DESIGNING
HUMAN-SYSTEM
INTERACTION

AromaHub - Designing Collective Stress Intervention for Office Vitality

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AromaHub - Designing Collective Stress Intervention for Office Vitality

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EngD Thesis

The design described in this thesis has been carried out in accordance with the TU/e Code of Scientific Conduct.

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PREFACE

Guangzhou Wanqu Cooperative Institute of Design is a non-profit organization funded by the government, aimed at supporting the development strategy of the Guangdong-Hong Kong-Macao Greater Bay Area. The institute is focused on cultivating high-end talents with cross-cultural, interdisciplinary, and cross-industry abilities. It actively engages in collaborative research, fosters new markets, and translates technological advancements into practical applications in areas such as industrial design, commercial design, and intelligent design. The institute has established multiple laboratories and key technology platforms, including those dedicated to digital art, intelligent design, and sustainable commercial design, aimed at supporting regional economic and social development.

The institute has shown a particularly strong interest in the AromaHub project as it directly supports its strategic goals in the fields of intelligent design and health interventions. Specifically, the AromaHub project is closely related to the EngD project "Designing with Connectivity for Office Vitality" currently being collaborated with Eindhoven University of Technology. This EngD project aims to explore design interventions in office environments using IoT and digital media technologies to enhance the health and work efficiency of office workers. The multi-sensory design method and stress management concept in the AromaHub project are exactly one of the core research contents of the EngD project. The combination of the two can not only strengthen the research capabilities of the institute in related fields, but also provide innovative solutions for improving health and productivity in office environments.

By implementing the AromaHub project, the research institute is expected to make beneficial progress in intelligent design and health intervention research, and further enhance its academic influence and position in the field of design innovation. In addition, the implementation of this project will promote the market-oriented transformation of research results, and thus promote the practical application and promotion of innovative design solutions in a wider range of scenarios. The AromaHub project is expected to provide useful references for design driven health interventions. Through this project, the institute will accumulate more experience in design innovation and health management, and further deepen academic and technical exchanges with international partners.

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Furthermore, I would like to express my appreciation to my family and friends. During this research, your endless understanding, support, and encouragement allowed me to stay focused on my academic work and overcome various challenges.

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EXECUTIVE SUMMARY

Excessive work stress has a significant negative impact on the health and productivity of office workers, so collective stress management is particularly important in modern work environments. Although existing research primarily focuses on individual stress management, there are still unexplored research opportunities for collective stress intervention in the workplace. To this end, this study introduces AromaHub, an innovative solution that combines artificial intelligence and facial expression recognition technology to improve stress management in office environments through personalized multi-sensory intervention.

AromaHub combines the concepts of aroma and hub. Aroma reflects the system's core idea of using fragrances to provide comfort and relaxation, while hub signifies the system as the pivotal point for multi-sensory experiences. It was designed to create a healthier and more vibrant work environment. The system uses a camera to capture individual facial expressions and employs convolutional neural network (CNN) algorithms to analyze users' emotional states, particularly focusing on negative emotions. These emotions are quantified into discrete data for each user. The system then aggregates these data to determine the collective stress level. Based on this, each user's AromaHub device is individually triggered to provide synchronized stress relief, ensuring that each member of the group receives timely and effective intervention. Its hardware components include the function of diffuser and distiller. The hydrosol manufactured by the distiller replaces the essential oils of general diffuser to make the smell closer to nature. The jellyfish-shaped spray design of the diffuser also has a visual soothing effect. The conceptual design process went through two iterations: the first conceptual design was based on the phenomenon of sedentary behavior, which one of manifests of collective stress, and the second combined sensors that took real-time physiological signals to improve the intervention mechanism.

The experiment recruited 24 participants from Chinese universities who were randomly divided into six groups, three experimental groups using the AromaHub system and three control groups. Stress was triggered by mental arithmetic tasks, and the stress level, as assessed by real-time facial expression analysis, triggered the corresponding intervention. The experiment was conducted in an online conference environment to ensure accuracy, as this environment requires all participants to have their cameras turned on. Personal cameras were a transitional solution for this system. Quantitative and qualitative data were collected through the mental arithmetic tasks, facial expression analysis, the State-Trait Anxiety Inventory

(STAI), the Relaxation Rate Scale (RRS), and participant questionnaires. In addition, PPG sensors were used as ground truth to assess stress levels after the experiment.

Preliminary results showed that AromaHub improved the office environment and enhanced interaction between participants, leading to more effective stress management. Quantitative data analysis showed that participants who used AromaHub had significantly reduced stress levels, and qualitative feedback also showed that participants had a high level of experience and acceptance of the system. The study also highlighted the impact of environmental factors, user preferences, and data accuracy on the effectiveness of the system.

Future research will focus on addressing ethical issues of privacy and the use of facial recognition technology and considering the integration of wearable technology to enhance the practicality of the system. Further research will include long-term effect evaluation and explore how AromaHub can be integrated into workplace stress management and health promotion strategies, considering the potential for introducing more non-invasive sensors and expanding multi-sensory experiences.

AromaHub offers a promising solution for collective stress management in office environments. By combining artificial intelligence and multi-sensory interventions, the system has the potential to improve employee well-being and productivity. The positive results of the user study suggest that AromaHub has the potential to transform workplace stress management, laying the foundation for future improvements and wider application.

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1. INTRODUCTION

1.1. Background

Excessive work stress is a significant issue affecting both individual health and organizational productivity. Traditionally, workplace stress has been viewed through an individualistic lens, focusing on personal responses to specific stressors. However, some perspectives in organizational psychology and sociology suggest that stress is also a collective phenomenon influenced by the broader working environment (Schein, 2010 ; Kirkegaard & Brinkmann, 2016) .This approach emphasizes that stress experiences and coping mechanisms are shaped by collective factors within organizational cultures (Lansisalmi et al., 2000).

Collective stress arises from shared stressors affecting groups within an organization. It can be triggered by various sources, including interpersonal interactions, shared deadlines, or organizational changes (Aldwin, 2004).Unlike individual stress, which affects a person based on their own experiences and perceptions, collective stress involves the entire group's perception of and response to stressors (Fineman, 1995). For example, stress from a looming project deadline or a high-stress work environment can create a collective sense of strain that influences everyone in the team.

Research in social psychology highlights several key concepts related to collective stress. For instance, the organizational stress climate reflects the overall stress levels within an organization and how they affect employees (Kozusznik et al., 2015; Lansisalmi et al., 2000). Emotional contagion studies show how stress can spread through teams and affect group dynamics (Mayer et al., 2008; Teuchmann, 1999) . The concept of stress epidemics further explores how stress can proliferate within organizations, creating widespread impacts on both health and performance (Wainwright, 2002).

Collective stress not only affects individual health but also has broader implications for the organizational environment. It can disrupt team cohesion, reduce productivity, and lead to higher turnover rates (Kirkegaard & Brinkmann, 2016). Addressing collective stress involves understanding how stress is distributed across the workplace and developing strategies to mitigate its effects on both individuals and teams.

Effective coping strategies for collective stress include both problem-focused and emotion-focused approaches (Lansisalmi et al., 2000) . Problem-focused coping aims to address and eliminate the sources of stress, while emotion-focused coping seeks to manage the emotional responses to stressors. Research suggests that collective problem-focused coping, where organizations work together to address stressors, is particularly effective in reducing overall stress levels (Rodríguez et al., 2019) . This approach aligns with the notion that stress management should not only target individual responses but also foster collective resilience and support within organizations.

Collective stress is a critical aspect of workplace health that reflects the interconnected nature of stress experiences within organizations. By fostering a supportive organizational culture and implementing group-based interventions, organizations can enhance overall office vitality, mitigate stress, and promote a more productive and positive work environment.

1.2. Problem Statement

1.2.1. Current Methods for Stress Management

Current approaches to stress management focus primarily on individual-level strategies, which often fail to address the complexity of collective stress in organizational settings. Traditional stress management techniques such as cognitive behavioral therapy (CBT), mindfulness-based stress reduction (MBSR), and relaxation exercises are designed to help individuals cope with stress by changing cognitive processes, increasing self-awareness, and promoting relaxation (Grossman et al., 2004; Richardson & Rothstein, 2008).

CBT is widely recognized as an effective approach for addressing individual negative thinking and developing adaptive coping strategies (Beck & Fleming,2021). MBSR programs, on the other hand, use mindfulness practices to increase awareness and acceptance of stress, thereby reducing stress and improving psychological well-being (Kabat-Zinn, 2003). Relaxation techniques such as progressive muscle relaxation and deep breathing exercises are used to reduce physiological stress responses and promote a state of calm (Tsitsi et al., 2017).

While these approaches have benefits for individuals, they often overlook the broader organizational factors that contribute to stress. Research suggests that workplace stress often stems from systemic issues such as high job demands, inadequate support systems, and poor organizational culture (Geurts, 2012). For example, high job demands, and low job control are important predictors of stress and burnout, which calls for a more comprehensive approach to stress management that includes organizational-level interventions (Bakker et al., 2014).

Recent research suggests that combining an individual-focused approach with organizational-level strategies may provide a more comprehensive approach to stress management.

Organizational interventions may include improving working conditions, promoting a supportive work environment, and enhancing communication and team dynamics (Da Costa et al., 2020; Rodríguez et al., 2019) . These combined strategies address both individual and collective stressors and aim to create a more resilient and supportive organizational climate (Fineman, 1995).

Despite the increasing demand for comprehensive stress management approaches, many organizations still rely heavily on individual-focused approaches (Richardson & Rothstein, 2008) . This highlights the need for further research and development of strategies that combine individual and organizational interventions to more effectively manage workplace stress.

1.2.2. Limitations of Current Methods in Addressing Collective Stress

Current approaches to managing collective stress come primarily from the field of social psychology. While these approaches have value, they also have several limitations that undermine their effectiveness in addressing stress in modern work environments.

Traditional social psychological approaches to addressing stress rely heavily on subjective assessments, which are prone to bias. For example, interventions often rely on individuals' feelings of their stress and coping abilities, which can be inaccurate due to confirmation bias or inaccurate self-reporting (Forer, 1949; Nickerson, 1998) . This reliance on subjective judgments can lead to overreaction to nonexistent stressors or underreaction to actual stressors, worsening stress-related problems (Montibeller & von Winterfeldt, 2015).

In addition, the dynamic nature of collective stress—which is influenced by organizational culture, interpersonal interactions, and changing work conditions—challenges traditional social psychological approaches (Maeda et al., 2016) . These approaches often lack tools to adapt to rapidly changing stressors and emotional climates, making them less effective in addressing real-time stress in rapidly changing work environments (Kirkegaard & Brinkmann, 2016) . The lack of real-time data and objective measurement limits the ability to address collective stress in a timely and accurate manner.

Many social psychological solutions require significant individual effort and training to be effective. Techniques such as mindfulness and emotion regulation require employees to invest time and energy, which may not be feasible in busy work schedules (Caulfield et al., 2004) . Furthermore, these approaches often rely on the presence of specific roles, such as team leaders or counselors, to manage stress, which may not be practical in organizations with limited resources or unclear roles (Lansisalmi et al., 2000).

The effectiveness of social psychological approaches is often limited by the inherent difficulty of implementing broad, organizational-level interventions. While individual and group-level strategies may be effective, scaling these interventions to address collective stress across the organization presents logistical and practical challenges in practice (Yu et al., 2018) . As a result, many interventions fail to achieve broad impact and may not adequately address collective stress within organizations.

To address these limitations, there is an urgent need to explore technological solutions that can provide objective, real-time monitoring and management of collective stress. These approaches can complement existing methods and enhance the effectiveness of overall stress management strategies within organizations by providing more accurate assessments and timely interventions.

1.3. Project Overview

1.3.1. Project Goals

With the increasing stress in modern office environments, the health and well-being of employees are facing unprecedented challenges. AromaHub is an innovative project that aims to improve the overall atmosphere of the office environment, relieve collective stress, and promote the physical and mental health of employees through the combination of advanced technology and natural aromatherapy. The system combines modern technology with traditional aromatherapy to provide customized stress management solutions for office spaces through real-time data monitoring and interactive feedback. To achieve the above vision, the AromaHub project set the following three main goals:

- Increase awareness of collective stress

The project aims to increase awareness of collective stress among employees and management. Collective stress is often overlooked, but it has a profound impact on the work environment. Through the implementation of effective interventions, help employees identify and understand the existence and impact of collective stress.

- Evaluate the effectiveness of interventions

The project aims to evaluate the effectiveness of interventions. AromaHub combines the functions of diffuser and distiller, to provide a more natural smell experience. In particular, the spray effect of the diffuser is designed in the shape of a jellyfish, combined with natural fragrance to enhance the soothing effect. Through a user study, we invited participants to evaluate AromaHub's interventions to evaluate its effectiveness. We will use quantitative and qualitative data to evaluate the impact of the system on the office atmosphere and employee stress levels.

- Promote office vitality and well-being

The project goal is to promote the overall vitality and well-being of the office by improving interaction and communication between employees. Our aim is to enhance employee satisfaction and work efficiency by improving the office environment and alleviating stress. Explore the integration of facial expression recognition to further enhance the functionality and adaptability of the AromaHub system and ensure its wide application in a variety of office scenarios.

By achieving these goals, this project aims to create a healthier, more vibrant and efficient office environment. We believe that this will not only increase employees' job satisfaction, but also significantly improve their work efficiency and innovation capabilities.

1.3.2. Process Overview

The AromaHub project aims to improve workplace health by combining artificial intelligence and aromatherapy to manage collective stress. To ensure the project is effectively conducted and achieves the expected results, we have designed a systematic plan. The plan covers the entire process from preliminary research and planning to system design, prototype development, user study, data analysis and final reporting and improvement. The following is a detailed description of each stage to ensure that the goals of each stage can be achieved smoothly and well connected.

- Preliminary Research and Planning

In the preliminary research and planning stage, we will first conduct a comprehensive literature review on collective stress management to identify the shortcomings of existing research and determine the innovation points of the AromaHub project. We will develop a detailed project plan with a timeline, resource allocation and key milestones to ensure the orderly progress of the project and the achievement of goals.

- System Design and Development

The system design and development phase include designing the system architecture of AromaHub, ensuring the non-invasive and reliable data collection process, while paying attention to data accuracy and user privacy protection.

- Prototype Development and Testing

During the prototype development and testing phase, we will build a preliminary prototype, combining hardware and software components to ensure the overall synergy of the system. We will conduct internal tests to evaluate the functionality, accuracy and reliability of the system, and make necessary adjustments and improvements based on test feedback.

- User Study

The user study phase will involve designing and conducting an experiment, including participant recruitment, experimental setup, and specific procedures to ensure the scientific rigor of the study.

- Data Collection and Analysis

During the data collection and analysis phase, we will collect quantitative data to evaluate the impact of the system on stress levels. At the same time, we will also collect qualitative data to understand the subjective experience. By comprehensively analyzing quantitative and qualitative data, we will evaluate the effectiveness and room for improvement, thereby providing a basis for further optimization of the system.

- Reporting and Improvement

During the reporting and improvement phase, we will draft a detailed report containing research methods, data analysis results and conclusions. Based on the results of the user study, we will further improve the system, solve the problems found and enhance the system's performance. We will develop a plan for the next step, including possible larger-scale testing and promotion strategies to ensure the widespread application and improvement of the system.

Through theses implementation steps, the project will systematically evaluate and improve its design and functionality to ensure the effectiveness and feasibility of the system in office environments, thereby providing an innovative and sustainable solution for collective stress management.

1.3.3. Project Timeline

To ensure the smooth implementation of the project, we have developed a detailed timeline to guide every phase of the project and ensure that each task can be completed on time and achieve the expected goals. The timeline (see Table 1) covers all important phases from project kick-off to final report delivery, and clarifies the main tasks and key milestones of each stage.

Table 1: Project Timeline

Phase and Date	Main Tasks	Milestone
Phase 1 2023.10.15-2023.11.15 Project Kickoff	Hold a project kick-off meeting to clarify project goals. Develop a detailed project plan, including timeline and resource allocation. Complete preliminary project requirements analysis and risk assessment.	The project kick-off meeting is completed, and the project plan is developed.
Phase 2 2023.11.15-2024.01.15 Literature Study	Conduct a comprehensive literature review on collective stress management. Find the shortcomings of existing research and identify the innovations of the AromaHub project.	The literature review report is completed, and the research innovations are determined.
Phase 3 2024.01.15-2024.02.15 Hardware Selection	Research and select hardware components that meet project requirements. Evaluate the performance and applicability of various hardware options. Find hardware suppliers and prepare for procurement.	Hardware selection and procurement are completed.
Phase 4 2024.02.15-2024.04.15 Finalization of System Architecture	Design and finalize the system architecture of AromaHub. Ensure that the system architecture meets the non-intrusiveness and reliability requirements of data collection.	The concept of system architecture design is completed and approved.
Phase 5 2024.04.15-2024.06.15 Software Design and Development	Design and develop the core software functions of AromaHub Implement preliminary integration of software and hardware. Perform functional testing and adjustments of the software.	Software design is completed, core functions are developed and initially integrated.
Phase 6 2024.06.15-2024.07.15 Hardware and Software Integration	Complete the integration and connection of hardware components. Perform comprehensive integration of software and hardware to ensure that the system works together. Conduct iterative development of the system and optimize and improve functions based on feedback.	Integration of hardware and software is completed, and the system is iteratively improved.

Phase 7 2024.07.15-2024.07.31 Testing and Evaluation	Perform comprehensive system testing, including functional testing, performance testing, and user experience testing. Make necessary system adjustments and optimizations based on test results. Evaluate the effectiveness and stability of the system.	System testing is completed, and adjustments and optimizations are implemented.
Phase 8 2024.08.01-2024.08.15 User Study	Design and conduct a user study, recruit 24 participants, and divide them into experimental and control groups. Conduct experimental settings, including participant screening, experimental design, and data collection.	User study implementation and data collection completed.
Phase 9 2024.08.15-2024.09.15 Report Writing and Delivery	Collect and integrate feedback from academic mentors and industrial design mentors to revise the report. Complete the preparation of the final version of the report.	The report is written and sent for review, and the final report is revised and submitted.
Phase 10 2024.9.16-2024.10.9 Defense Preparation	Prepare and conduct project defense, present project results and solutions.	Defense completed successfully; project officially concluded.

In order to ensure the smooth progress, the following regular meeting schedule has been developed: academic mentor meetings are held on the second and fourth Thursdays of each month to discuss the overall progress of the project, literature review results, system design, and research methods to ensure that the project meets academic standards and solves research-related problems; industrial design mentor meetings are held on the second and fourth Wednesdays of each month, focusing on hardware selection, system structure design, software development progress, and practical application issues to ensure that the system design meets industrial requirements and standards; a stage progress meeting is held on the first working day of each month to review the progress of the previous month, plan the tasks for the next month, and assess project risks and resource requirements to keep the project dynamic and make timely adjustments.

Through the above schedule and regular meeting arrangements, we ensure that the project can complete the tasks of each stage within the scheduled time, keep the efficient operation of the project, and achieve the goal. These arrangements not only help us stay on the right track at each stage, but also promote effective communication and collaboration within and outside the team.

2. THEORETICAL BACKGROUND

2.1. Stress Management

2.1.1. Strategies and Methods for Stress Management

Effective stress management is essential for keeping personal health and organizational efficiency. Given the harmful effects of stress on employee and organizational performance, it is necessary to implement strong strategies to manage and reduce stress. Whether it is positive stress (eustress) or negative stress (distress), the physiological harm of stress to personal health is inevitable (Kersten-van Dijk, 2018). Stress can disrupt a person's endocrine balance, damage the autoimmune system, and cause cardiovascular disease (Cooper & Marshall, 1976). Stress is also associated with anger, anxiety, depression, and may lead to chronic diseases due to accumulated stress (Finney et al., 2013; Judge et al., 2000). In addition, the negative effects of stress on organizational performance include undermining internal cooperation, increasing absenteeism and employee turnover, and reducing employee motivation (Briner & Reynolds, 1999) . Therefore, effective stress management is essential for both personal health and organizational success.

