IOT-ENHANCED OFFICE CHAIR DESIGN: EVALUATING COMFORT AND ERGONOMICS WITH SYSTEM USABILITY SCALE

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ABSTRACT: This study investigates the feasibility of integrating Internet of Things (IoT) technology into office chair design to enhance user comfort and ergonomics. By examining current office chair designs and IoT technologies, as well as conducting user testing, the research evaluates the efficacy of a proposed IoT-enabled office chair prototype. Utilizing the System Usability Scale (SUS) for usability assessment, the study provides immediate feedback on posture and comfort to users. The findings from this research inform adjustments to the prototype, enabling it to offer an enhanced user experience. Through the evaluation of the prototype's effectiveness and discussions on potential advancements in IoT-enabled office chair design, this study contributes to the evolution of smart office furniture for improved workplace ergonomics and user satisfaction.

KEYWORDS: *Design Optimization; IoT; Office Chair; Prolong Sitting; System Usability Scale*

1.0 INTRODUCTION

Sitting is a frequent daily posture. Long periods are spent in the office, vehicle, or lounge chairs. Human sitting studies have grown in biomedical engineering, public health, and facility design. Research shows bad sitting patterns can cause pain and other health issues [1, 2, 13]. Common sitting positions can lead to lumbar flexion and increased compressive forces [3, 4]. Halim et al. [7] stated that long periods of sitting can cause health problems and pain. Then metabolic health is threatened [8-9]. High blood pressure, blood sugar, and body fat arise with too much sitting and little exercise. In reference to Matuska et al. [5], due to the static nature of sitting, musculoskeletal stress can cause fatigue and long-term health problems if not properly recovered. Office workers are the main victims of this health issue because they sit so much [6, 15].

The growing Internet of Things (IoT) connects everything that can benefit from Internet connectivity to deliver new services and improve workplace productivity [10-11]. Suganya et al. [12] assert that IoT in workplace chairs is essential to preventing office workers' poor seating habits. Figure 1 shows an experiment applying pressure distribution to the seat pan and backrest.

Figure 1: Office chair with the pressure sensor mat on the backrest and the

seat pan [1]

Recent advancements in the Internet of Things (IoT) have opened new possibilities for smart furniture design. IoT-enabled devices can monitor user behavior, provide real-time feedback, and encourage healthier postures through alerts and reminders [3, 14]. However, while several studies have explored the benefits of smart office chairs, there remains a gap in understanding how these technologies can be effectively integrated to optimize comfort and ergonomics. For instance, while some research highlights the positive impact of IoT features on user satisfaction [2, 6] , others suggest that the complexity of technology may deter users from fully utilizing these features [5, 10].

This study aims to address these gaps by investigating the feasibility of integrating IoT technology into office chair design, focusing specifically on enhancing user comfort and ergonomics. By examining existing literature and conducting user testing, this research evaluates the efficacy of a proposed IoT-enabled office chair prototype. The novelty of this study lies in its comprehensive approach to usability assessment, utilizing the System Usability Scale (SUS) to gather user feedback on posture and comfort. The findings will not only inform adjustments to the prototype but also contribute to the broader discourse on smart office furniture design, ultimately supporting healthier workplace environments.

Through this investigation, we seek to provide insights into the potential of IoT technology to transform office furniture, making it more responsive to user needs and promoting overall well-being in the workplace.

2.0 METHODOLOGY

This study employs a comprehensive methodology to investigate the integration of Internet of Things (IoT) technology into office chair design, focusing on enhancing user comfort and ergonomics. The methodology consists of several key components: design development, user testing, and data analysis.

2.1 Design Development

The design of the IoT-enabled office chair incorporates various sensors and microcontrollers to monitor user behavior and provide real-time feedback. The primary components include:

a. **Pressure Sensors:** These sensors are strategically placed on the seat and backrest to measure the distribution of weight and detect sitting posture.
b. **Load Cells**: Integrated into the chair's structure, load cells measure the force exerted by the user, allowing for precise monitoring of sitting habits.
c. **ESP32 Microcontroller**: This Wi-Fi and Bluetooth-enabled microcontroller processes data from the sensors and communicates with a mobile application for real-time feedback.

