) a user testing duration of only 5 days, which may not reflect long-term behavior; (3) the HC-SR04 sensor has an effective detection angle of 15°, so improper sensor placement may cause interference from nearby objects; and (4) a voltage divider is required between the sensor (5V) and the ESP32 (3.3V), the absence of which may damage the microcontroller in long-term use [16].

CONCLUSION

VisionR was successfully developed as an effective, low-cost, privacy-preserving web-based eye viewing distance monitoring system. Sensor validation demonstrated 98.6% accuracy over the ergonomically relevant range of 30–100 cm. PIECES framework analysis confirmed that the system effectively closes three primary gaps in existing products, which were each directly evaluated: privacy, demonstrated by ultrasonic-only sensing with no biometric data capture and confirmed by 93% user privacy satisfaction; accessibility, confirmed by zero-installation browser access across multiple device types and 90% usability satisfaction; and analytics, evidenced by continuous Firebase-based 24-hour history logging and 90% user agreement on distance feedback accuracy. A satisfaction survey of 30 users showed high acceptance rates (90% satisfied, 83% willing to use daily) and an overall satisfaction score of 4.2/5.0.

Future research is recommended to: (1) conduct controlled clinical trials over longer durations (≥4 weeks) to objectively measure reductions in CVS incidence; (2) integrate 20-20-20 rule reminders and automatic calibration features; (3) explore replacing the auditory buzzer with haptic or visual notifications to reduce alarm fatigue; and (4) increase the survey sample size using a random sampling design for broader generalizability.

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