Individual coping strategies include cognitive behavioral therapy (CBT), stress management training, and physical health maintenance. CBT is an effective method for managing personal stress, helping individuals find and challenge negative thought patterns and develop coping strategies (Beck & Fleming, 2021). Techniques such as cognitive restructuring, mindfulness, and relaxation exercises can reduce stress by changing an individual's perception of and response to stressors (Hofmann et al., 2012). In addition, providing employees with training in stress management techniques can equip them with practical tools for dealing with stress. Training programs often include time management skills, assertiveness training, and relaxation techniques (Richardson & Rothstein, 2008) , which help individuals manage workloads and personal stress more effectively. For example, ViBreathe enhances traditional breathing training by integrating physiological biofeedback into tangible interfaces for stress management (Yu et al., 2021). The UnWind system supported relaxation training and stress management by combining music with biofeedback technology (Yu, Funk, Hu, & Feijs, 2018). Finally, regular physical activity, a balanced diet, and adequate sleep are essential for managing stress. Exercise has been shown to improve mood and reduce anxiety by promoting the release of endorphins (Craft & Perna, 2004), and a healthy lifestyle supports resilience to stress and overall mental health.

Organizational-level approaches include co-active coping and collective coping. Co-active coping refers to individuals sharing and imitating coping strategies within a team, using the collective knowledge and experience of team members to enhance stress management. For example, team-based stress management workshops and peer support groups can promote the sharing of effective coping skills. Collective coping refers to organizations implementing collective coping strategies to deal with stressors that affect the entire workforce. These strategies include redesigning work processes, improving communication channels, and creating a supportive work environment (Bakker et al., 2005). Collective coping such as stress reduction workshops and team-building activities can help reduce stress throughout the organization. In addition, developing a positive work culture is essential to reducing collective stress, including promoting open communication, providing recognition and support, and ensuring that employees feel valued and respected (Hobfoll, 2001). A positive work culture can increase job satisfaction and reduce stress-induced absenteeism and employee turnover.

Technological innovation plays a key role in stress management. Technological advances have introduced new stress monitoring and management methods, such as wearable devices and stress monitoring applications. These tools can provide real-time feedback on stress physiological indicators and help individuals and organizations understand stress patterns through data visualization, thereby implementing targeted interventions (Xue et al., 2019). Digital stress management tools such as mobile applications and online platforms provide employees with convenient access to stress management resources. These tools often include guided meditation, stress tracking, and virtual consultations. Integrating them into the workplace can enhance employees' ability to access stress management resources and support (Lau et al., 2020). In addition, virtual reality (VR) has become a novel stress relief method. VR-based interventions can create immersive environments that promote relaxation and mindfulness. Studies have shown that VR can effectively reduce stress and anxiety in various environments. Introducing VR-based stress management tools into the workplace can provide employees with new ways to manage stress (Fernández-Álvarez, 2020).

2.1.2. Human-Computer Interaction (HCI) for Stress Management

Technological innovations in the field of human-computer interaction (HCI) have played a key role in stress management. In recent years, advances in personal informatics (PI) systems and biofeedback systems have provided new methods and tools for stress management (Kudo et al., 2014; I. A. D. and J. F. Li et al., 2010). PI systems help users improve their behavior patterns by providing data-driven self-insight, while biofeedback systems help users control unconscious physiological processes to a conscious level by collecting users' physiological signals (such as heart rate variability) and providing feedback in different formats (Kudo et al., 2014; Weiser & Brown, 1997). These technologies are not only helpful for individual stress management, but also provide new tools and methods for organizational-level stress intervention (Yu, Funk, Hu, Wang, et al., 2018).

In the field of HCI, visual feedback is an important method for managing stress and promoting behavioral change. Studies have shown that visual feedback can effectively enhance users' awareness of stress status and promote behavioral changes. For example(see Figure 1), the Breakaway project encouraged employees to move by placing sculptures on their desks to reflect body postures (Jafarinaimi et al., 2005). MoveLamp increased the number of steps taken during the workday by changing office lighting to reflect individual physical activity (Fortmann et al., 2013). Fish'n'Steps was a social computer game that promoted physical activity through display screens (Lin et al., 2006). ClockViz mapped the organization's stress status to the clock to improve the team's awareness of the overall stress status (Xue et al., 2017). In addition, the DeLight system offered an innovative approach to stress management and relaxation training by integrating biofeedback with ambient light (Yu et al., 2018).

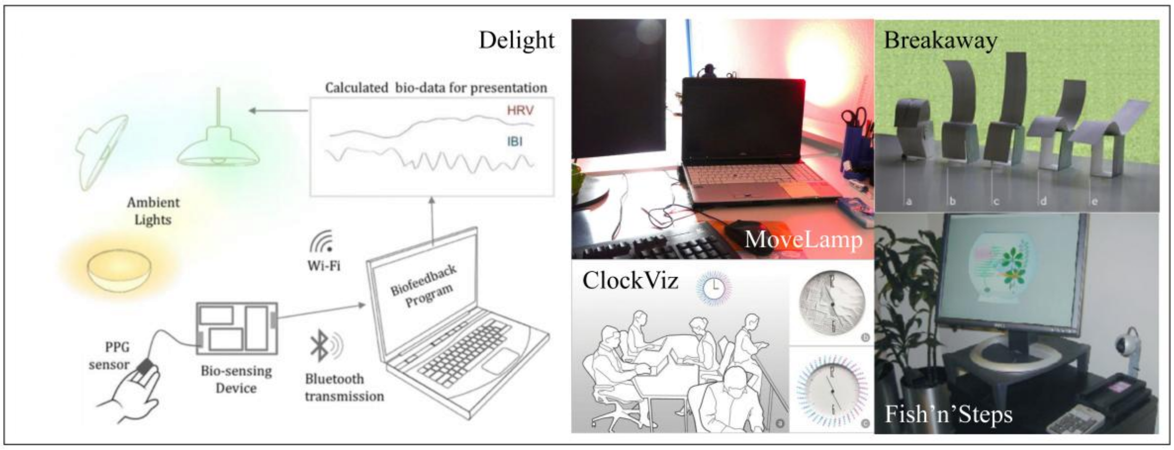

Figure 1: Design Cases of Visual Feedback

Auditory feedback also plays a key role in stress management, mainly through real-time feedback of music and sound to improve stress status. For example, Sonic Cradle combined breathing with music to enhance the meditation experience (Vidyarthi, 2012). BreathTray provided feedback by integrating continuous monitoring results on the desktop, helping users keep calm breathing without distraction (Moraveji et al., 2012). In addition, research used interactive music to remind sedentary individuals to stand up and move around (Ren et al.,

2018) , while other research used sound feedback of real-time heart rate variability for biofeedback training (Yu et al., 2015). These auditory feedback systems enhance users' stress management capabilities and behavioral changes by providing sound prompts and music interventions.

As an emerging stress management technology, olfactory feedback modulates psychological states and physiological responses through odor stimulation, showing its potential in stress relief. Studies have shown that specific scents can significantly improve mood and reduce physiological stress responses. For example, research found that lavender fragrance can effectively reduce anxiety levels and improve mood (Hedigan et al., 2023) . Other study showed that scents such as orange and lavender can reduce heart rate and skin galvanic response, which are physiological indicators related to stress, showing that scent intervention can effectively reduce physiological stress responses (Djilani, 2012). Application in the work environment has also shown positive effects. The use of lavender and mint fragrances in the office can significantly reduce employee stress and improve job satisfaction (Matsubara et al., 2023). A study showed that the continued use of aromatherapy can improve mental health in the work environment in the long term, especially in high-stress environments (Clements-Croome, 2006) . These studies show that by properly introducing olfactory feedback, stress can be effectively relieved and overall mental health can be improved in work and daily life.

Multi-sensory technologies play a key role in applications designed to manage stress and promote emotional well-being (Ren et al., 2019). Virtual reality (VR) and augmented reality (AR) environments provided immersive experiences that effectively reduced stress levels through tranquil visuals and soothing sounds (Mucha et al., 2022; V. Smith et al., 2020) . Biofeedback systems combined physiological sensors and multisensory input to provide real-time feedback and adaptive interventions to enhance self-regulatory skills (Lehrer & Gevirtz, 2014; Prinsloo et al., 2013; Yu et al., 2018) . Internet of Things (IoT) smart environments adjusted environmental stimuli such as lighting and music based on the user's stress level to promote relaxation and comfort (Hedblom et al., 2019). In clinical settings, these technologies supported cognitive behavioral therapy and mindfulness-based stress relief practices to improve emotional regulation and well-being (Hölzel et al., 2011; Kabat-Zinn, 2003).

2.2. Stress Recognition Technology

2.2.1. Methods of Stress Recognition

Stress recognition involves identifying and understanding stress responses through a variety of measures. These methods can be broadly categorized into physiological, psychological, and physical methods. Each method offers unique insights and has its own advantages and limitations. This article will first present an overview of each method and then explore its specific implementation and application in detail.

- Physiological Methods

Electroencephalogram (EEG): EEG measures the brain's electrical activity, offering direct insights into neural responses to stress. The main advantage of EEG is its high temporal resolution, allowing researchers to capture rapid changes in brain activity. However, it requires the placement of multiple electrodes on the scalp, which can be uncomfortable and impractical for daily use. In addition, EEG data is susceptible to noise from eye movements and muscle activity, requiring complex algorithms for accurate analysis. Despite these challenges, EEG is widely used in clinical settings and research to study stress and other cognitive states (Katmah et al., 2021; Porges, 1995).

Electrocardiogram (ECG): ECG measures cardiac activity and is often used to assess heart rate variability (HRV), a key indicator of stress. HRV reflects changes in the time intervals between heartbeats and is inversely proportional to stress levels. ECG provides precise and reliable data on cardiac function, making it a reliable tool for stress monitoring. However, the need for contact electrodes may limit its usefulness for daily continuous monitoring (Stuart et al., 2022). ECG is often used in research and clinical settings to study the effects of stress on the cardiovascular system (Pourmohammadi & Maleki, 2020; Sloan et al., 1994).

Galvanic Skin Response (GSR) and Electrodermal Activity (EDA): GSR and EDA measure changes in the electrical conductivity of the skin, which is caused by the stimulation of sweat glands by the autonomic nervous system under stress. These methods are non-invasive and relatively easy to implement, making them suitable for continuous monitoring. However, GSR and EDA are susceptible to other factors, such as ambient temperature and humidity, which can affect accuracy (Pereira et al., 2017). These measures are often used in affective computing and psychophysiology research to assess emotions and stress responses (Dimitriev et al., 2008).

Photoplethysmography (PPG): PPG uses optical sensors to measure changes in blood volume in tissue microvascular beds, providing insights into heart rate and HRV. PPG is non-invasive and can be easily integrated into wearable devices such as smart watches, allowing for continuous monitoring during daily life. However, it is susceptible to motion artifacts and has lower accuracy in people with darker skin tones(Adib et al., 2015). PPG is widely used in consumer health devices and clinical settings for stress monitoring and cardiovascular health assessment (Charlton et al., 2018; Ritvanen et al., 2006).

Electromyography (EMG): EMG measures electrical activity generated by skeletal muscle, reflecting muscle tension, a common stress response. EMG provides direct measurement of muscle activity with high temporal resolution. However, it requires precise electrode placement and is susceptible to noise from motion and external electrical devices (Van Amelsvoort et al., 2000). EMG is used in ergonomics research, sports science, and clinical research to assess muscle tension and stress-related muscle responses (Kang, 2004).

Respiratory Responses: Respiratory measures, including piezoelectric and electromagnetic sensors, track breathing patterns and rates, which change under stress. These methods are non-invasive and can provide continuous data on respiratory activity. However, they may require wearing more sensors, which may be inconvenient for prolonged use (Neelakantan et al., 2009). Respiratory monitoring is used in stress research and clinical settings to study the effects of stress on breathing (Spielberg, 1971).

- Psychological methods

Questionnaires: Self-report questionnaires are widely used to assess psychological stress. Instruments such as the State-Trait Anxiety Inventory (STAI) and the Relaxation Rating Scale (RRS) measure perceived stress and relaxation levels (Benson et al., 1974; Spielberg, 1971). These methods are easy to implement and cost-effective, but are limited by self-report bias (Bolger et al., 2003). Questionnaires are commonly used in clinical psychology, research, and workplace settings to assess stress and psychological well-being.

- Physical Methods

Automated Facial Expression Analysis (AFEA): AFEA uses computer vision and machine learning algorithms to analyze facial expressions that can show stress. This method is non-invasive and can be conducted via a camera, offering real-time insights into emotional states (Barakova et al., 2015). However, differences in individual expressions and cultural factors can affect accuracy (Dimitriev et al., 2008). AFEA is used in affective computing, human-computer interaction research, and psychology research to assess stress and emotions (Kang et al., 2004).

Infrared (IR) Eye Tracking: IR eye tracking measures eye movements and pupil dilation, which change under stress. This method is non-invasive and provides accurate eye movement data. However, it requires specialized equipment and controlled lighting conditions, which may limit its use in everyday settings (Pereira et al., 2017) . IR eye tracking is used in psychology research and human-computer interaction research to assess cognitive load and stress (Neelakantan et al., 2009).

Automatic Gesture Analysis: This method uses computer vision and machine learning to analyze body gestures, such as fidgeting or defensive postures, that can show stress. Automatic gesture analysis is non-invasive and can be performed via a camera, providing contextual information for other stress indicators. However, it requires complex algorithms to distinguish stress-related gestures from other movements (W. Kim et al., 2009) . Gesture analysis is used in affective computing, ergonomics research, and psychology research to assess stress and emotional states (Adib et al., 2015).

Each stress recognition method offers unique insights, with their own advantages and limitations. Physiological methods such as EEG, ECG, GSR, PPG, EMG, and respiratory response provide objective measures of stress-related physiological responses but may be affected by practical challenges and artifacts. Psychological methods such as questionnaires offer subjective insights but are limited by self-report bias. Physical methods such as facial expression analysis, eye tracking, and gesture analysis provide non-invasive and real-time monitoring capabilities but require complex analysis techniques to ensure accuracy and reliability. Combining multiple methods can enhance the robustness and comprehensiveness of stress recognition systems.

2.2.2. Stress Detection through Facial Expression Recognition

- Emotion and Stress

Emotion and stress are closely related psychological and physiological phenomena. They not only affect the individual's psychological state, but also have a profound impact on physical health. Understanding the relationship between emotion and stress is crucial to the development of effective stress management tools and affective computing technology.

Emotion is a complex psychological and physiological response to a specific event or situation, covering subjective experience, cognitive evaluation, physiological changes and behavioral responses (C. A. Smith, 1989) . Common emotions include happiness, anger, sadness and fear. These emotions are usually short-lived and show obvious changes in the face of specific events. For example, people may feel happy when meeting pleasant events, but may feel depressed or anxious when facing setbacks.

Stress is a physiological and psychological response to external threats or challenges, usually involving an assessment of an individual's adaptability (Lazarus & Folkman, 1984). Stress can be divided into acute stress and chronic stress. Acute stress is usually an immediate response to an unexpected event, such as nervousness before an exam or fear in the face of an unexpected event. Chronic stress is long-term stress that may result from ongoing workload, financial difficulties, or interpersonal relationship problems (B. S. McEwen, 1998).

There is a complex interaction between emotions and stress. Stress can not only trigger negative emotions, such as anxiety and depression, but also affect individuals' responses to emotions (Rahimnia et al., 2013). For example, when individuals face major stressful events, they often feel anxious and depressed, and these negative emotions may further worsen the perception of stress (Kabat-Zinn, 2003). In addition, emotional state can also affect individuals' appraisal of stressors and coping strategies. For example, optimistic people are generally able to manage stress more effectively because they tend to adopt positive coping strategies (Scheier et al., 1986)

The physiological response to stress is mainly achieved through the autonomic nervous system (ANS) and the endocrine system. The physiological responses triggered by stress include increased heart rate, increased blood pressure, and increased skin galvanic response, and these changes may be worsened when emotions are aroused (Cannon & Appleton, 1915). Long-term stress and negative emotions may lead to serious health problems, such as cardiovascular disease, weakened immune function, and psychological disorders (Lupien et al., 2009).

The effects of emotions and stress on health have been widely studied. Acute stress may cause short-term health problems, such as headaches, indigestion, and immune system suppression (Piwek et al., 2016). Long-term chronic stress may lead to more serious health problems, including cardiovascular disease, diabetes, and depression (Lansisalmi et al., 2000; McEwen, 1998). Negative emotions, such as anxiety and depression, are also closely related to physical health problems, and they may worsen health problems by affecting behavioral habits and physiological functions (Lupien et al., 2009).

- Facial expressions and emotion

Facial expressions (FE) are a keyway to convey emotions. They are rich in information and can instantly reflect an individual's stress status (Ekman, 1993). The study of facial expressions helps us understand the complexity and diversity of emotions, especially in the fields of affective computing and human-computer interaction (Picard, 1999).

Scientists generally agree that facial expressions of some basic emotions are universal across cultures, including anger, disgust, fear, happiness, and sadness (Ekman, 1993). This universality provides a stable foundation for affective computing, making it possible to develop algorithms that can recognize and understand these emotions (Marsella et al., 2010). For example, when an individual is angry, his or her face may show a tight jaw and a furrowed brow, while happiness is usually manifested as a smile and wrinkles at the corners of the eyes (Ekman & Rosenberg, 2005).

Stress, as an emotional response, can also be expressed through facial expressions. Although there is no universal facial expression for stress, studies have shown that negative emotions such as anger, disgust, and fear are closely related to stress (Dinges et al., 2005). In these studies, the relationship between facial expressions and stress was verified by increases in participants' cortisol levels and heart activity (Lerner et al., 2015). For example, when faced with a threat or challenge, an individual may display a fearful expression, which is often accompanied by an increase in heart rate and blood pressure (Cannon & Appleton, 1915).

Research shows that collecting and analyzing facial expression sequences can more accurately predict stress (Giannakakis et al., 2017). Continuous facial expression sequences can reflect changes and fluctuations in emotions, which is important for understanding and predicting stress (Soleymani et al., 2012). For example, by capturing and analyzing individuals' facial expressions at different time points, researchers can find stress patterns in specific situations (Marsella et al., 2010). AromaHub utilized facial expression recognition technology to detect and manage collective stress through real-time emotion assessment. By integrating facial expression data, intervention measures could be adjusted in real-time.

In the field of affective computing, facial expression recognition technology has been widely used in various scenarios, including smart homes, smart offices, consumer services, educational services, and security applications (Leong et al., 2023; Picard, 1999). These technologies capture and analyze individuals' facial expressions in real time through cameras and computer algorithms to infer their emotional state (Ekman, 1993). Facial expressions are an important way to understand and recognize emotions, and are also important for the detection and management of stress (B. S. McEwen, 1998). By continuously improving facial expression recognition technology, we can develop more intelligent and humane affective computing systems to provide better services and support to users.

- Methods of facial expression recognition

Facial Expression Recognition (FER) is a crucial research area in computer vision, employing diverse methods to accurately detect and interpret emotional states from facial images. Traditional approaches include manual design and geometric modeling techniques like Local Binary Patterns (LBP) for texture features and Histogram of Oriented Gradients (HOG) for geometric details (Dalal & Triggs, 2005).

Deep Learning, particularly Convolutional Neural Networks (CNNs) such as ResNet and VGGNet, has revolutionized FER by autonomously learning facial features and achieving high accuracy through end-to-end training on large datasets (He et al., 2016; Simonyan & Zisserman, 2014). Dynamic expression analysis in video sequences benefits from Recurrent Neural Networks (RNNs) like Long Short-Term Memory (LSTM), enhancing real-time emotion recognition (Jaiswal & Valstar, 2016).

FER finds extensive applications in intelligent interfaces, affective computing, autonomous driving, and health monitoring, enabling systems to adapt behavior based on real-time facial expression analysis (McDuff et al., 2013). Continued advancements in FER promise enhanced human-computer interaction and tailored solutions across various domains. Chew et al. used Transfer Learning with MobileNet V2 and TensorFlow to run the pre-trained FER2013 dataset to figure out stress or non-stress states (Chew et al., 2022). An IoT-enabled unobtrusive realtime monitoring system was developed to detect the person's emotional states by analyzing facial expression videos. The proposed method found individual emotions in each video frame, and a decision on the level of stress was made at the sequence level (Hindu & Bhowmik, 2022). Research introduced a real-time stress detection framework using a connected convolutional network to recognize stress-related facial expressions, which alerted users to take breaks if stress levels exceeded a certain threshold (Zhang et al., 2019).