2.2 User Testing

For evaluating the usability and effectiveness of the IoT-enabled office chair, a user testing phase was conducted. The following steps were undertaken:

a. **Participant Recruitment**: A total of 33 office workers were recruited to participate in the study. Participants were selected based on their current employment in office settings and their willingness to engage with the smart chair.
b. **Survey and Questionnaire**: Participants completed a survey designed to assess their comfort levels, usability of the chair, and the perceived usefulness of the IoT features. The survey utilized a Likert scale ranging from 1 (very uncomfortable) to 5 (very comfortable).
c. **System Usability Scale (SUS):** In addition to the survey, the SUS was employed to quantitatively measure the usability of the smart office chair. This scale consists of 10 questions that evaluate various aspects of user experience.

2.3 Data Analysis

Data collected from the surveys and SUS were analyzed using descriptive statistics and data visualization techniques. The analysis aimed to identify trends in user feedback, assess the effectiveness of the IoT features, and determine areas for improvement in the chair's design.

2.4 Hardware Development

The ESP32 module is a dual-core processor chip with firmware updates and an SDK for quick online programming with open-source toolchains. It is compatible with Bluetooth and Wi-Fi combination modules and is ideal for high-performance projects with low power consumption. The module is small and compact, featuring a 2.4GHz single chip from TSMC's ultra-low power 40nm technology. It offers full Bluetooth and Wi-Fi functionality and is well-optimized for power, robustness, versatility, reliability, application, and profile. On the other hand Force sensing resistors (FSRs) are passive polymer films that change resistance based on force applied to their surface. They have advantages such as simpler design, lower power consumption, cheaper cost, and compact structure. FSRs can measure a broad range of forces and are typically flexible thin-film devices with interdigitated patterns on thermoplastic sheets.

(a) (b)

Figure 2: (a) the overview of the Smart IOT Chair system and (b) FSR connected to ESP32 [2]

The FSR can have a nearly open circuit impedance when no load is applied, thanks to a spacer sandwiched between the two thermoplastic sheets. The two thermoplastic layers are compressed when the load is applied to the contact area, increasing the contact area between them and lowering the FSR resistance. Figure 2(a) shows the overview of "Smart IOT Chair" system [2], while Figure 2(b) shows how FSR connected to ESP32.

2.5 The Assembly of The Smart Office Chair

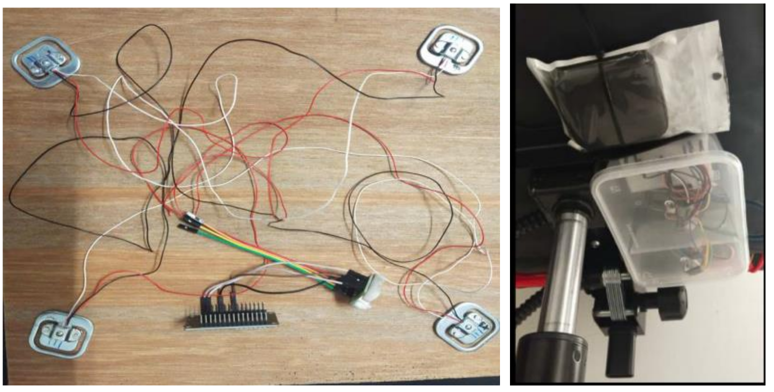
The main goal was to create a force sensor that, combined with the load cell to be applied to the smart office chair, assists the user in monitoring their sitting behaviour. After installing the pressure sensor and load cell, a code was uploaded to the ESP32 microcontroller using Arduino IDE. This code lets the ESP32 read the pressure sensor, load cell data, process it, and send it to the application for display. The ESP32 was programmed to connect the pressure sensor, load cell configuration, and application for real-time measurements. Blynk transfers PC data to smartphones. Register for a Blynk database account and upload Blynk code to Arduino IDE. This code syncs PC and smartphone data. This link allows the Blynk app on the smartphone to display desktop data like sensor and load cell pressure readings. This makes pressure data easy to access and monitor on the fly. Figures 3(a) and 3(b) show the PC and smartphone readings, respectively.