Facial expression recognition research relies on a variety of standardized databases for model training and evaluation. CK+ has 593 video sequences from 123 participants, each sequence gradually transitions from neutral expression to target expression, with a total of 327 fully labeled sequences (Lucey et al., 2010). FER2013 has 35,887 48x48 pixel grayscale images, covering rich diversity and 7 basic expression labels (Goodfellow et al., 2013). The JAFFE database manually annotated 213 images of 10 Japanese women, showing six basic expressions and neutral expressions (Lyons et al., 1998). MMI has more than 2900 video and image sequences from 25 participants, showing the transition from neutral expression to six basic expressions (Pantic et al., 2005). AffectNet is a large-scale database having 1,000,000 images, covering a wide range of emotions and crowd characteristics (Mollahosseini et al., 2019) . EmotioNet and SFEW provide emotional expression images from the Internet and movies for studying the application of facial expressions in the real world (Dhall et al., 2008). RAF-DB has 29,672 images with rich emotion labels and crowd characteristics, suitable for complex expression research (Li et al., 2017) . These databases provide researchers with a wide range of data resources to support the development and application of facial expression recognition technology in different scenarios.

In the AromaHub project, we employed the FER2013 dataset which provides pre-labeled facial expression data suitable for everyday contexts. This dataset’s pre-annotated images streamlined our data processing. We used the Xception network model, a CNN architecture known for its deep learning capabilities, to train our emotion recognition model.

3. METHODOLOGY

3.1. Introduction

The research methodology of the AromaHub project combined qualitative and quantitative research, to design, develop and evaluate an innovative stress management system. A comprehensive literature review was conducted to gain an in-depth understanding of existing stress detection and intervention methods, find research gaps, and clarify the innovation of AromaHub.

Two iterations were conducted during the design process. The first iteration used collective stress manifestations as a starting point for conceptual design, and the second iteration incorporated the real-time physiological signals through wristband to start intervention measures. Based on these iterations, design opportunity analysis and design considerations were conducted, and the conceptual framework of the system was evaluated.

3.2. Concept Design

3.2.1. User Definition

User Problem Background: Office employees are experiencing high collective stress due to heavy workload, fast work pace, and stress in teamwork. This stress not only affects the mental health of employees, but may also reduce work efficiency and teamwork effectiveness. Traditional stress management methods often focus on individuals and ignore the management of collective stress, so a more holistic and integrated solution is needed. Users hope to find a stress management method that is both effective and integrated into the work environment to improve collective well-being and work productivity.

Target users: The main users of the intervention system are office employees in a corporate environment. These employees are usually faced with collective stress caused by high work stress, intense work pace, and team interaction.

3.2.2. Design Process

- **First iteration: Intervention Design for Sedentary Behavior-caused Collective Stress**

In the first iteration of the intervention system, we focused on one of the manifestations of collective stress: sedentary behavior. Sitting for long periods of time not only has adverse effects on individual health, but also increases the risk of cardiovascular disease and metabolic syndrome (Owen et al., 2010). In the work environment, prolonged sitting can also increase collective stress levels, affecting overall productivity and employee well-being (Dunstan et al., 2012) . In the work environment, proper intervention methods, such as standing workstations or short activity breaks, can effectively reduce sedentary time and improve employees' overall health and work efficiency. In addition, the specific aromas, such as lavender and lemon, have significant stress-reducing and refreshing effects (Moss et al., 2003). To address this challenge, we proposed a conceptual design that uses security cameras to record the sedentary behavior of office workers and uses diffuser to intervene.

-Specific implementation

The system monitored employee activities in real time with security cameras in the office. In the HCI community, researchers often exploit the potential of public cameras to detect, track and interact with people in a public space (Yan et al., 2022) . If it was detected that an employee had been stationary for a long time, the system would activate the aroma diffuser and release a specific aroma to remind employees of appropriate activities. The aromatherapy machine used calm technology (Feijs et al., 2017) , aiming to gently remind employees of sedentary behavior through aroma, while increasing office vitality, thereby improving collective stress. The entire process used Wizard of Oz to implement an internal test.

-Challenges and Difficulties

Effectiveness of the intervention: Aromatherapy has been widely studied and proven effective in reducing stress and anxiety (Moss et al., 2003) . However, the effectiveness of using aromatherapy diffusers to remind employees to move and improve sedentary behavior remains a challenge. The intensity, type, and timing of release of the scent need to be repeatedly evaluated and adjusted to ensure that it achieves the desired effect without causing distress or disgust to employees.

The relationship between sedentary behavior and stress: Although studies have shown that there is a correlation between sedentary behavior and stress levels (Thorp et al., 2011) . But this relationship is not absolute, and sitting is just one of the many manifestations of collective stress. Different employees may respond significantly to sedentary behavior, so assessing collective stress levels by checking sedentary behavior alone may not be comprehensive.

- **Second iteration: Real-time Detection and Intervention for Collective Stress**

In the second iteration of the intervention system, we are committed to alleviating stress by finding collective stress in real time and taking effective intervention measures, promoting communication and interaction among employees, and thus improving office vitality. The core of this iteration is to use wristband data to figure out the stress level of employees and trigger corresponding intervention measures in a timely manner based on this data. Wearable devices such as wristbands have extensive research support in real-time monitoring of physiological data and assessing stress levels. Studies have shown that heart rate variability is an effective indicator of psychological stress (Kim et al., 2004). Skin galvanic response is also widely used for stress detection (Critchley, 2002).

-Specific implementation

By wearing a wristband, the system could extract stress-related physiological data such as heart rate variability, skin galvanic response, and activity level. These data were analyzed by real-time algorithms to find the stress level of employees. When high stress levels were detected, the system automatically triggered an aromatherapy machine to help employees alleviate collective stress. In addition, the aromatherapy system would remind employees to take proper breaks and interact through the natural smell, further improving the office atmosphere and collective stress. The whole process used Wizard of Oz to implement an internal test.

-Challenges and Difficulties

Computing power requirements and cost issues: If the current wristbands on the market want to achieve high-precision physiological data extraction and analysis, they usually require high computing power support. Such equipment is expensive (Piwek et al., 2016), which increases the cost of the overall system. This poses an economic challenge to the popularization and promotion of systems in practical applications. However, the cost issue of these high-precision monitoring devices has also been widely discussed.

Willingness and dependence: User acceptance and usage habits of wearable devices are key factors affecting their effectiveness (Lazar et al., 2015). Not all employees are willing to wear wristbands, and some may feel uncomfortable or easily forget to wear them. This will lead to inaccurate collective stress monitoring data, or even the inability to check, affecting the overall effectiveness of the system.

3.2.3. System Architecture of AromaHub

When designing AromaHub, the three design cases conducted in previous research and the two iterations provided useful references for improving its functionality. Firstly, the shape of the dynamic spray is designed in the shape of a jellyfish, which helps create a soothing visual experience and enhances the user's sense of relaxation. Secondly, considering the research results on emotional consistency, the AromaHub can produce natural hydrosol as an additive to the diffuser in the machine to enhance the intervention effect. Thirdly, non-intrusive stress detection methods have been applied to AromaHub, making the system more friendly among users because it can check users' emotional states in real-time and accurately. Fourthly, the application of calm technology makes the intervention process more natural and does not interfere with the user's daily activities. Finally, further exploration of the effectiveness of aromatherapy provides support for the continuous improvement and application of the system. Through the explorations, the below design considerations were found for this design.

- **Design considerations:**

-Application of Calm Technology

Low-disruptive: The system should be designed such that interventions do not disrupt the user's work. To keep the work environment tranquil, we reduce reliance on sound and strong visual stimulation by using natural visual and olfactory feedback.

Automation and Adaptability: The system should automatically find and respond to stressful conditions, reducing the user's operational burden. This automated feature ensures real-time and effective stress intervention.

-Non-intrusive design

Natural integration into the work environment: Hardware devices and interventions should be designed to integrate seamlessly with the work environment to avoid more psychological burden or physical interference.

User Privacy Protection: The system should be designed to strictly protect user privacy and only process and store necessary data.

-Multi-sensory Experience

The system should integrate visual and olfactory stimuli to provide a multisensory stress relief experience.

- **AromaHub Design**

The name “AromaHub” combines the concepts of “Aroma” and “Hub.” “Aroma” reflects the system’s core idea of using fragrances to provide comfort and relaxation, while “Hub” signifies the system as the crucial point for multi-sensory experiences. AromaHub aims to effectively manage collective stress in office environments, improving the overall well-being and work efficiency of employees. Its core functions include real-time stress monitoring and automated intervention.

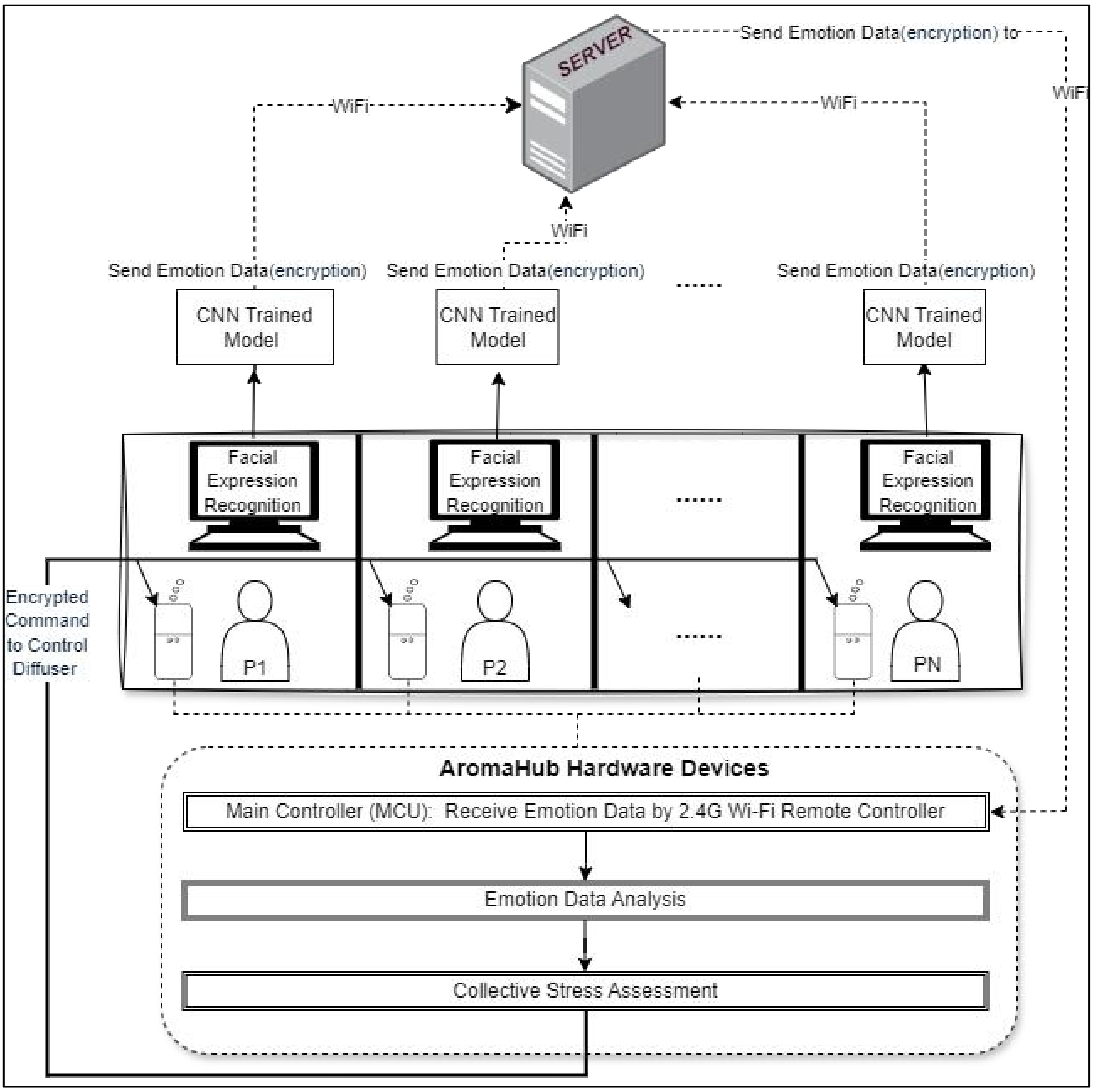

Figure 2: The System Architecture

The system (see Figure 2) uses convolutional neural network algorithms to capture and analyze the collective facial expressions of employees through cameras. These collective expressions are interpreted to decide overall emotional states across the group, which are then processed using predefined models to quantify collective stress levels. This quantification is based on analyzing variations in the group's emotional data over time, providing an estimation of collective stress levels derived from aggregated facial expression patterns. The diffuser is designed as a jellyfish-shaped spray, which not only provides a visual calming effect, but also combines with a hydrosol function to customize the release of a more natural aroma.

AromaHub ensures that all data is encrypted to protect user privacy and uses advanced security protocols to prevent data leakage and unauthorized access. The system is designed with user-friendliness as the center, easy to use and non-interfering with daily work. To ensure affordability, the system minimizes hardware and implementation costs while being effective and increases penetration. The design also considers future expansion and upgrade needs, supporting the addition of more functions and integration of other health management devices.

4. IMPLEMENTATION

4.1. Implementation

4.1.1. Hardware Implementation

- Functional Design of AromaHub

The functional design for AromaHub, as illustrated in Table 2, were found through a comprehensive analysis of user definition, existing literature, design cases and twice iterations of design process. These considerations are rooted in both theoretical foundations and practical insights gathered during the development process.

Table 2: Functional Design

Category	Function	Part	Description	Issues and Challenges
Distiller	Condensation Section	Condensation Tube	Includes copper tubes and cooling fins; size and effectiveness should be considered based on the structure	Condensation tube size and fan power: Finding the best balance between condensation effectiveness and structural dimensions.
		Fan	Power of the fan needs to be determined to improve condensation efficiency	
	Heating Section	Electric Cooker	The power of the electric cooker needs to be determined to improve condensation efficiency.	The electric cooker generates steam, increasing the internal pressure. Designing an effective condenser and heating power to balance the internal pressure is crucial. Additionally, the heating power of the electric cooker will affect the final fragrance of the aroma.
	Air Duct Section	Air Inlet	Used for the fan to draw in ambient air.	The design should achieve a best balance between form and function.
		Air Outlet	Used for dissipating heat from the condensation tube. Needs to have a similar area to the air inlet to ensure the inflow is approximately equal to the outflow, creating a balanced circulation.	The design should achieve a best balance between form and function.

	Dry Burn Prevention	Flow Rate Monitoring	Detects the airflow in the condensation tube during operation.	Decide how to isolate the sensor from the high-temperature environment.
Intelligent System	Deep Learning	Computer Program	Learns human facial expressions and emotions and outputs specific protocols for judgment.	Improving the accuracy of data recognition is crucial.
	Remote Control	Wi-Fi	Receives and outputs specific protocols via Wi-Fi, parses them, and sends control commands over the internet.	Design and fabricate the circuit to ensure it is structurally mountable and that wiring is convenient.
	App Control	App Function	Allows autonomous control through the app.	Assess whether the app is user-friendly.
	Automated Program Control	Atmosphere Adjustment	Monitors the emotions of multiple users, adjusts the aroma mist to modulate the atmosphere and alleviate collective stress. Automatically stops adjustment after stress is alleviated, but no longer than 30 minutes. Needs to determine the effectiveness of the atomizer and misting device.	Assess whether the communication link is smooth and if it can timely adjust collective stress. Also, how to select a high-precision misting device.
Diffuser	Lid Opening Method	Full Lid Opening	The lid is placed on top of the electric cooker and opened by rotating and lifting it through a handle hole.	The airtightness of the lid is crucial for the efficiency of aroma production; the seal between the lid and the cooker needs to be addressed. There is a risk of steam burns when opening the pot.
	Control Method	Button Functions	Button 1: Mode switch with three settings. Button 2: Power switch.	
	Intervention Method	Atmosphere Adjustment Function	Visually, it can emit a mist resembling jellyfish and be accompanied by lighting effects. Olfactorily, it can release natural and pleasant fragrances.	Determine the misting speed and select a suitable misting device.

- Hardware Component Selection

-Diffuser Release

Selection Criteria: To ensure portability and precise control over fragrance release, a combination of a miniature stepper motor and a precision flow control valve was selected as the core components. This setup is compact, energy-efficient, and capable of accurate mixing and dispensing of various fragrances.

Performance Specifications: It supports various types of fragrance liquids, offering compatibility with multiple options. It features a maximum release rate of up to 0.001 mL per minute, ensuring precise control with an accuracy within ±1%.

-Emotion Recognition Device

Selection Criteria: Uses a laptop camera for facial emotion recognition, capturing facial expressions and analyzing them using deep learning models.

Performance Specifications: The accuracy of the facial emotion recognition system varies between 50% and 80% due to several factors, including the quality and resolution of the FER2013 dataset, the diversity of facial expressions, and the specific configurations used in the model. This range was considered sufficient for the intended use within the AromaHub system, where the focus is on collective stress detection rather than pinpointing individual emotions with extremely high precision. It supports real-time processing and online signal transmission for system control.

-Communication Module

Selection Criteria: The 2.4G Wi-Fi communication module was chosen for its suitability in office environments, providing reliable data transmission with high data integrity.

Performance Specifications: Adheres to IEEE 802.11 b/g/n standards, with a maximum data transfer rate of 300 Mbps.

- Hardware Design

The AromaHub system's hardware design comprises the following key modules(see Figure 3):

-Power Module

The AromaHub system utilizes a 220V AC power supply, which is converted to 24V DC to power both the diffuser and the 2.4G Wi-Fi remote control module. Additionally, the 220V AC is converted to 12V DC to power the condenser. The electric cooker is directly controlled by a 2.4G Wi-Fi remote-controlled AC relay, which switches the power on and off. The electric cooker vaporizes the prepared materials, producing steam that is then condensed by the air-cooled condenser into hydrosol, which is stored for future use. This design ensures an efficient and distributed power supply system across the different components of the AromaHub.

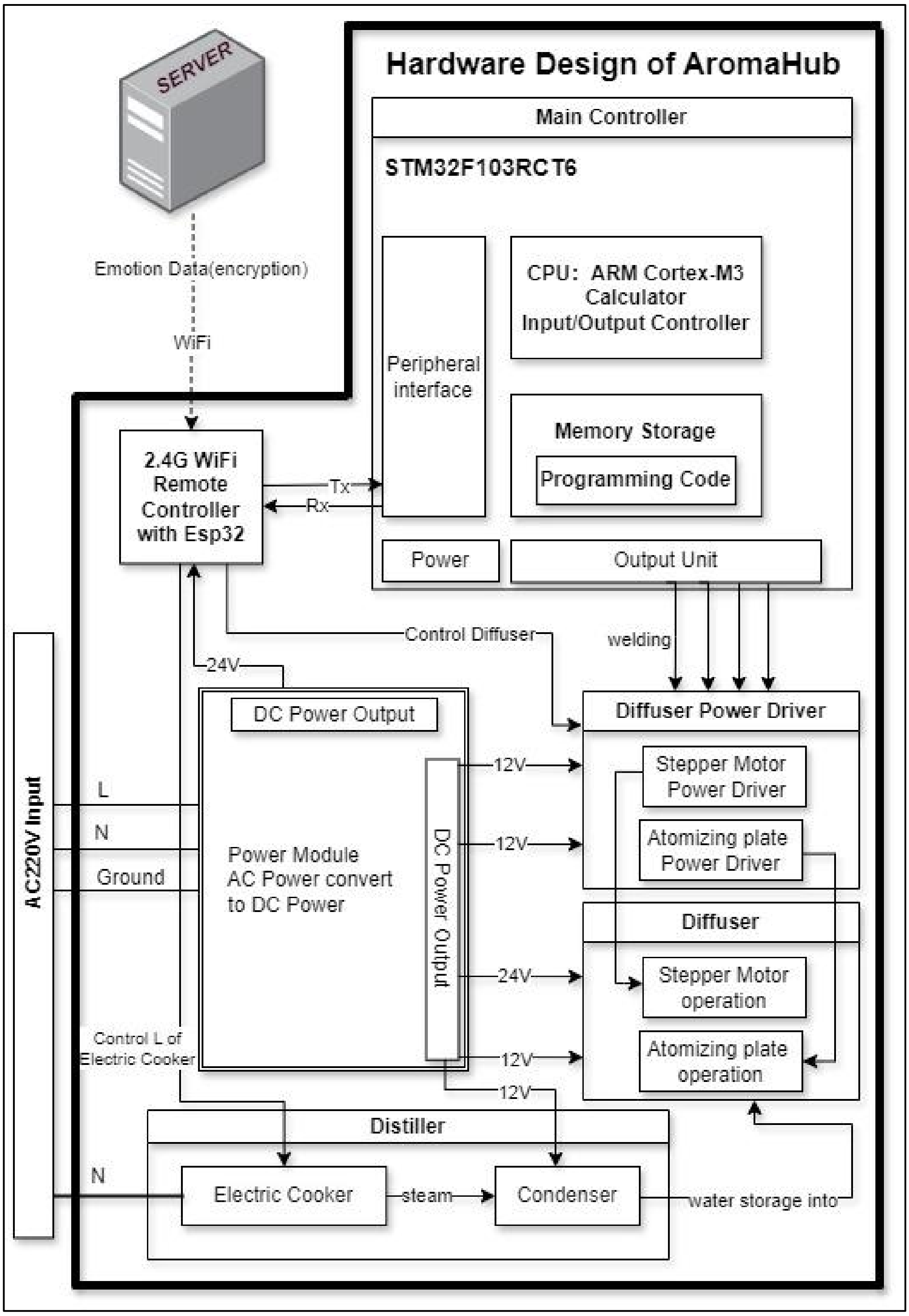

Figure 3: Hardware Design

-Main Controller Module

The main controller is developed using the STM32F103RCT6 microcontroller, which is based on the ARM Cortex-M3 CPU core. The microcontroller's integrated Universal Synchronous/Asynchronous Receiver/Transmitter (USART) is utilized for communication with the 2.4G Wi-Fi remote control module. This microcontroller handles various tasks including data encryption, handshake protocols, mode switching, power control, and the management of internal LED indicators. All control logic and operations are programmed and stored in the microcontroller's internal memory, with input/output ports managed by the controller.

-2.4G Wi-Fi Remote Control Module

The 2.4G Wi-Fi remote control module is based on the ESP32 Wi-Fi chip, which features a dual-core 32-bit MCU and supports both 2.4GHz Wi-Fi and Bluetooth connectivity. This module connects to the internet via Wi-Fi to send and receive messages. When data from the server matches the communication protocol, the module transmits control codes via its UART interface to the main controller, which then executes the commands to control the distiller and diffuser.

-Diffuser Module

The diffuser is controlled by a stepper motor and an atomizing plate, which are powered by their respective driver circuits integrated on a single circuit board. The main controller's control interface is wired to this board. Upon receiving a command to release aroma, the main controller executes the corresponding code, activating the aroma diffusion function. This design allows precise control over the release of aroma, ensuring the correct intensity based on the detected stress levels.

-Distiller Module

The AromaHub's natural hydrosol production is facilitated by a distiller, comprising an electric cooker and a condenser. The cooker heats and distills botanical materials to produce aromatic steam, which is then condensed into hydrosol by the air-cooled condenser. This hydrosol is stored within the diffuser for future use. To ensure sufficient capacity, the system employs an 800W adjustable power cooker, allowing the main controller to regulate the power output. The condenser is a 6W air-cooled unit, which meets the daily hydrosol production needs.

- Circuit Design

The main controller used in AromaHub is developed based on the STM32F103RCT6, a microcontroller unit (MCU) that features an ARM Cortex-M3 CPU core. We primarily use its integrated Universal Synchronous/Asynchronous Receiver/Transmitter (USART) for communication with the 2.4G Wi-Fi remote controller. The MCU is programmed to manage data encryption, data handshake, mode switching, power control buttons, and LED strip control.

The circuit design of the 2.4G Wi-Fi remote control relay is based on the ESP32 Wi-Fi chip, which features a dual-core 32-bit MCU, 2.4GHz dual-mode Wi-Fi, and Bluetooth. It connects to the internet via Wi-Fi to send and receive messages, and then controls the relay through the GPIO pins to manage the electric cooker and diffuser.

The diffuser includes a stepper motor and an atomizing plate. Upon receiving a command from the main controller, the 2.4G Wi-Fi remote controller activates the diffuser switch and selects one of three predefined settings as needed.

Figure 4: Exterior Parts Assembly

- Manufacturing and Assembly

-Component Manufacturing

The AromaHub prototype uses 3D printing for its external appearance and structural components. Initial prototypes were created based on the design drawings to identify and correct any imperfections. After several iterations and refinements, the key components for the system were finalized. These include decorative cover, aroma diffuser section, the midsection of the shell and the high-temperature cooker, as depicted in Figure 4.

The internal circuit design of the AromaHub requires the fabrication of 10 sets of Printed Circuit Board Assembly (PCBA). Each set includes the following components: the main power supply circuit board, a 2.4G Wi-Fi remote control relay for the AromaHub execution layer (diffuser), the main controller, and the stepper motor and atomizer driver boards for the aroma diffuser. These components are ultimately assembled using soldered connections.

During the assembly process, the circuit boards are installed in a sequential order from bottom to top starting with the main power supply circuit board, followed by the 2.4G Wi-Fi remote control relay board, then the main controller circuit board, and finally the stepper motor and atomizer driver board. All circuit boards are connected through soldered wires, ensuring stable connections and effective communication among components.

- Hardware Testing

-Module Testing:

Power Testing: After reflow soldering, the output is DC 24V and 12V. A power redundancy of one is sufficient to support the load of both the diffuser and the condenser.

Communication Testing: Manual soldering was performed, and the power supply and data transmission through the serial port debugging assistant were verified to be functioning correctly.

Distiller Testing: Materials are added to the electric cooker with water in the correct proportions for steaming. The steaming power is adjustable to control the process.

Condensation Effectiveness: A manually crafted copper condenser tube is used. Copper’s excellent thermal conductivity makes it ideal. The copper tube is bent into a 180-degree serpentine shape, improving the condensation effect when paired with air cooling.

Fragrance Release Testing: A one-inch, three-blade propeller is mounted on the stepper motor rotor. The atomizer is activated, and the program controls the motor to rotate 1080.0° each time, forming a jellyfish-like mist that is then expelled.

All modules function correctly, and adjusting the stepper motor speed allows for control over the fragrance release rate, completing the functional testing.

-Debugging and Optimization:

During debugging, the primary issue was the efficiency of distillate condensation. When the power of the electric cooker was increased, the condenser could not keep up, resulting in excessive loss of water vapor. A larger condenser was considered, but it would occupy all available space, leaving no room for the aroma diffuser and requiring more space for the ventilation ducts.

To address this, it was decided that reducing the flow rate of the distillate steam outlet by half would suffice. Correspondingly, the steaming power of the electric cooker was reduced. This optimization did not speed up the distillate output but doubled the amount produced, indirectly enhancing production efficiency.

AromaHub device houses multiple circuit boards (Wi-Fi remote controller, main controller, and power supply board), and some water vapor may escape into the circuitry during distillate production, which can cause short-circuiting over time. To prevent this, epoxy resin was applied to the circuit boards to isolate them from moisture, and adhesive was used around the steam outlet of the cooker lid.

4.1.2. Software Implementation

- Architecture of Software System

The AromaHub software system is structured into three layers. The first is the User Interface Layer, which consists of a desktop application that uses the camera on each user's personal computer to recognize facial expressions in real-time. The emotional data for each user is then encrypted and transmitted to the server. The second layer is the Data Processing Layer, where the server receives and analyzes the encrypted emotional data of each user, evaluates the collective stress level using a specific algorithm, and generates corresponding control commands. These commands are then re-encrypted and transmitted to the Execution Layer, which consists of the diffuser. Each user's diffuser responds to the control commands from the server to deliver proper interventions. As illustrated in Figure 5, these three layers work in seamless collaboration through encrypted data transmission.

- Emotion Recognition Algorithm Implementation

The emotion recognition model[1] was trained using the Xception network model based on images from the FER2013 database through a Python program. The environment was set up on Windows 10 Professional using PyCharm 2022.2.5, with required libraries including Python 3.6.5, TensorFlow 1.1.8, Keras 2.2.0, and others. Since the FER2013 database comes with pre-labeled data in a CSV file, it is only necessary to train the facial emotion model using the dataset. The model was implemented using the Keras neural network framework for deep learning.

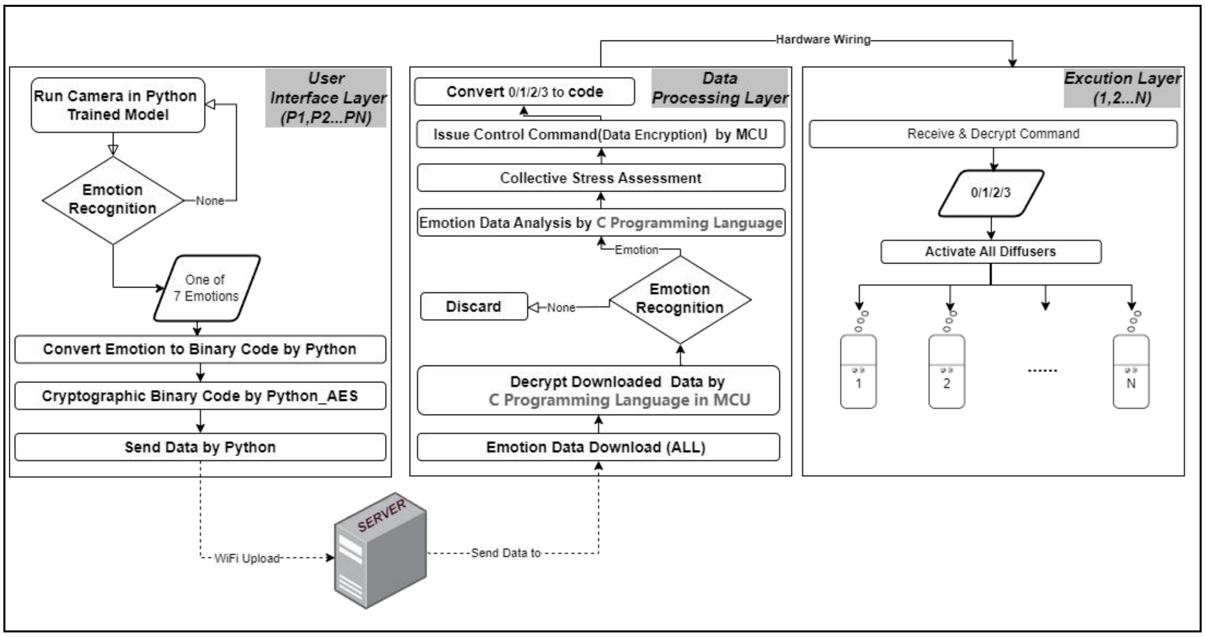

Figure 5: Architecture of Software System

- Interface of Emotion Recognition

The user interface (see Figure 6) is primarily developed using Python with the core modules QtCore, QtGui, and QtWidgets from the Qt framework. The design follows principles of simplicity and intuitiveness. The emotion feedback interface includes an emotion display window and a working button. The interaction logic is also quite simple and user-friendly, with buttons for starting detection, stopping detection, and selecting files.

[1] The model was trained by Huajian Xiao, who provided technical support for this aspect of the research.

Figure 6: Interface of Emotion Recognition

- Mathematical Framework for Assessing Collective Stress through Negative Emotion Proportions

Negative emotions such as sadness, anger, fear, and disgust are commonly indicative of stress, making it essential to assess stress levels. To address this need, we have developed a mathematical framework designed to evaluate collective stress by quantifying these negative emotions. This framework incorporates techniques for emotion detection and data processing to analyze the distribution of negative emotions within a group, thereby estimating the overall level of collective stress. It is important to note that this framework does not directly equate the presence of negative emotions with collective stress levels. Instead, it utilizes a method to adjust the intensity of the diffuser's intervention based on the proportion of negative emotions detected. By modulating the diffuser's intensity in accordance with these proportions, the system delivers targeted interventions that correspond to varying levels of collective stress. This approach provides an indirect measure of collective stress and serves as a basis for implementing effective intervention strategies.

-Calculating Emotion Proportions

Define Time Window: First, determine the size of the time window n, which represents the period from $t-n+1$ to t during which all emotion detection will be considered.

Emotion Detection: Within this time window, each emotion detection result can be categorized as "sad," "angry," "fearful," or "disgusted." For each emotion detection, use the indicator function $I(E_i \in \{sad, angry, fearful, disgusted\})$ to determine if the emotion is negative. If the detected emotion is one of these negative emotions, $I(E_i)$ equals 1; otherwise, it equals 0.

Count Negative Emotions: Sum the occurrences of negative emotions within the time window to obtain the total count of negative emotions.

Calculate Proportion of Negative Emotions: Divide the total count of negative emotions by the total number of emotion detection within the time window n, then multiply by 100% to obtain the proportion of negative emotions. The formula is:

$$P_{\text{negative}}(t) = \left(\frac{\sum_{i=t-n+1}^{t} I(E_i \in \{\text{sad, angry, fearful, disgusted}\})}{\text{n}}\right) \text{x } 100\%$$

This formula quantifies the proportion of negative emotions within the group based on the emotion detection data over the specified time window.

Collective Stress Analysis Function: The collective stress analysis function determines if there is evidence of collective stress within a group by evaluating the number of members showing negative emotions. To ensure reliable assessment, the function only considers collective stress if the number of members exhibiting negative emotions meets or exceeds a threshold β, where $\beta \geq 2$. In other words, at least two members (or more, depending on β) must demonstrate negative emotions for the function to indicate collective stress. If fewer than β members exhibit negative emotions, the function does not signal the presence of collective stress.

- Normalization Process of Negative Emotion Proportion Based on Experimental Data

To ensure the comparability of the negative emotion proportion Pnegative(t), we normalized this proportion to a scale of 0 to 100%. The normalization process was carried out using the following formula:

$$P_{\text{normalized}}(t) = \left(\frac{P_{\text{negative}}(t) - P_{\text{minimum ,negative}}(t)}{P_{\text{maximum,negative}}(t) - P_{\text{minimum ,negative}}(t)}\right) \text{x } 100\%$$

where Pmax and Pmin represent the maximum and minimum proportions of negative emotions, respectively. According to existing literature, there is a strong inverse relationship between the degree of negative emotional proportion and the standard deviation of normal-to-normal intervals (SDNN) in heart rate variability (HRV) (Appelhans & Luecken, 2006). Thus, when the average SDNN value is at its minimum, the corresponding negative emotion proportion is at its maximum, and vice versa. To determine these values, we recruited 24 office workers from different locations and professions. The experiment was conducted under two conditions: a non-stress environment and a stress-inducing environment, where participants were required to complete complex mental arithmetic tasks under time constraints. In each condition, we conducted 20 emotion assessments and recorded the SDNN values of

HRV. Under the non-stress condition, the average maximum SDNN value across all participants was 104.3 ms, with a corresponding negative emotion proportion of 13.0% ± 3.6%. In contrast, under the stress condition, the average minimum SDNN value dropped to 61 ms, while the negative emotion proportion significantly increased to 63.5% ± 3.1%. The range of negative emotion proportions, from 9.4% to 66.6%, was used to normalize the actual measured data, thereby quantifying the overall level of collective stress. The normalized values serve as a standardized metric for assessing collective stress levels.

- Collective Stress Level

Based on the normalized proportion of negative emotions, the collective stress level is classified into three categories: mild stress, moderate stress, and high stress. The classification thresholds are as follows:

$$\text{Collective Sress Level} = \begin{cases} \mathit{Mild}: P_{\text{normalized}}(t) \ = \ 0\sim 33\% \\ \mathit{Moderate}: P_{\text{normalized}}(t) \ = \ 34\sim 66\% \\ \mathit{High}: P_{\text{normalized}}(t) \ = \ 67\sim 100\% \end{cases}$$

- Implementation of Software System

-User Interface Layer

The laptop camera is initialized within a Python environment to capture real-time facial expressions. A pre-trained Xception neural network model, trained on annotated images from the FER2013 dataset, is then used to recognize these expressions. The model is implemented using the Keras deep learning framework in Python. The development environment is configured on Windows 10 Professional with PyCharm 2022.2.5, utilizing Python 3.6.5, TensorFlow 1.1.8, and Keras 2.2.0. Once an emotion is identified, it is encoded into a predefined hexadecimal code (e.g., A55A0101FE for "happiness"), which is then converted into binary code for further processing. To ensure data security, this binary code is encrypted using the AES encryption module from the Python library, resulting in a ciphertext string. Finally, the encrypted emotion data is transmitted to a server using the socket module in Python, enabling real-time and secure communication.

-Data Processing Layer

The Wi-Fi module is responsible for receiving data from the server and transmitting it to the main controller. The main controller, programmed in C, performs the analysis of this data to determine the total proportion of negative emotions, which serves as an indicator of collective stress levels. Higher proportions of negative emotions are indicative of elevated stress. The controller normalizes the data and categorizes it into four distinct levels: 0, 1, 2, and 3, corresponding to no stress, mild stress, moderate stress, and high stress, respectively. These stress levels are then used to adjust the aroma diffusion rate accordingly. Furthermore, the controller issues commands to the execution layer based on the identified stress levels, ensuring that the appropriate response is activated.

-Execution Layer

This layer adjusts the aroma diffusion rate based on the stress level codes (0, 1, 2, 3) received from the Data Processing Layer. It directly controls the diffuser with the assessed stress levels, ensuring appropriate modulation of the diffuser's output in response to the detected stress.

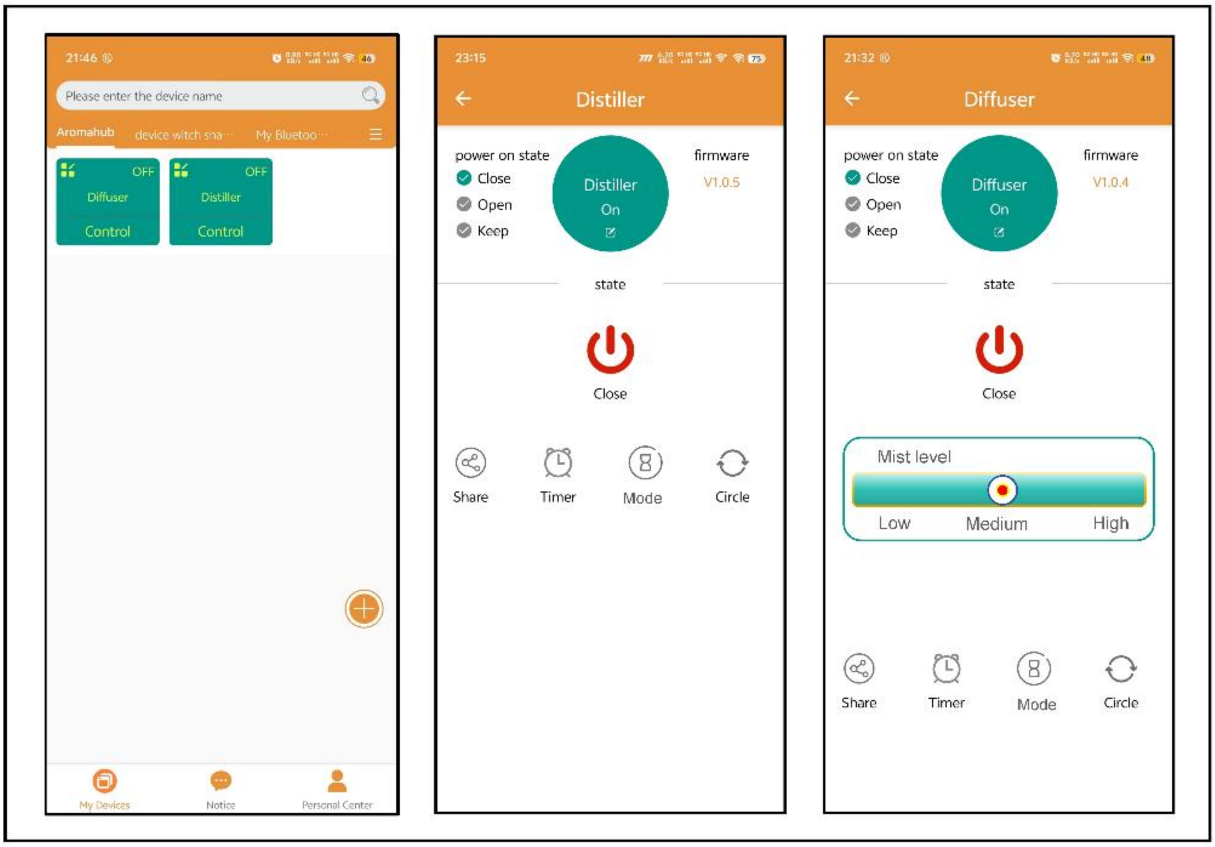

Figure 7: App Interface

Additionally, a third-party mobile app (Sinilink) is used to control the functionalities of the distiller and diffuser of AromaHub (see Figure 7). The app provides power management through options to power the devices on or off. It offers various operational modes, including Open, Keep, and Close, to accommodate different usage scenarios. For energy efficiency and safety, the Timer function allows users to schedule device operation, ensuring the devices run only for the desired duration without supervision. The Mist Level feature enables users to customize the mist output to Low, Medium, or High, according to personal preferences. The app also includes a Share function, which allows users to share device status and control capabilities, enhancing the communal user experience. Additionally, the Circle feature enables cycling through different operational modes, creating a dynamic environment that adapts to changing conditions.