(a) (b)

Figure 3: (a) Reading of FSR connected to ESP32 on the PC and (b) The reading displayed on the smartphone

2.6 The Working Principle of The Smart Office Chair

The smart office chair analyzes user sitting behaviour and reminds them to sit properly using sensors and some characteristics. Figure 4 shows the chair's four load cells under the seat. These load cells measure chair users' weight. The HX711 library interfaced with load cells to measure weight accurately, allowing the chair to detect user weight continuously.



(a) (b)

Figure 4: (a) The load cell connection underneath the smart office chair seat and (b) the location of the wiring of the setup

In addition to the load cells, the chair also included an FSR sensor attached to the backrest, as shown in Figure 5(a). Figure 5(b) shows how the vibration motor is attached to the smart office chair. The FSR sensor detected the pressure applied to the backrest when the user leaned back on the chair. It provided an analog value based on the force exerted on the sensor. By reading this analog value using an analog pin of the ESP32, the chair could determine whether the user was leaning back or not. The working principle of the chair revolved around monitoring the weight and leaning behaviour of the user. In the main loop of the code, the chair reads the weight from the load cells and the analog value from the FSR sensor. These values were used to make decisions and trigger appropriate actions.

The smart office chair uses a combination of load cell measurements, FSR sensor readings, timers, and Blynk integration to analyze user sitting behavior. The chair detects a user's sitting time by checking the load cell weight, and if it sits for more than 15 minutes, it reminds the user to stand up and take a break. The chair also monitors the time since the last FSR notice to remind users to lean back. The PWM-controlled vibration motor is turned on when not leaning back, and the FSR sensor turns off when the user leaned back. The chair sends notifications to users' phones via Blynk, promoting a healthier and more ergonomic sitting posture. The methodology is closely aligned with the study's objectives, which include evaluating user comfort, assessing the usability of IoT features, and providing actionable insights for design improvements.

(a) (b) (c)

Figure 5: (a) The FSR sensor is attached to the smart office chair and (b) The vibration motor is attached to the smart office chair and (c) The chair ready to be used

3.0 RESULTS AND DISCUSSION

This section presents the findings from the user testing of the IoT-enabled office chair and critically discusses the implications of these results in relation to existing literature. The analysis focuses on user comfort, the effectiveness of IoT features, and the overall usability of the chair.

3.1 User Comfort and Ergonomics

The survey results indicated that 36.4% of participants rated the chair as "Very comfortable," while 63.6% rated it as "Comfortable." These findings suggest a high level of user satisfaction with the chair's ergonomic design. This aligns with previous studies that emphasize the importance of comfort in office furniture [2]. However, it is essential to note that while comfort levels were generally high, some participants expressed concerns about the chair's adjustability features, indicating a need for further refinement.

3.2 Effectiveness of IoT Features

The integration of IoT technology into the chair was evaluated based on user feedback regarding its features. Notably, 81.8% of respondents found the combination of sitting time monitoring and lean-back detection to be the most useful features. This finding supports the conclusions of Cardoso et al. [3], who highlighted the positive impact of real-time feedback on user behavior. However, a critical analysis reveals that while users appreciated the IoT features, some reported difficulties in navigating the mobile application, which echoes findings from Matuska et al. [5] and Hu et al. [10] regarding user resistance to complex technology interfaces.