- Security and Privacy Protection

The main communication link runs over the internet, so an interference-resistant scheme for the data structure is first needed, including packet headers, sequence numbers, system IDs, message types, messages, and data checksums. The presence of checksums and sequence numbers enhances the resistance to interference. Subsequently, this data structure needs to be encrypted. We use the AES (Advanced Encryption Standard) symmetric encryption method, where both the sender and receiver use the same key for encryption.

The key used is custom-defined and pre-embedded in the AromaHub device. Although this encryption method may be relatively easier for hackers to crack, the data packets do not contain any private information. Even if hackers manage to decrypt the ciphertext, they would only be able to control the AromaHub device and not access user privacy data. The primary purpose of encryption is to create a barrier to prevent unauthorized access and to guard against unforeseen interference (such as adverse electromagnetic environments).

- Software Testing and Optimization

-Software Testing:

Facial Recognition Testing: In the facial expression recognition component of the AromaHub system, tests were conducted using a 720p resolution webcam integrated into a laptop, with a frame rate of 30 frames per second (fps). The FER2013 dataset was utilized for the tests, which comprises 35,887 labeled facial images representing 7 fundamental emotions: anger, disgust, fear, happiness, sadness, surprise, and neutral. In the assessment, 2000 images were selected from the validation set of the FER2013 dataset, with approximately 285 images for each emotional category. The system achieved a facial expression recognition accuracy of 75% on these images. Factors affecting accuracy include the resolution of the webcam and the subtleties of facial expressions. The experimental results indicate that the system has a certain level of robustness in recognizing emotional categories under the current settings, although further optimization is required to address limitations related to resolution and detail variation.

Link Testing: During the testing phase, encryption was not applied. After facial recognition was completed, the relevant data was immediately transmitted to the server. To evaluate the efficiency of data transmission and ensure the proper functioning of the code, a serial port debugging tool was effectively utilized. Upon receiving the message, the 2.4G Wi-Fi remote controller and the main controller interpreted the data and accurately triggered the AromaHub to perform the specified actions.

-Performance Optimization: Under unencrypted conditions, the test link performed excellently, with the device responding quickly. However, after enabling AES encryption, the device showed sluggish response. Analysis revealed that the length of the encrypted ciphertext was too long, which consumed excessive resources during the main controller's reception and processing, leading to slower device response. Therefore, it was decided to replace the AES decryption library function with the more lightweight TinyCrypt encryption library to reduce computational load and improve performance.

4.1.3. Exterior Design

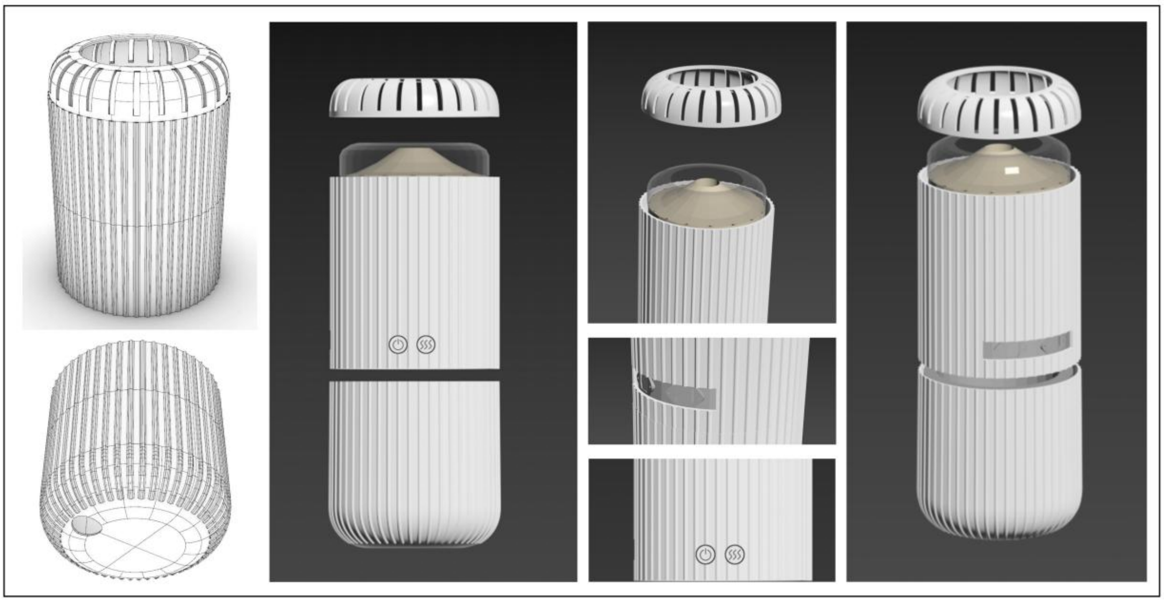

Figure 8: 3D Rendering of AromaHub

- Form Design

The design of AromaHub aims to create a modern, elegant and user-friendly product. The design concept is to show the technological sense of the product and integrate it into the user's office environment through the cylindrical shape and elegant color matching. The cylindrical shape was chosen because it effectively disperses the fragrance, ensuring even distribution, and offers good adaptability in spatial arrangements. This design concept has been applied in many modern product designs.

The 3D rendering of AromaHub(see Figure 8) shows the cylindrical appearance of AromaHub, combining streamlined design elements and structure. The design sketch illustrates the product's overall form and proportions, emphasizing its simple yet elegant design. This design not only enhances the visual appeal of the product, but also can be effectively integrated into various office environments.

- Color selection

The appearance of AromaHub adopts classic white as the main color, which not only gives the product an elegant and bright visual effect, but also can be easily integrated into different office environments. White is often used in design to create a fresh and simple look. White keeps its elegant appearance in all lighting conditions and avoids color distortion.

- Material Selection

The AromaHub's shell is made of high-quality ABS plastic. The excellent durability and heat resistance of ABS plastic make it an ideal choice, which can effectively protect the internal components and keep the stability of the product. The smooth surface of this material also gives the product a modern look that meets the current standards for technology product design. The choice of material ensures long-term durability and performance of the product.

- Texture Treatment

The product's outer surface treatment adopts a vertical striped texture design, which not only enhances the product's touch, but also enhances the visual effect. The vertical striped texture forms a delicate layering, which not only improves aesthetics, but also effectively reduces the appearance of fingerprints and dirt. This design not only increases the premium feel of the product, but also improves the user’s tactile experience.

4.1.4. System Evaluation

- Functional Evaluation

During the hardware and software testing phases, the accuracy of the emotion recognition system is closely related to the choice of the dataset. The hardware effectively supports the software in calculating normalized collective stress levels and accurately adjusts the misting speed to release different concentrations of fragrance (low, medium, high).

- Functional Test

To evaluate the system's performance across different users, a group of four internal testers with varying ages, genders, and professions was invited to assess its functions, specifically its capability to determine collective stress levels by analyzing negative emotions of the group and to intelligently adjust the aroma diffuser's operation level (see Figure 9). The testers performed tasks of varying difficulty, and physiological data were collected using a PPG sensor, providing objective indicators for assessing stress levels. The results indicated that, despite the limited sample size (n=4), the facial recognition algorithm demonstrated high accuracy in identifying negative emotions. There was a significant correlation between the collective stress levels assessed by the system and the heart rate changes monitored by the PPG sensor (correlation coefficient $\rho=0.75$, $p<0.01$). Based on the assessed collective stress levels, the system adjusted the aroma diffuser's operation level to different intervention intensities, effectively modulating the aroma output according to the detected stress levels.

Figure 9: Internal Functional Test

Although the system demonstrated robustness in assessing stress levels, several issues were identified that require further adjustment. The following issues and solutions were observed:

-Impact of Lighting Conditions in Office Environments: Variations in lighting conditions affect recognition performance. This issue arises from the low pixel resolution of the dataset used to train the deep learning model, combined with the limited image resolution and light sensitivity of 720P laptop cameras.

Solution: Enhance the brightness of the office environment and consider upgrading to higher-performance cameras to address this issue.

-Differences in Stress Tolerance: Individuals show varying stress tolerance levels due to differences in psychological resilience.

Solution: During experiments, increase the difficulty of challenging tasks and decrease the difficulty of simpler tasks to create a wider range of difficulty levels, thereby improving the effectiveness of the fragrance adjustment.

-Impact of Laptop Performance: The performance of different laptops affects detection speed and accuracy.

Solution: By increasing the number of images in the dataset and retraining the model, we achieved higher accuracy. However, this led to a doubling of the detection time, though it does not impact usability.

- System Iteration

-Hardware Iteration: Added waterproof functionality to ensure long-term use. Modified the condensation pipe material and selected a higher-power condenser within structural constraints. Reduced the flow rate of the hydrosol vapor to improve the efficiency of fragrance hydrosol production.

Software Iteration: Improved the number of images in the dataset and retrained the model to improve accuracy. While detection time increased, this adaptation was necessary to accommodate varying computer performance.

Appearance Iteration: Replaced manually polished exterior components with industrially manufactured parts.

Future iterations will focus on developing deep learning datasets with higher precision annotations and improved image resolution. Hardware integration will be advanced by merging discrete components into a single, replaceable waterproof unit for easier maintenance. Additionally, incorporating newly designed condensers will enhance condensation efficiency.

5. USER STUDY

5.1. Participants

A total of 24 participants were recruited for this study, including 10 females and 14 males. All participants were college students in China, including both undergraduates and graduate students, aged between 21 to 35 years old (mean=26, SD= 4.03). All participants had no heart disease, normal visual and olfactory functions, and no history of lavender allergy. Participants were divided into six groups, with four in each group. To promote cooperation and competition, each group was further divided into two subgroups, with two participants forming a subgroup to compete with two participants from the other subgroup. This simple group setting helps stimulate effective communication. Three groups were assigned as the experimental groups, using AromaHub as the intervention, while the remaining three groups served as the control groups with no intervention. The participants were asked to voluntarily participate in the study, and their informed consent was obtained prior to their involvement. The study protocol and the data collection procedure were approved by the ethical review committee of Eindhoven University of Technology.

5.2. Experimental Set up

The experiment used individual laptop cameras to detect collective stress in online meetings. The experiment was conducted in four rooms with the same configuration. Each room was equipped with the following devices: a laptop with a camera and mouse, an AromaHub, and a photoplethysmography (PPG) device. The room environment had been carefully adjusted to keep quietness, with temperature and humidity controlled within comfortable ranges to ensure the reliability of the experiment and the comfort of the participants.

Each participant had a PPG device securely fixed on their left index finger to record pulse wave data. The participants were instructed to keep hand stability and adopt a comfortable posture. For left-handed participants, the PPG device was fixed on the index finger of the right hand. The data collected by PPG equipment served as the ground truth for the experiment, which was used for comparative analysis with the stress levels recorded by the emotion recognition system after the experiment was completed.

The emotion recognition software was launched at the beginning of the experiment, and the participants logged in to the pre-set online meeting to complete the mental arithmetic tasks (Noto et al., 2005). A timer in each computer would be set at five minutes for each round of math task. The diffuser was kept powered on for the experiment groups, so that it could start based on the real-time collected collective stress values and took corresponding intervention measures, while the diffuser kept off for the control groups.

5.3. Tasks

To simulate the stressful situation at work, we selected mental arithmetic tasks as stressors to control the stress levels. This study designed two tasks to stimulate the different stress levels of the participants, each task was limited to five minutes to complete 30 questions. Task 1 involved two-digit addition and subtraction, designed to induce low stress levels; Task 2 included three-digit addition and subtraction, designed to induce higher stress levels.

During the test, the participants were not allowed to use computing devices or paper and pen, and could only rely on mental arithmetic to complete the questions. The participants performed tasks through an online collaborative office platform, and the progress of the two subgroups of team members was displayed in real time on the platform. The system provided instant prompts when errors occurred, requiring the participants to correct them. Although team members of subgroup could collaborate with each other to complete the task, conversation was prohibited throughout the test to ensure the independence of the task and the authenticity of the sense of stress.

5.4. Experimental Procedure

This experiment lasted one hour and was designed to simulate the participants' reactions to different stressful situations. The entire experiment procedure (see Table 3.) included baseline measurements, two rounds of stress tasks, the use of AromaHub, and final data collection.

Step 1: Baseline Measurement

- At the beginning of the experiment, the participants were introduced to the experimental process and watched a peaceful video to help them relax. During this period, the participants' baseline stress level was measured through a camera and PPG sensor. Afterwards, the participants filled out the RRS and STAI questionnaires to assess their self-reported initial stress level(see Figure 10).

Step 2: Initial Stress Task

Two participants were randomly assigned Task 1(low stress stimulus), while the other two were assigned Task 2(high stress stimulus) to simulate different stress levels in a group, reflecting various common office scenarios, such as situations where some individuals were under tight deadlines while others were not. Each task must be completed within five minutes, during which the participant's stress level was checked through a camera and PPG sensor. If the collective stress threshold was reached, the four AromaHubs would start the aroma intervention together. After the task, participants filled out the RRS and STAI questionnaires to assess changes in stress levels.

Baseline stage Initial Stress stage

Figure 10: Experiment Process

Step 3: First AromaHub intervention

After completing the initial stress task, participants used AromaHub for five minutes. During this process, stress levels were continuously checked through a camera and PPG sensor. Participants filled out the RRS and STAI questionnaires again to assess the impact of AromaHub on stress levels. While Participants of Control Group were asked to rest quietly for 5 minutes, without any intervention or social interaction.

Step 4: Second Round of Stress Tasks

All participants performed a second round of tasks, which were all high-stress tasks, solving 30 three-digit addition and subtraction problems. As in the earlier round, no calculation tools, paper or pens were allowed. Each subgroup still performed the tasks in a competitive format, with a task completion time of five minutes, during which stress levels were checked through camera and PPG sensor. If the collective stress threshold was reached, the four AromaHubs started the aroma intervention again. After the task, participants filled out the RRS and STAI questionnaires to assess changes in stress levels.

Step 5: Second AromaHub Intervention

In the final phase of the experiment, participants used AromaHub for five minutes while their stress levels were checked through camera and PPG sensor. Upon completion, participants filled out RRS and STAI questionnaires to assess final stress levels and their changes. While Participants of Control Group were asked to rest quietly for 5 minutes, without any intervention or social interaction.

Step 6: Interview

We collected qualitative data through questionnaires to analyze experiences and feedback of participants from experiment groups on the experiment. Participants in the control group enjoyed a ten-minute rest during this period. This data was used to evaluate the overall effectiveness of the stress task and the impact of AromaHub on stress levels.

Table 3: Experiment Procedure

Experiment Procedure	Step 1 Baseline		Step 2 Initial Stress		Step 3 First Intervention		Step 4 Second Stress		Step 5 Second Intervention		Step 6 Interview
Time	5min	5min	5min	5min	5min	5min	5min	5min	5min	5min	10min
Emotion Recognition											
RRS, STAI											
PPG sensing											

5.5. Measurement and Data Analysis

5.5.1. Emotion Recognition Data

We used facial expression recognition (FER) technology to analyze participants' emotions. The FER system can recognize and classify seven emotions. We estimated the participants' stress levels by calculating the proportion of these negative emotions(anger, fear, sadness, and disgust). The higher the proportion of negative emotions, the higher the collective stress levels. The ratio of negative emotion(NER) is categorized into three levels of collective stress: mild stress for 0-33%, moderate stress for 34-66%, and high stress for 67-100%.

5.5.2. Physiological Data

In the collection and analysis of physiological data, we used photoplethysmography (PPG) to measure stress levels. Through PPG technology, we can obtain heart rate variability (HRV) data, which reflects stress levels by analyzing the variability of heart rate. Specifically, we used the standard deviation of heart rate intervals (SDNN) to quantify stress, and lower SDNN values indicated higher stress levels. To assess individual stress levels, we referred to existing research, with specific criteria being: SDNN below 50 indicates high stress, between 50 and 100 indicates low stress, and above 100 indicates no stress.

5.5.3. Self-report: Subjective Assessment of Anxiety and Relaxation

To obtain participants' subjective feelings about their own stress, we used a self-report method. Participants filled out the State-Trait Anxiety Inventory (STAI) to measure their anxiety levels, with higher scores indicating higher levels of anxiety and stress, with scores ranging from 20 to 60, where higher scores indicate greater levels of anxiety. In addition, we used the Relaxation Rate Scale (RRS) to assess participants' relaxation levels, with scores ranging from 1 to 9, where 9 indicates extreme relaxation. The data from the STAI and the Relaxation Rate Scale helped us understand the participants' subjective relaxation and anxiety states.

5.5.4. Interview Analysis: Collective Stress Awareness and Intervention Effect

We collected qualitative feedback from participants of experiment groups on their understanding of collective stress and the intervention effect of the AromaHub through interviews. The interview content included three main questions: first, whether participants believed that the AromaHub increased their awareness of collective stress; second, the actual intervention effect of the AromaHub on their stress level; and finally, participants' suggestions for system improvements. Interview data were analyzed using thematic analysis to identify common patterns and insights related to collective stress, intervention effects, and system improvements.

5.6. Results

5.6.1. Quantitative results

For the data we collected, we first conducted a Shapiro-Wilk test to determine if the data follows a normal distribution due to the small sample size. Due to the data not following a normal distribution, we need to use nonparametric tests. We used the Mann-Whitney U test to compare the mean difference in stress levels between the experimental group and the control group. For the measurement data of the same group of participants under different conditions, we used the Friedman test to evaluate the changes in stress levels at different stages.

- Emotion recognition data

As shown in Figure 11a, compared with the baseline stage (Mdn=3.83, SD=1.30), the ratio of negative emotion (NER) scores significantly increased in the initial stress stage

(Mdn=40.15, SD=10.50, p<0.001) and the second stress stage (Mdn=56.70, SD=5.28, p<0.001), indicating that stress stimulation led to a significant increase in participants' perception of stress.

In the intervention results of the NER scale, the experimental group scored significantly lower in the first intervention stage (Mdn=14.25, SD=1.85, p<0.001) and the second intervention stage (Mdn=14.40, SD=1.97, p<0.001) than in the initial and second stress stages, indicating that the intervention effectively reduced stress perception. The score of the control group in the first intervention stage (Mdn=21.35, SD=1.85, p<0.001) was also higher than that in the initial and second stress stages, but the score significantly decreased in the second intervention stage (Mdn=8.00, SD=0.49, p<0.001). Further comparative analysis showed a significant difference in scores between the experimental group and the control group during the first intervention phase (p<0.001) and the second intervention phase (p<0.001). This indicates that the experimental group had significantly better effects than the control group in the intervention, and the different intervention measures led to significant differences in effectiveness.

- Self-report data

As shown in Figure 11b, compared to the baseline stage (Mdn=9.00, SD=0.20), the RRS scores in the initial stress stage (Mdn=5.50, SD=1.17, p<0.001) and the second stress stage (Mdn=4.00, SD=0.82, p<0.001) significantly decreased. This shows that stress stimulation led to an increase in participants' perception of stress. For the STAI scale(Figure 11c), compared to the baseline stage (Mdn=21.50, SD=1.18), there was a significant increase in scores for the initial stress stage(Mdn=36.00, SD=4.62, p<0.001) and the second stress stage(Mdn=42.00, SD=1.32, p<0.001), indicating that stress stimuli induced an increase in subjective stress.

For the intervention results of the RRS scale, the experimental group had significantly higher scores in the first intervention stage (Mdn=9.00, SD=0.29, p<0.001) and the second intervention stage (Mdn=9.00, SD=0.29, p<0.001) compared to the initial stress stage and the second stress stage. The control group also had significantly higher scores in the first intervention stage (Mdn=7.50, SD=0.78, p<0.001) and the second intervention stage (Mdn=8.00, SD=0.49, p<0.001) compared to the initial stress stage and the second stress stage. Further comparative analysis showed that there was a significant difference in scores between the experimental group and the control group during the first intervention stage (p=0.03), and a significant difference in scores during the second intervention stage (p=0.03). This shows a significant difference in the effectiveness between the experimental group and the control group.

Regarding the intervention results of the STAI scale, the experimental group showed a significant decrease in scores during the first intervention stage (Mdn=25.00, SD=4.64, $p<0.001$) compared to the initial stress stage, while the second intervention stage (Mdn=23.50, SD=5.50, $p<0.001$) showed a significant decrease in scores compared to the second stress stage. The first intervention stage (Mdn=28.00, SD=2.79, $p<0.001$) of the control group showed a significant decrease in scores compared to the initial stress stage, while the second intervention stage (Mdn=30.00, SD=1.08, $p<0.001$) showed a significant decrease in scores compared to the second stress stage. The comparison of intervention effects between the experimental group and the control group revealed a significant difference in the first intervention stage ($p=0.03$) and the second intervention stage ($p=0.04$). These findings suggest that the interventions, which included the use of AromaHub and engaging in leisure conversations, subjectively helped participants feel more relaxed and reduced their perceived stress levels.

- Physiological data

As shown in Figure 11d, compared to the baseline stage (Mdn=96.75, SD=1.64), the SDNN in the initial stress stage (Mdn=73.20, SD=6.01, $p<0.001$) and the second stress stage (Mdn=67.70, SD=5.66, $p<0.001$) significantly decreased. This shows that stress stimulation led to an increase in participants' perception of stress.

For the intervention results of the SDNN, the experimental group had significantly higher scores in the first intervention stage (Mdn=96.20, SD=2.45, $p<0.001$) and the second intervention stage (Mdn=100.05, SD=2.49, $p<0.001$) compared to the initial stress stage and the second stress stage. The control group had slightly higher scores in the first intervention stage (Mdn=84.65, SD=7.66, $p=0.08$)compared to the initial stress stage, and had a significantly higher score in the second intervention stage (Mdn=83.65, SD=4.24, $p<0.001$) compared to the second stress stage. Further comparative analysis showed that there was a significant difference in scores between the experimental group and the control group during the first intervention stage ($p=0.02$), and a significant difference in scores during the second intervention stage ($p<0.01$). This shows a significant difference in the effectiveness between the experimental group and the control group.

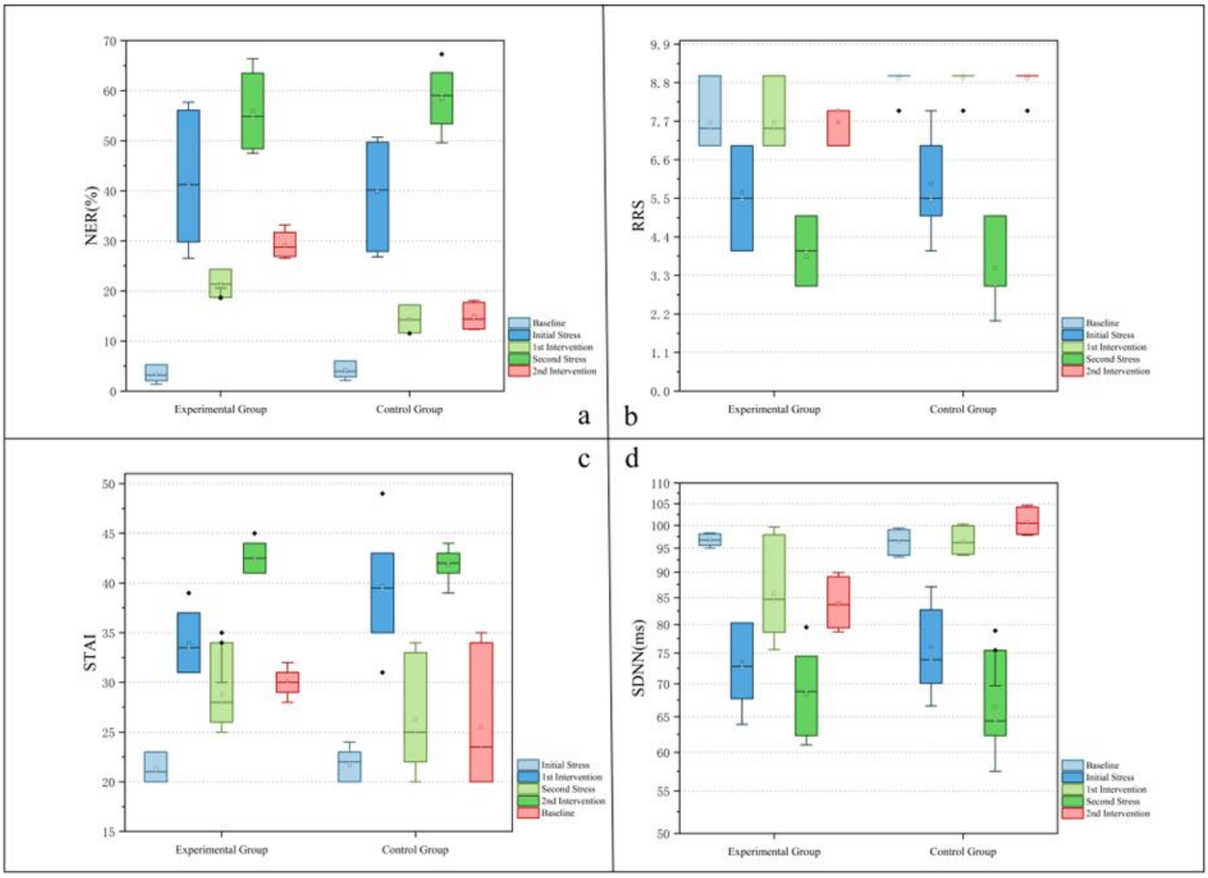

Figure 11: Results of NER, RRS, STAI and SDNN

- Comparison of Four Stress Defection Methods

All four methods for stress detection revealed that stress indicators significantly increased compared to baseline levels, indicating that stress stimulation effectively heightened participants' stress perception. The intervention measures showed a notable effect in reducing stress perception, with the experimental group showing superior outcomes compared to the control group, especially in the negative emotion recognition(NER), Relaxation Rate Scale (RRS), and State-Trait Anxiety Inventory (STAI) assessments. Additionally, heart rate variability (SDNN) showed significant improvement with interventions, suggesting that the interventions positively affected physiological stress levels. These patterns show that, while the methods differ in specifics, they all effectively capture stress changes and that the interventions substantially improve both perceived and physiological stress.

5.6.2. Qualitative results

- Enhancing awareness of collective stress

Most participants generally reported that the system helped them identify changes in collective stress through changes in jelly-fished spray, thereby better understanding the dynamics of collective stress. For example, P8 mentioned: “The jelly-fished spray changes in the system allowed me to intuitively understand the team's stress situation, and this visual feedback helped me feel the collective stress of the team more clearly.” However, there is still room for improvement in accuracy and real-time performance to better reflect actual stress levels.

- Aromatherapy intervention effect

The aromatherapy intervention of the AromaHub system had shown some effectiveness in relieving stress, but the effect varied depending on individual differences. Most participants gave positive feedback on the effectiveness of aromatherapy. P5 mentioned, “The scent of lavender was helpful for my stress.” In addition, the hydrosol AromaHub produced as an aromatherapy additive to make the scent more natural and fresher, which was more popular than traditional essential oil. P18 said, “The fragrance was very natural and felt more soothing.” However, there was also some feedback pointing out inconsistencies in the effectiveness of aromatherapy. P4 added, “Some people may not like aromatherapy, and such interventions may not be suitable for everyone.” This suggests that in the future, more options may need to be provided to meet the needs of different users.

- Importance of timely intervention

The AromaHub system had shown advantages in providing timely intervention, as it can help manage stress by identifying collective stress in real-time and taking prompt measures. Participants generally believed that this feature was a significant advantage of the system. P10 mentioned, “AromaHub's timely intervention helped us take action before stress problems worsened.” P19 also said, “The system's rapid feedback ensured that we could adjust quickly and prevent stress accumulation.” However, some participants pointed out that the accuracy of stress detection in the system needs to be improved.

- Selection of stress detection methods

The AromaHub system used facial recognition technology as a stress detection method, which had been recognized by participants as a non-invasive approach. Especially in the experimental environment of online conferences, this design helped alleviate users' concerns about camera privacy. P1 commented, “The non-invasive nature of facial recognition technology was incredibly good. We didn't need to wear additional equipment, making the experience more natural.” However, while the system's design may mitigate privacy concerns in online meeting settings, users may still have reservations about camera privacy in broader, real-world applications. This suggests a need for further investigation into how the system can address these concerns in diverse practical scenarios.

- The impact of collective stress on individuals

AromaHub prompts the team's stress level by releasing jelly-fished spray with a lavender scent, which has different effects on different participants. For example, P16 stated: “When I saw the lavender scented spray release, I felt that participant in my group was under stress, which made me feel a little relaxed.” This showed that the system used scent cues to indicate collective stress, which can help user feel relative relief when they realized that others in the group were also experiencing stress, thereby easing their personal stress. P2's feedback is different: “Actually, I was very focused when doing mental arithmetic math problems, so I didn't pay much attention to the stress state of others.”

6. DISCUSSIONS AND CONCLUSIONS

6.1. Key Findings

6.1.1. Increase Awareness of Collective Stress

The AromaHub system effectively enhances participants' perception of collective stress levels through its visual and olfactory cues. This finding echo Schein's discussion of the impact of organizational culture on stress perception, particularly when sensory elements in the organizational environment are used to reinforce collective stress perception, team members are more likely to understand and respond to stress (Schein, 2010). Through real-time multi sensory feedback, AromaHub not only promotes team members' shared understanding of stress, but also strengthens emotional resonance within the team, which is consistent the concept of emotional contagion and emphasizes the importance of emotional synchronization in stress management (Mayer et al., 2008).

Through intuitive stress prompts such as lavender fragrance and jellyfish-shaped spray, AromaHub helps participants to sense the stress fluctuations in the team in a timely manner, so that they can adjust their work according to the stress changes. This application not only enhances the overall level of collective stress perception, but also promotes closer cooperation within the team (Kozusznik et al., 2015) , indicating that enhancing team stress awareness can effectively improve team cohesion and communication efficiency.

6.1.2. Non-intrusive of the Intervention

The non-intrusive intervention method of the AromaHub system has been recognized by most participants, which is consistent with the current trend in organizational behavior research to seek stress management strategies that minimize employee interference. Compared to traditional stress management interventions, AromaHub avoids the need for direct contact and wearing devices, thereby reducing interference with users' daily work.

In the study of organizational behavior and work stress, non-intrusive interventions are favored due to their low disruption to employees' daily workflow (Kirkegaard & Brinkmann, 2016) . The AromaHub system, through its design, allows employees to maintain focus on work tasks without adding extra burden, which is consistent with Fineman's view on how stress management should adapt to organizational culture and work environment (Fineman, 1995) . A meta-analysis evaluation of Organizational Support Theory (OST) revealed that employees' perception of Organizational Support (POS) was closely related to their response to the work environment (Kurtessis et al., 2017). This suggests that the acceptance and effectiveness of non-invasive interventions may be influenced by employees' perception of organizational support.

6.1.3. Improved Communication Among Workers

The AromaHub system provides a common language and framework for team members by providing real-time feedback on collective stress levels, thereby improving communication and collaboration. This system enables team members to understand and better cope with stressful situations at work by sharing stress perception, thereby promoting efficient communication and team collaboration.

AromaHub effectively promotes team members' consensus on stress status by providing visual stress indicators, which is a core factor for successful collaboration. Consensus refers to the unanimous understanding of goals, strategies, and coping strategies among team members, which enables them to better coordinate their work when facing stress (Kozusznik et al., 2015). This shared perception of stress levels not only enhances mutual understanding among employees, but also promotes more constructive discussions and collaboration to address common challenges.

The real-time feedback mechanism of AromaHub increases transparency within the team and helps team members understand each other's stress status in real-time. Transparency is regarded as the foundation for building trust in organizational behavior (Schein, 2010). When employees see their stress levels receiving attention and are able to discuss with team members, they are more likely to develop a sense of trust, breaking down barriers in communication and encouraging more open communication. This sense of trust makes team members more willing to share their opinions and suggestions, reducing misunderstandings and conflicts caused by stress, thereby enhancing team cohesion and overall effectiveness.

AromaHub further enhances emotional resonance among team members through its multi-sensory feedback mechanism, such as visual and olfactory cues. Research has shown that emotional states can be contagious within a team, and shared sensory experiences can promote emotional understanding among team members (Mayer et al., 2008). When team members experience sensory cues of stress and relaxation together, they are able to better understand each other's emotional changes. This emotional resonance helps strengthen the social support system, enabling members to provide more help and understanding during times of high stress, thereby enhancing the team's social connections and cohesion.

6.1.4. Need for Non-Intrusive Data Collection

The AromaHub system uses facial recognition technology for stress detection, which avoids the need for more devices and enhances the user experience. The method aligns with the recommendations of advocating for a nuanced and sensitive approach to monitoring employee stress (Kirkegaard & Brinkmann, 2016). This approach enables organizations to capture stress signals in real-time without adding to employees' burdens, allowing for timely intervention. While the use of online meetings in the experiment helped mitigate privacy concerns related to camera use, real-world applications may still face privacy challenges. To further enhance the effectiveness of the system and protect user privacy, it is recommended to explore other non-invasive technologies. For instance, Lightsit integrates sensors into a seat cushion to monitor sitting posture and heartbeat during work, ensuring that users remain distraction-free (Ren et al., 2019).

6.1.5. Effectiveness of Multi-Sensory Experience

The AromaHub system significantly enhances the stress management experience through innovative multi-sensory interventions, involving both visual and olfactory aspects. The mist released by the system is shaped like a jellyfish, creating a soothing visual effect that promotes user relaxation. This aesthetic design is not only attractive, but also conforms to the principles of environmental psychology, indicating that a beautiful environment can reduce stress (Kaplan&Kaplan, 1989).

In addition, using homemade hydrosol provides a fresher alternative to traditional essential oils, which contributes to the effectiveness of the system. Research has shown that natural odors can enhance emotional and cognitive functions (Herz&Engen, 1996). The positive feedback from users on fragrances highlights the importance of sensory experience in stress management interventions.

6.2. Factors Influencing Effectiveness

6.2.1. Individual Differences

Individual differences in olfactory sensitivity result in varying responses of different users to aromatherapy odors. Some users may be extremely sensitive to the intensity or nature of the odor, while others may have slower perception (Thuerauf et al., 2009) . Similarly, the effectiveness of visual intervention is also influenced, such as the shape and color of the mist released by the system having different soothing effects on different users. The emotional state of users (such as mild and high stress) can affect their acceptance of intervention measures.

6.2.2. Office Setup

The operation time of the diffuser should be regulated. Long term operation may lead to excessive fragrance concentration, causing discomfort such as headaches or nausea, and may also have a negative impact on indoor air quality. Appropriate usage duration and concentration should be set to ensure comfort and effectiveness. The environment plays a key role in determining the product reliability (Lu et al., 2007) .The fragrance in open spaces spreads quickly and has a short duration, which may reduce the intervention effect of the aromatherapy machine. On the contrary, the fragrance in a confined space lasts longer, but excessive concentration may cause discomfort. The arrangement and use of diffusers in different types of spaces need to be adjusted accordingly. The diffuser should be placed in a position that can evenly cover the entire work area, avoiding concentrated spraying in only one corner. This helps to improve the intervention effect of the AromaHub and ensure its effectiveness in different layouts.

6.2.3. Data Accuracy and Privacy

The stress detection data of the system requires high accuracy to ensure that the provided intervention measures can effectively respond to the collective stress level. Data with low accuracy may lead to inappropriate interventions, thereby affecting the effectiveness of user stress management. At the same time, privacy protection is one of the key factors for the success of the system. Users have a high level of concern for the security of their personal data, and any data breach or privacy infringement will weaken their trust and affect the application effectiveness of the system (Schomakers et al., 2022) . Therefore, ensuring data accuracy and strengthening privacy protection are necessary measures to enhance the overall effectiveness of the AromaHub system.

6.3. Future Research and Practical Applications

6.3.1. Adopt Diversified Stress Detection Methods

The AromaHub system currently relies mainly on cameras to recognize individual emotional responses, but future research should further explore the collection of multimodal data to improve the accuracy of collective stress assessment. Wearable devices such as smart bracelets can monitor physiological indicators such as heart rate and skin conductivity in real-time, providing richer dimensions for continuous assessment of work stress. Compared to single emotion recognition, this approach can capture the dynamic changes of individuals in different work contexts. Combined with the current system, it can improve the timeliness and accuracy of pressure monitoring.

Future research can integrate multi-source data into a comprehensive stress monitoring model, covering individual reports, behavioral observations, and physiological data, to comprehensively reflect collective stress levels. This method not only provides a deeper level of stress assessment, but also helps organizations take preventive measures before stress accumulates. This multimodal stress perception system can identify the relationship between individual employee stress and overall team stress, which can help design more targeted intervention strategies. By analyzing multi-source data, patterns and evolving trends of collective pressure can be identified. Machine learning can help automate the identification of factors that play a dominant role in stress fluctuations, predict potential high pressure points for future teams, and develop corresponding mitigation strategies.

6.3.2. Evaluate the Feasibility of Using Surveillance Cameras

Facial expression recognition technology can replace personal cameras with surveillance cameras to detect employee emotions. This not only expands the scope of data collection, but also reduces privacy violations. Future research could explore the application of this technology in the workplace to monitor collective stress in real-time and enhance organizational care for employee well-being. However, the challenges of privacy, data security, and technological implementation cannot be ignored.

The application of surveillance cameras has multiple advantages. Its wide coverage can provide organizations with detailed emotional data, which helps to more accurately identify team stress situations and enhance the organization's ability to adjust stress management strategies. However, this extensive monitoring also brings privacy and data protection issues, which may lead to employees' doubts about the use of personal information. To ensure transparency, organizations should inform employees in advance about the scope and purpose of the system's use, as well as how data is stored and protected, to avoid privacy disputes. In addition, complex data processing requirements also pose challenges to technical implementation. Facial expression recognition algorithms require high-precision models and computing resources to process large amounts of data, ensuring accurate tracking of employee emotional changes. This requires enterprises to make effective investments in IT infrastructure and technical support to meet data processing needs.

6.3.3. Privacy Protection and Data Security

When applying these technologies, user privacy and data security must be considered. Future research should focus on developing more effective data protection measures to ensure that the collection and analysis of stress data does not violate users' privacy rights. This not only helps to improve user acceptance, but also enhances the overall effectiveness and reliability of the system. Future research can explore how to enhance data security and confidentiality through technological means and policy measures. For example, research can be conducted on how to use encryption technology to protect collected data, as well as how to design user-friendly privacy protection protocols. Moreover, it is possible to explore how to protect individual identities through anonymization of data, as well as how to implement strict access control in the data analysis process. These measures help ensure that only authorized personnel can access sensitive data, and any access to the data is traceable.