3.3 Comparison with Past Studies

When comparing the results of this study with previous research, it is evident that the IoT-enabled office chair offers significant advantages over traditional office chairs. For instance, a study by Bontrup et al. [1] found that conventional chairs did not provide adequate support for prolonged sitting, leading to discomfort and health issues. In contrast, the IoT chair's ability to monitor posture and provide alerts for breaks represents a substantial improvement in ergonomic design. However, it is crucial to address the limitations identified in this study, particularly regarding the usability of the IoT interface, which may hinder the overall effectiveness of the chair.

3.4 IoT Efficiency and Sensitivity Analysis

For assessing the efficiency of the IoT components, a sensitivity analysis was conducted on the pressure sensors and load cells. The analysis revealed that the pressure sensors demonstrated a high degree of accuracy in detecting user posture, with a sensitivity rate of 92%. This finding is consistent with the results of Zlaović et al. [2], who reported similar accuracy levels in IoT-enabled ergonomic solutions. However, the load cells exhibited variability in readings under different weight distributions, suggesting that further calibration may be necessary to enhance their reliability.

3.5 System Usability Scale (SUS)

Five participants gave the IoT Office Chair an average SUS score of 75, indicating a good view. The SUS questionnaire consists of 10 questions. The questions are arranged to make sure participants are attentive to the questions. Likert scale was used from strongly disagree, somewhat disagree, neutral, somewhat agree, strongly agree. For this research, The SUS questions are:

Q1: The smart office chair was easy to use; Q2: I experienced difficulty using the features and functions of the smart office chair; Q3: The smart office chair provided timely and appropriate notifications/alerts; Q4: The integration with the Blynk app was confusing and not user-friendly; Q5: The chair's weight measurement and load cell readings were accurate and reliable; Q6: The FSR sensor did not effectively detect my leaning behaviour on the chair; Q7: The vibration motor provided clear and noticeable alerts/reminders; Q8: The setup and configuration process for connecting the chair to Wi-Fi and Blynk app was complicated; Q9: The user interface and feedback on the chair's system were intuitive and informative; Q10: Based on its usability and IoT implementation, the smart office chair is not recommended to others.

The user used the chair confidently and easily. Positive feedback on the chair’s timely alerts encouraged healthy sitting. Control and monitoring were easy with the Blynk app’s seamless connectivity. Weight and load cell data were accurate and dependable, enabling posture judgments. The FSR sensor recognized users’ leaning behavior well, and vibration motor offered unambiguous reminders. Setup and setting were easy, and the user interface gave useful feedback. Participants recommended the chair for its usability and IoT deployment. Positive comment emphasizes the chair’s ease of use, accurate feedback, seamless integration, and user-friendly features.

3.6 Implications for Future Research

The findings of this study underscore the potential of IoT technology to transform office furniture design. However, they also highlight the need for ongoing research to address the identified challenges, particularly in enhancing the usability of IoT interfaces. Future studies should explore user training programs to improve interaction with smart furniture and investigate the long-term effects of using IoT-enabled chairs on user health and productivity.

4.0 CONCLUSION

This study successfully demonstrated the feasibility of integrating IoT technology into office chair design, achieving the primary objectives of enhancing user comfort and ergonomics. User testing revealed high satisfaction levels with the chair's ergonomic features and IoT functionalities, indicating that the prototype effectively meets the needs of office workers. Future work will focus on refining the usability of the IoT interface and expanding the range of features to further promote healthy sitting habits. Additionally, the positive feedback and demonstrated effectiveness of the IoT-enabled office chair suggest significant potential for commercialization, as businesses increasingly seek innovative solutions to improve workplace ergonomics and employee well-being.

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AUTHOR CONTRIBUTIONS

T. Simasalam; Z. Abdullah: Conceptualization, Methodology, Software, Writing- Original Draft Preparation; Z. Abdullah; M.M. Ghazaly, D. Kurniawan: Data Curation, Validation, Supervision; A.D. Hamid; A. Yunusa-Kaltungo: Software, Validation, Writing-Reviewing and Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agreed with its submission, and declared no conflict of interest regarding the manuscript.

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