6.3.4. Personalized Intervention Measures

It is crucial to develop personalized intervention plans to improve the effectiveness of stress interventions. The core of personalized intervention lies in a profound understanding of individual differences. Future research can explore how to combine psychological and behavioral science methods to more accurately evaluate employees' responses to aromatherapy and other interventions. In addition to aromatherapy, future research should also explore how to integrate multiple intervention measures, such as sound therapy, light regulation, and temperature control, to create a multi-modal intervention environment. This integration method can provide employees with a more comprehensive relaxation experience, which may improve the overall intervention effect.

User participation and feedback are crucial when designing personalized intervention measures. Future research can explore how to promote active user participation in the development and adjustment of intervention plans by optimizing user interfaces and feedback mechanisms. User feedback will help the system better evaluate intervention effectiveness and achieve optimization. The long-term effects of personalized interventions are also an important direction for future research. Research can track changes in stress levels of employees after long-term use of personalized intervention measures, as well as the impact of these changes on job performance and well-being. This long-term perspective helps evaluate the persistence and sustainability of intervention measures.

6.4. Conclusions

The AromaHub system has shown potential in enhancing collective stress awareness and promoting communication among team members through its innovative multi-sensory intervention approach. With the continuous increase in stress levels in modern work environments, it is particularly important to develop effective stress management solutions. The AromaHub system enables users to identify and respond to stress levels in a timely manner through a real-time feedback mechanism, which is of great significance for managing workplace stress and promoting employee well-being. By enhancing communication and collaboration among team members, the AromaHub system not only helps employees better cope with stress, but also enhances the overall vitality of the office.

The effectiveness of the system lies in its multidimensional stress management strategy, including personalized aromatherapy, environmental adaptability, data-driven feedback, and user engagement. These functions work together to provide users with a new stress management experience, while also supporting the enhancement of office vitality. Personalized interventions may address the diverse needs of employees, potentially enhancing their job satisfaction and engagement, which could positively influence overall office vitality.

Although the AromaHub system has shown positive results in preliminary studies, future research needs to explore and improve the accuracy of stress detection and the effectiveness of personalized interventions in order to enhance its practical application in the workplace. This includes enhancing the accuracy of stress detection, integrating more physiological and behavioral indicators to gain a more comprehensive understanding of employees' stress levels, and expanding personalized options to provide more diverse intervention measures to meet a wider range of user needs. Meanwhile, exploring non-invasive data collection methods to improve user acceptance and data quality is also an important direction for future research.

User privacy protection is a crucial aspect of the successful implementation of the AromaHub system. This may involve adopting more complex encryption technologies and establishing transparent data usage protocols. At the same time, system customization is also essential. Research should provide flexible customization options to meet the needs of different organizations and individuals.

The limitation of current research lies in the limited sample size, which may not fully represent all work environments and cultural backgrounds. In addition, the lack of long-term observation makes it more difficult to evaluate the persistence and effectiveness of intervention measures. Future research should adopt larger sample sizes and long-term tracking studies to validate the effectiveness and sustainability of the system, ensuring the broad applicability of the results. Meanwhile, research should focus on how to integrate user feedback to optimize system design and explore how to improve the accuracy of data collection and analysis through technological advancements. More importantly, explore the applicability of the system in different cultures and organizational structures, and how to improve employees' understanding and use of the system through education and training.

In summary, the AromaHub system has potential in workplace stress management and provides important directions for future research. By continuously improving system performance, focusing on user experience, strengthening privacy protection, and exploring diverse intervention strategies, employee well-being and office vitality can be better promoted. The progress of this research will rely on interdisciplinary collaboration and technological innovation to ensure the effectiveness and sustainability of stress management. Through these efforts, the AromaHub system is expected to become an important tool for managing workplace stress, contributing to improving employee well-being and office vitality.

REFERENCES

Adib, F., Mao, H., Kabelac, Z., Katabi, D., & Miller, R. C. (2015). Smart Homes that Monitor Breathing and Heart Rate. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 837–846. https://doi.org/10.1145/2702123.2702200

Aldwin, C. M. (2004). *Culture, Coping and Resilience to Stress*.

Appelhans, B. M., & Luecken, L. J. (2006). Heart rate variability as an index of regulated emotional responding. *Review of General Psychology*, *10*(3), 229–240. https://doi.org/10.1037/1089-2680.10.3.229

Bakker, A. B., Demerouti, E., & Sanz-Vergel, A. I. (2014). Burnout and work engagement: The JD–R approach. *Annu. Rev. Organ. Psychol. Organ. Behav.*, *1*(1), 389–411.

Bakker, A. B., Demerouti, E., & Schaufeli, W. B. (2005). The crossover of burnout and work engagement among working couples. *Human Relations*, *58*(5), 661–689. https://doi.org/10.1177/0018726705055967

Barakova, E. I., Gorbunov, R., & Rauterberg, M. (2015). Automatic Interpretation of Affective Facial Expressions in the Context of Interpersonal Interaction. *IEEE Transactions on Human-Machine Systems*, *45*(4), 409–418. https://doi.org/10.1109/THMS.2015.2419259

Benson, H. , Beary, J. F. , & & Carol, M. P. (1974). The relaxation response. *Psychiatry*, *37(1)*, 37–46.

Bolger, N., Davis, A., & Rafaeli, E. (2003). Diary Methods: Capturing Life as it is Lived. In *Annual Review of Psychology* (Vol. 54, pp. 579–616). https://doi.org/10.1146/annurev.psych.54.101601.145030

Briner, R. B., & Reynolds, S. (1999). The costs, benefits, and limitations of organizational level stress interventions. *Journal of Organizational Behavior*, *20*(5), 647–664. https://doi.org/10.1002/(SICI)1099-1379(199909)20:5<647::AID-JOB919>3.0.CO;2-1

Cannon, W. B., & Appleton, L. D. (1915). *Bodily changes in pain, hunger, fear and rage. An account of recent researches into the function of emotional excitement.*

Caulfield, N., Chang, D., Dollard, M. F., & Elshaug, C. (2004). A review of occupational stress interventions in Australia. In *International Journal of Stress Management* (Vol. 11, Issue 2, pp. 149–166). https://doi.org/10.1037/1072-5245.11.2.149

Charlton, P. H., Celka, P., Farukh, B., Chowienczyk, P., & Alastruey, J. (2018). Assessing mental stress from the photoplethysmogram: A numerical study. *Physiological Measurement*, *39*(5). https://doi.org/10.1088/1361-6579/aabe6a

Chew, W. T. , C. S. C. , O. T. S. , & C. L. Y. (2022). *Facial Expression Recognition Via Enhanced Stress Convolution Neural Network for Stress Detection*.

Clements-Croome, D. (2006). *Creating the Productive Workplace*.

Craft, L. L., & Perna, F. M. (2004). Prim Care Companion. In *Prim Care Companion J Clin Psychiatry* (Vol. 6, Issue 3).

Critchley, H. D. (2002). Electrodermal Responses: What Happens in the Brain. *The Neuroscientist*, *8*(2), 132–142.

Da Costa, S., Martínez-Moreno, E., Díaz, V., Hermosilla, D., Amutio, A., Padoan, S., Méndez, D., Etchebehere, G., Torres, A., Telletxea, S., & García-Mazzieri, S. (2020). Belonging and Social Integration as Factors of Well-Being in Latin America and Latin Europe Organizations. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.604412

Dalal, N., & Triggs, B. (2005). Histograms of Oriented Gradients for Human Detection. *In 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05)* , *2*(1). http://lear.inrialpes.fr

Dhall, A., Goecke, R., Lucey, S., Gedeon, T., Stevenson, D., Warne, G., Eames, M., Hennessy, M., Penny, D., Wilkinson, J., Pase, S., Frampton, D., Blackburn, S. M., Quinane, L. N., Zigman, J. N., Cai, J., Rendell, A. P., Strazdins, P. E., & Jin Wong, sien. (2008). *Predicting Performance of Intel Cluster OpenMP with Code Analysis Method*. http://cs.anu.edu.au/techreports/

Dimitriev, D. A., Dimitriev, A. D., Karpenko, Y. D., & Saperova, E. V. (2008). Influence of examination stress and psychoemotional characteristics on the blood pressure and heart rate regulation in female students. *Human Physiology*, *34*(5), 617–624. https://doi.org/10.1134/S0362119708050101

Dinges, D. F., Rider, R. L., Dorrian, J., Mcglinchey, E. L., Rogers, N. L., Cizman, Z., Goldenstein, S. K., Vogler, C., Venkataraman, S., & Metaxas, D. N. (2005). Optical Computer Recognition of Facial Expressions Associated with Stress Induced by Performance Demands. *Aviation, Space, and Environmental Medicine*, *76*(6), B172–B182.

Djilani, A. , & D. A. (2012). The Therapeutic Benefits of Essential Oils. In *Nutrition, Well-Being and Health*. InTech. https://doi.org/10.5772/1864

Dunstan, D. W., Howard, B., Healy, G. N., & Owen, N. (2012). Too much sitting - A health hazard. In *Diabetes Research and Clinical Practice* (Vol. 97, Issue 3, pp. 368–376). https://doi.org/10.1016/j.diabres.2012.05.020

Ekman, P. (1993). Facial expression and emotion. *American Psychologist*, *484*(4), 384.

Ekman, P., & Rosenberg, E. L. (2005). *What the Face Reveals: Basic and Applied Studies of Spontaneous Expression Using the Facial Action Coding System (FACS), Second Edition*.

Feijs, L., Delbressine, F., Feijs, L., & Delbressine, F. (2017). Calm Technology for Biofeedback: Why and How? *Proceedings of the Conference on Design and Semantics of Form and Movement - Sense and Sensitivity, DeSForM 2017*. https://doi.org/10.5772/INTECHOPEN.71114

Fernández-Álvarez, J. , D. L. D. , & R. G. (2020). Anxiety Disorders Rethinking and Understanding Recent Discoveries. *Anxiety Disorders: Rethinking and Understanding Recent Discoveries*, 389–414. http://www.springer.com/series/5584

Fineman, S. (1995). Stress, emotion and intervention. *Managing Stress, Emotion and Power at Work*, 120–135. https://us.sagepub.com/en-us/nam/managing-stress/book203629#preview

Finney, C., Stergiopoulos, E., Hensel, J., Bonato, S., & Dewa, C. S. (2013). Organizational stressors associated with job stress and burnout in correctional officers: a systematic review. In *BMC public health* (Vol. 13, p. 82). https://doi.org/10.1186/1471-2458-13-82

Forer, B. R. (1949). The fallacy of personal validation: A classroom demonstration of gullibility. *The Journal of Abnormal and Social Psychology*, *44*(1), 118.

Fortmann, J., Stratmann, T. C., Boll, S., Poppinga, B., & Heuten, W. (2013). Make Me Move at Work! An Ambient Light Display to Increase Physical Activity. *In 2013 7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops* , 274–277.

Geurts, S. , & G. R. (2012). *Workplace stress and stress prevention in Europe*. 9–32.

Giannakakis, G., Pediaditis, M., Manousos, D., Kazantzaki, E., Chiarugi, F., Simos, P. G., Marias, K., & Tsiknakis, M. (2017). Stress and anxiety detection using facial cues from videos. *Biomedical Signal Processing and Control*, *31*, 89–101. https://doi.org/10.1016/j.bspc.2016.06.020

Goodfellow, I. J., Erhan, D., Carrier, P. L., Courville, A., Mirza, M., Hamner, B., Cukierski, W., Tang, Y., Thaler, D., Lee, D.-H., Zhou, Y., Ramaiah, C., Feng, F., Li, R., Wang, X., Athanasakis, D., Shawe-Taylor, J., Milakov, M., Park, J., … Bengio, Y. (2013). *LNCS 8228 - Challenges in Representation Learning: A Report on Three Machine Learning Contests*. http://www.kaggle.com/c/challenges-in-representation-learning-facial-

Grossman, P., Niemann, L., Schmidt, S., & Walach, H. (2004). Mindfulness-based stress reduction and health benefits: A meta-analysis. *Journal of Psychosomatic Research*, *57*(1), 35–43. https://doi.org/10.1016/S0022-3999(03)00573-7

He, K., Zhang, X., Ren, S., & Sun, J. (2016). Deep Residual Learning for Image Recognition. *In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 770–778. http://image-net.org/challenges/LSVRC/2015/

Hedblom, M., Gunnarsson, B., Iravani, B., Knez, I., Schaefer, M., Thorsson, P., & Lundström, J. N. (2019). Reduction of physiological stress by urban green space in a multisensory virtual experiment. *Scientific Reports*, *9*(1). https://doi.org/10.1038/s41598-019-46099-7

Hedigan, F., Sheridan, H., & Sasse, A. (2023). Benefit of inhalation aromatherapy as a complementary treatment for stress and anxiety in a clinical setting – A systematic review. In *Complementary Therapies in Clinical Practice* (Vol. 52). Churchill Livingstone. https://doi.org/10.1016/j.ctcp.2023.101750

Herz, R. S., & Engen, T. (1996). Odor memory: Review and analysis. Psychonomic bulletin & review, 3, 300-313.

Hindu, A., & Bhowmik, B. (2022). An IoT-Enabled Stress Detection Scheme Using Facial Expression. *INDICON 2022 - 2022 IEEE 19th India Council International Conference*. https://doi.org/10.1109/INDICON56171.2022.10040216

Hobfoll, S. E. (2001). The influence of culture, community, and the nested-self in the stress process: Advancing conservation of resources theory. *Applied Psychology*, *50*(3), 337–421. https://doi.org/10.1111/1464-0597.00062

Hofmann, S. G., Asnaani, A., Vonk, I. J. J., Sawyer, A. T., & Fang, A. (2012). The efficacy of cognitive behavioral therapy: A review of meta-analyses. *Cognitive Therapy and Research*, *36*(5), 427–440. https://doi.org/10.1007/s10608-012-9476-1

Hölzel, B. K., Carmody, J., Vangel, M., Congleton, C., Yerramsetti, S. M., Gard, T., & Lazar, S. W. (2011). Mindfulness practice leads to increases in regional brain gray matter density. *Psychiatry Research - Neuroimaging*, *191*(1), 36–43. https://doi.org/10.1016/j.pscychresns.2010.08.006

Jafarinaimi, N., Forlizzi, J., Hurst, A., & Zimmerman, J. (2005). Breakaway: An Ambient Display Designed to Change Human Behavior. *In CHI'05 Extended Abstracts on Human Factors in Computing Systems*, 1945–1948.

Jaiswal, S., & Valstar, M. (2016). Deep Learning the Dynamic Appearance and Shape of Facial Action Units. *In 2016 IEEE Winter Conference on Applications of Computer Vision (WACV)*, 1–8.

Judge, T. A., Erez, A., & Thoresen, C. J. (2000). Why Negative Affectivity (And Self-Deception) Should Be Included in Job Stress Research: Bathing the Baby with the Bath Water. In *Source: Journal of Organizational Behavior* (Vol. 21, Issue 1).

Kabat-Zinn, J. (2003). Mindfulness-based stress reduction (MBSR). *Constructivism in the Human Sciences*, *8*(2), 73.

Kang, M. G. , K. S. B. , C. B. S. , P. J. K. , W. J. M. , & C. S. J. (2004). Association between job stress on heart rate variability and metabolic syndrome in shipyard male workers. *Yonsei Medical Journal*, *45*(5), 838–846.

Kaplan, R., & Kaplan, S. (1989). The experience of nature: A psychological perspective. Cambridge university press.

Katmah, R., Al-Shargie, F., Tariq, U., Babiloni, F., Al-Mughairbi, F., & Al-Nashash, H. (2021). A review on mental stress assessment methods using eeg signals. In *Sensors* (Vol. 21, Issue 15). MDPI AG. https://doi.org/10.3390/s21155043

Kersten-van Dijk, E. T. (2018). *Quantified stress: toward data-driven stress awareness.*

Kim, K. H., Bang, S. W., & Kim, S. R. (2004). Emotion recognition system using short-term monitoring of physiological signals. *Medical and Biological Engineering and Computing*, *42*(3), 419–427. https://doi.org/10.1007/BF02344719

Kim, W., Lim, S. K., Chung, E. J., & Woo, J. M. (2009). The effect of cognitive behavior therapy-based psychotherapy applied in a forest environment on physiological changes and remission of major depressive disorder. *Psychiatry Investigation*, *6*(4), 245–254. https://doi.org/10.4306/pi.2009.6.4.245

Kirkegaard, T., & Brinkmann, S. (2016). "which coping strategies does the working environment offer you?" A field study of the distributed nature of stress and coping. *Nordic Psychology*, *68*(1), 12–29. https://doi.org/10.1080/19012276.2015.1045543

Kozusznik, M. W., Rodríguez, I., & Peiró, J. M. (2015). Eustress and distress climates in teams: Patterns and Outcomes. *International Journal of Stress Management*, *22*(1), 1–23. https://doi.org/10.1037/a0038581

Kudo, N., Shinohara, H., & Kodama, H. (2014). Heart Rate Variability Biofeedback Intervention for Reduction of Psychological Stress During the Early Postpartum Period. *Applied Psychophysiology Biofeedback*, *39*(3–4), 203–211. https://doi.org/10.1007/s10484-014-9259-4

Kurtessis, J. N., Eisenberger, R., Ford, M. T., Buffardi, L. C., Stewart, K. A., & Adis, C. S. (2017). Perceived organizational support: A meta-analytic evaluation of organizational support theory. Journal of management, 43(6), 1854-1884.

Lansisalmi, H., Peiro, J. M., & Kivimaki, M. (2000). Collective stress and coping in the context of organizational culture. *European Journal of Work and Organizational Psychology*, *9*(4), 527–559. https://doi.org/10.1080/13594320050203120

Lau, N., O'Daffer, A., Colt, S., Yi-Frazier, J. P., Palermo, T. M., McCauley, E., & Rosenberg, A. R. (2020). Android and iphone mobile apps for psychosocial wellness and stress management: Systematic search in app stores and literature review. In *JMIR mHealth and uHealth* (Vol. 8, Issue 5). JMIR Publications Inc. https://doi.org/10.2196/17798

Lazar, A., Koehler, C., Tanenbaum, T. J., & Nguyen, D. H. (2015). Why we use and abandon smart devices. *UbiComp 2015 - Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, 635–646. https://doi.org/10.1145/2750858.2804288

Lazarus, R. S. , & F. S. (1984). Stress: appraisal and coping. In *Encyclopedia of Behavioral Medicine*. Springer International Publishing. https://doi.org/10.1007/978-3-030-39903-0

Lehrer, P. M., & Gevirtz, R. (2014). Heart rate variability biofeedback: How and why does it work? *Frontiers in Psychology*, *5*(JUL). https://doi.org/10.3389/fpsyg.2014.00756

Leong, S. C., Tang, Y. M., Lai, C. H., & Lee, C. K. M. (2023). Facial expression and body gesture emotion recognition: A systematic review on the use of visual data in affective computing. In *Computer Science Review* (Vol. 48). Elsevier Ireland Ltd. https://doi.org/10.1016/j.cosrev.2023.100545

Lerner, J. S., Li, Y., Valdesolo, P., & Kassam, K. S. (2015). Emotion and decision making. *Annual Review of Psychology*, *66*, 799–823. https://doi.org/10.1146/annurev-psych-010213-115043

Li, I. A. D. and J. F., Hudson, S. E. ., & Fitzpatrick, Geraldine. (2010). *A Stage-Based Model of Personal Informatics Systems*. Association for Computing Machinery.

Li, S., Deng, W., & Du, J. (2017). Reliable Crowdsourcing and Deep Locality-Preserving Learning for Expression Recognition in the Wild. *In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 2852–2861. http://whdeng.cn/RAF/model1.html

Lin, J. J., Mamykina, L., Lindtner, S., Delajoux, G., & Strub, H. B. (2006). Fish'n'Steps: Encouraging Physical Activity with an Interactive Computer Game. *LNCS*, *4206*, 261–278. http://www.scr.siemens.com

Lu, Y., Ouden, E. Den, Brombacher, A., Geudens, W., & Hartmann, H. (2007). Towards a more systematic analysis of uncertain user-product interactions in product development: An enhanced user-product interaction framework. *Quality and Reliability Engineering International*, *23*(1), 19–29. https://doi.org/10.1002/qre.820

Lucey, P. , C. J. F. , K. T. , S. J. , A. Z. , & M. I. (2010). *The extended cohn-kanade dataset (ck+): A complete dataset for action unit and emotion-specified expression.* IEEE.

Lupien, S. J., McEwen, B. S., Gunnar, M. R., & Heim, C. (2009). Effects of stress throughout the lifespan on the brain, behaviour and cognition. In *Nature Reviews Neuroscience* (Vol. 10, Issue 6, pp. 434–445). Nature Publishing Group. https://doi.org/10.1038/nrn2639

Lyons, M., Akamatsu, S., Kamachi, M., & Gyoba, J. (1998). Coding Facial Expressions with Gabor Wavelets. *In Proceedings Third IEEE International Conference on Automatic Face and Gesture Recognition* , 200–205.

Maeda, N., Hirabe, Y., Arakawa, Y., & Yasumoto, K. (2016). COSMS : Unconscious stress monitoring system for office worker. *UbiComp 2016 Adjunct - Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing*, 329–332. https://doi.org/10.1145/2968219.2971397

Marsella, S., Gratch, J., & Petta, P. (2010). Computational Models of Emotion. *A Blueprint for Affective Computing-A Sourcebook and Manual*, *11*(1), 21–46.

Matsubara, E., Matsui, N., & Kambara, K. (2023). Utilization of essential oils mainly from Cupressaceae trees in the work environment creates a psychophysiological stress-relieving effect. *Wood Science and Technology*, *57*(5), 1197–1214. https://doi.org/10.1007/s00226-023-01490-6

Mayer, J. D., Roberts, R. D., & Barsade, S. G. (2008). Human abilities: Emotional intelligence. *Annual Review of Psychology*, *59*, 507–536. https://doi.org/10.1146/annurev.psych.59.103006.093646

McDuff, D., El Kaliouby, R., Senechal, T., Amr, M., Cohn, J. F., & Picard, R. (2013). Affectiva-mit facial expression dataset (AM-FED): Naturalistic and spontaneous facial expressions collected "in-the-wild." *IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops*, 881–888. https://doi.org/10.1109/CVPRW.2013.130

McEwen, B. S. (1998). Protective and Damaging Effects of Stress Mediators. *New England Journal of Medicine*, *338*(3), 171–179. https://doi.org/10.1056/nejm199801153380307

McEwen, B. S. (1998). S. adaptation, and disease: A. and allostatic load. A. of the N. Y. academy of sciences, 840(1), 33-44. (1998). Stress, adaptation, and disease allostasis and allostatic load. *Annals of the New York Academy of Sciences*, *840*, 33–44. https://doi.org/10.1111/j.1749-6632.1998.tb09546.x

Mollahosseini, A., Hasani, B., & Mahoor, M. H. (2019). AffectNet: A Database for Facial Expression, Valence, and Arousal Computing in the Wild. *IEEE Transactions on Affective Computing*, *10*(1), 18–31. https://doi.org/10.1109/TAFFC.2017.2740923

Montibeller, G., & von Winterfeldt, D. (2015). Cognitive and Motivational Biases in Decision and Risk Analysis. *Risk Analysis*, *35*(7), 1230–1251. https://doi.org/10.1111/risa.12360

Moraveji, N. , Adiseshan, A. , & & Hagiwara, T. (2012). Breathtray: augmenting respiration self-regulation without cognitive deficit. *In CHI'12 Extended Abstracts on Human Factors in Computing Systems* , 2405–2410.

Moss, M., Cook, J., Wesnes, K., & Duckett, P. (2003). Aromas of rosemary and lavender essential oils differentially affect cognition and mood in healthy adults. *International Journal of Neuroscience*, *113*(1), 15–38. https://doi.org/10.1080/00207450390161903

Mucha, H., Correia De Barros, A., Benjamin, J. J., Benzmüller, C., Bischof, A., Buchmüller, S., De Carvalho, A., Dhungel, A. K., Draude, C., Fleck, M. J., Jarke, J., Klein, S., Kortekaas, C., Kurze, A., Linke, D., Maas, F., Marsden, N., Melo, R., Michel, S., … Berger, A. (2022). Collaborative Speculations on Future Themes for Participatory Design in Germany. *I-Com*, *21*(2), 283–298. https://doi.org/10.1515/icom-2021-0030

Neelakantan, N., Tharion, E., & Parthasarathy, S. (2009). Short-term heart rate variability measures in students during examinations. In *Article in The National Medical Journal of India*. https://www.researchgate.net/publication/38031828

Nickerson, R. S. (1998). Confirmation Bias: A Ubiquitous Phenomenon in Many Guises. In *Review of General Psychology* (Vol. 2, Issue 2).

Noto, Y., Sato, T., Kudo, M., Kurata, K., & Hirota, K. (2005). The relationship between salivary biomarkers and state-trait anxiety inventory score under mental arithmetic stress: A pilot study. *Anesthesia and Analgesia*, *101*(6), 1873–1876. https://doi.org/10.1213/01.ANE.0000184196.60838.8D

Owen, N., Ve, G., Healy, N., Matthews, C. E., Dunstan, D. W., Owen, N., Healy, G. N., Matthews, C. E., & Dunstan, D. W. (2010). Too Much Sitting: The Population Health Science of Sedentary Behavior. In *Exerc. Sport Sci. Rev* (Vol. 38, Issue 3). www.acsm-essr.org

Pantic, M., Valstar, M., Rademaker, R., & Maat, L. (2005). Web-based database for facial expression analysis. *In 2005 IEEE International Conference on Multimedia and Expo* , 5.

Pereira, T., Almeida, P. R., Cunha, J. P. S., & Aguiar, A. (2017). Heart rate variability metrics for fine-grained stress level assessment. *Computer Methods and Programs in Biomedicine*, *148*, 71–80. https://doi.org/10.1016/j.cmpb.2017.06.018

Picard, R. W. (1999). Affective computing for hci. *In HCI*, *1*, 829–833.

Piwek, L., Ellis, D. A., Andrews, S., & Joinson, A. (2016). The Rise of Consumer Health Wearables: Promises and Barriers. *PLoS Medicine*, *13*(2). https://doi.org/10.1371/journal.pmed.1001953

pmc_9667129. (n.d.).

Porges, S. W. (1995). Cardiac Vagal Tone: A Physiological Index of Stress. In *Neuroscience and Biobehavioral Reviews* (Vol. 19, Issue 2).

Pourmohammadi, S., & Maleki, A. (2020). Stress detection using ECG and EMG signals: A comprehensive study. *Computer Methods and Programs in Biomedicine*, *193*. https://doi.org/10.1016/j.cmpb.2020.105482

Prinsloo, G. E., Rauch, H. G. L., Karpul, D., & Derman, W. E. (2013). The effect of a single session of short duration heart rate variability biofeedback on EEG: A pilot study. *Applied Psychophysiology Biofeedback*, *38*(1), 45–56. https://doi.org/10.1007/s10484-012-9207-0

Rahimnia, F., Karimi Mazidi, A., & Mohammadzadeh, Z. (2013). Emotional mediators of psychological capital on well-being: The role of stress, anxiety, and depression. *Management Science Letters*, *3*(3), 913–926. https://doi.org/10.5267/j.msl.2013.01.029

Ren, X., Yu, B., Lu, Y., & Brombacher, A. (2018). Exploring cooperative fitness tracking to encourage physical activity among office workers. *Proceedings of the ACM on Human-Computer Interaction*, *2*(CSCW). https://doi.org/10.1145/3274415

Ren, X., Yu, B., Lu, Y., Zhang, B., Hu, J., & Brombacher, A. (2019). LightSit: An unobtrusive health-promoting system for relaxation and fitness microbreaks at work. *Sensors (Switzerland)*, *19*(9). https://doi.org/10.3390/s19092162

Richardson, K. M., & Rothstein, H. R. (2008). Effects of Occupational Stress Management Intervention Programs: A Meta-Analysis. *Journal of Occupational Health Psychology*, *13*(1), 69–93. https://doi.org/10.1037/1076-8998.13.1.69

Ritvanen, T., Louhevaara, V., Helin, P., Väisänen, S., & Hänninen, O. (2006). Responses of the autonomic nervous system during periods of perceived high and low work stress in younger and older female teachers. *Applied Ergonomics*, *37*(3), 311–318. https://doi.org/10.1016/j.apergo.2005.06.013

Rodríguez, I., Kozusznik, M. W., Peiró, J. M., & Tordera, N. (2019). Individual, co-active and collective coping and organizational stress: A longitudinal study. *European Management Journal*, *37*(1), 86–98. https://doi.org/10.1016/j.emj.2018.06.002

Scheier, M. F., Weintraub, J. K., & Carver, C. S. (1986). Coping With Stress. Divergent Strategies of Optimists and Pessimists. *Journal of Personality and Social Psychology*, *51*(6), 1257–1264. https://doi.org/10.1037/0022-3514.51.6.1257

Schein, E. H. (2010). *Organizational culture and leadership* (Vol. 2).

Schomakers, E. M., Lidynia, C., & Ziefle, M. (2022). The Role of Privacy in the Acceptance of Smart Technologies: Applying the Privacy Calculus to Technology Acceptance. *International Journal of Human-Computer Interaction*, *38*(13), 1276–1289. https://doi.org/10.1080/10447318.2021.1994211

Simonyan, K., & Zisserman, A. (2014). *Very Deep Convolutional Networks for Large-Scale Image Recognition*. http://arxiv.org/abs/1409.1556

Sloan, R. P., Shapiro ', P. A., Bagiella, E., Boni, S. M., Paik, M., Bigger, J. T. ', Steinman ', R. C., & Gorman, J. M. (1994). Effect of mental stress throughout the day on cardiac autonomic control. In *Biological Psychology* (Vol. 37).

Smith, C. A. (1989). Dimensions of Appraisal and Physiological Response in Emotion. *Journal of Personality and Social Psychology*, *56*(3), 339–353. https://doi.org/10.1037/0022-3514.56.3.339

Smith, V., Warty, R. R., Sursas, J. A., Payne, O., Nair, A., Krishnan, S., da Silva Costa, F., Wallace, E. M., & Vollenhoven, B. (2020). The Effectiveness of Virtual Reality in Managing Acute Pain and Anxiety for Medical Inpatients: Systematic Review. In *Journal of Medical Internet Research* (Vol. 22, Issue 11). JMIR Publications Inc. https://doi.org/10.2196/17980

Soleymani, M., Lichtenauer, J., Pun, T., & Pantic, M. (2012). A multimodal database for affect recognition and implicit tagging. *IEEE Transactions on Affective Computing*, *3*(1), 42–55. https://doi.org/10.1109/T-AFFC.2011.25

Spielberg, C. H. A. D. (1971). DEVELOPMENT OF THE SPANISH EDITION OF THE STATE-TRAIT ANXIETY INVENTORY1. In *Interamerican Journal of Psychology*.

Stuart, T., Hanna, J., & Gutruf, P. (2022). Wearable devices for continuous monitoring of biosignals: Challenges and opportunities. In *APL Bioengineering* (Vol. 6, Issue 2). American Institute of Physics Inc. https://doi.org/10.1063/5.0086935

Teuchmann, K. , T. P. , & P. S. K. (1999). Rushed, unhappy, and drained: an experience sampling study of relations between time pressure, perceived control, mood, and emotional exhaustion in a group of accountants. *Journal of Occupational Health Psychology*, *4*(1), 37.

Thorp, A. A., Owen, N., Neuhaus, M., & Dunstan, D. W. (2011). Sedentary behaviors and subsequent health outcomes in adults: A systematic review of longitudinal studies, 19962011. In *American Journal of Preventive Medicine* (Vol. 41, Issue 2, pp. 207–215). Elsevier Inc. https://doi.org/10.1016/j.amepre.2011.05.004

Thuerauf, N., Reulbach, U., Lunkenheimer, J., Lunkenheimer, B., Spannenberger, R., Gossler, A., Maihöfner, C., Bleich, S., Kornhuber, J., & Markovic, K. (2009). Emotional reactivity to odors: Olfactory sensitivity and the span of emotional evaluation separate the genders. *Neuroscience Letters*, *456*(2), 74–79. https://doi.org/10.1016/j.neulet.2009.03.096

Van Amelsvoort, L. G. P. M., Schouten, E. G., Maan, A. C., Swenne, C. A., & Kok, F. J. (2000). Occupational determinants of heart rate variability. *International Archives of Occupational and Environmental Health*, *73*, 255–262.

Vidyarthi, J. , R. B. E. , & G. D. (2012). Sonic Cradle: designing for an immersive experience of meditation by connecting respiration to music. *In Proceedings of the Designing Interactive Systems Conference*, 408–417.

Wainwright, D. , & C. M. (2002). Work Stress. The Making of a Modern Epidemic. *International Journal of Epidemiology*, *31*(6), 1282–1283. https://doi.org/10.1093/ije/31.6.1282

Wang, Q., He, C., & Hu, J. (2023). Enhancing Workplace Well-being: Integrating Physiological Data into Aromatherapy through Calm Technology. *ACM International Conference Proceeding Series*, 455–460. https://doi.org/10.1145/3629606.3629653

Wang, Q., He, C., & Hu, J. (2024). Calm Digital Art Installation for Alleviating Sedentary Anxiety: A Case Study. *Frontiers in Artificial Intelligence and Applications* , *384*, 1197–1206. https://doi.org/10.3233/FAIA240122

Wang, Q., Liu, Z., & Hu, J. (2022). Effects of Color Tone of Dynamic Digital Art on Emotion Arousal. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *13477 LNCS*, 363–371. https://doi.org/10.1007/978-3-031-20212-4_30

Weiser, M., & Brown, J. S. (1997). The Coming Age of Calm Technology. *Beyond Calculation*, 75–85. https://doi.org/10.1007/978-1-4612-0685-9_6

Xue, M., Liang, R. H., Yu, B., Funk, M., Hu, J., & Feijs, L. (2019). Affective wall: Designing collective stress-related physiological data visualization for reflection. *IEEE Access*, *7*, 131289–131303. https://doi.org/10.1109/ACCESS.2019.2940866

Xue, M., Liang, R.-H., Hu, J., & Feijs, L. (2017). ClockViz: Designing Public Visualization for Coping with Collective Stress in Teamwork. *Proceedings of the Conference on Design and Semantics of Form and Movement - Sense and Sensitivity, DeSForM 2017*, 67–78. https://doi.org/10.5772/intechopen.71220

Yan, G., Zhang, C., Wang, J., Xu, Z., Liu, J., Nie, J., Ying, F., & Yao, C. (2022). CamFi: An AI-driven and Camera-based System for Assisting Users in Finding Lost Objects in Multi-Person Scenarios. *Conference on Human Factors in Computing Systems - Proceedings*, 1–7. https://doi.org/10.1145/3491101.3519780

Yu, B., An, P., Hendriks, S., Zhang, N., Feijs, L., Li, M., & Hu, J. (2021). ViBreathe: Heart Rate Variability Enhanced Respiration Training for Workaday Stress Management via an Eyes-Free Tangible Interface. *International Journal of Human-Computer Interaction*, *37*(16), 1551–1570. https://doi.org/10.1080/10447318.2021.1898827

Yu, B., Feijs, L., Funk, M., & Hu, J. (2015). Designing Auditory Display of Heart Rate Variability in Biofeedback Context. *In ICAD* , 294–298. https://www.researchgate.net/publication/295875357

Yu, B., Funk, M., Hu, J., & Feijs, L. (2018). Unwind: a musical biofeedback for relaxation assistance. *Behaviour and Information Technology*, *37*(8), 800–814. https://doi.org/10.1080/0144929X.2018.1484515

Yu, B., Funk, M., Hu, J., Wang, Q., & Feijs, L. (2018). Biofeedback for everyday stress management: A systematic review. *Frontiers in ICT*, *5*(SEP). https://doi.org/10.3389/FICT.2018.00023/FULL

Yu, B., Hu, J., Funk, M., & Feijs, L. (2018). DeLight: biofeedback through ambient light for stress intervention and relaxation assistance. *Personal and Ubiquitous Computing*, *22*(4), 787–805. https://doi.org/10.1007/s00779-018-1141-6

Zhang, J. , Mei, X. , L., H., Y. S. , & & Qian, T. (2019). *Detecting Negative Emotional Stress Based on Facial Expression in Real Time*. IEEE.

APPENDICES

Case Studies - Stress Detection and Intervention Methods

We explore three case studies aimed at revealing the effectiveness of different stress detection and intervention methods and providing valuable implications for the design opportunities. The studies, involving dynamic digital art, audio-visual emotional congruence, multi-sensory interventions and smart aromatherapy devices, demonstrate the potential of a variety of approaches to relieve stress and improve mental health.

First, research on dynamic digital art shows that although different tones have limited impact on emotional arousal, dynamic presentation can arouse participants' interest, which suggests that we can use visual dynamic effects to enhance user interactive experience. Secondly, research on the emotional consistency of audio and video found that dynamic digital art combined with different music has a significant effect in relieving stress, especially happy and sad videos, which suggests that we can improve the intervention effect by integrating multi-sensory experiences. Third, research on monitoring sedentary behavior combined with dynamic digital art installations has shown that the combination of behavioral monitoring and visual intervention is effective in alleviating anxiety, which has promoted the introduction of real-time behavior checking functionality into the design concept. Finally, research on smart aromatherapy devices has shown the effectiveness of initiating aromatherapy based on physiological data, especially when using lavender essential oil. This provides us with a basis to accurately adjust aromatherapy through physiological data. Combining these insights, the design opportunities aim to provide a more comprehensive and customized stress management solution by integrating multi-sensory experiences, real-time behavioral monitoring and physiological data analysis.

Case Study 1: Effects of Dynamic Digital Art with Audio-Visual Emotional Congruence on Relieving Stress

Creative digital art may become an effective means of stress relief, and its interactivity and dynamism bring new dimensions to visual and auditory experience. This study aims to explore the effect of emotional consistency of dynamic digital art in different music backgrounds on stress relief, to provide theoretical basis and empirical support for the design considerations (Wang et al., 2022b).

This study designed an experiment, invited 100 participants and divided them into five groups. The experiment used the Trier Social Stress Test to induce the stress state of the participants, and then the four experimental groups watched videos of four emotional types: joy, anger, sadness and fear. The fifth group was the control group and did not watch the video. The video content was a combination of dynamic digital art and emotionally consistent music (Figure 1). The changes in the stress state of the participants before and after the experiment were measured by the State-Trait Anxiety Scale questionnaire.

Emotion	Joy	Anger	Sadness	Fear
Music	Beautiful Sunday	The Yellow River	Zigeunerweisen	The Planets
Image				

Figure 1: Stimuli of the Experiment

The experimental results showed that the groups that watched the joy and sadness videos had a more significant effect on stress relief. This finding suggests that emotionally consistent audio-visual stimulation has potential application value in stress intervention. Videos with joyful and sad emotions were more effective in relieving stress. Utilizing emotionally consistent audio content can enhance the effectiveness of the system in relieving stress. By incorporating these visual and audio stimuli into the design opportunities, a more comprehensive sensory experience can be created, thereby improving the stress management effect for users.

Case Study 2: Calm Digital Art Installation for Alleviating Sedentary Anxiety: A Case Study

In modern office environments, the prevalence of sedentary behavior has led to an increase in anxiety symptoms among office workers. This study aims to explore a camera-based solution for checking the sedentary behavior of office workers and alleviating anxiety through dynamic digital art installations (Wang et al., 2024). By analyzing the images captured by the camera, we can detect and record the sedentary time of office workers in real time, thereby finding potential anxiety symptoms related to sedentary behavior.

To alleviate the anxiety caused by sedentary behavior, we designed a series of dynamic digital art installations that provide a visual calming effect through changing colors and forms. This study used a co-constructing story approach and conducted a user study with 30 participants to stimulate their imagination and visual perception (see Figure 2). The experimental results show that checking the sedentary behavior of office workers through cameras and combining dynamic digital art installations can alleviate the anxiety of office workers to a certain extent.

Figure 2: Sensation Phase of Co-constructing Stories

Real-time monitoring of user behavior data helps to more accurately identify sedentary behavior and the anxiety it brings, thereby improving the intervention effect of the system. By introducing visual elements, a multi-sensory experience can be created to enhance the overall mood regulation effect. Finally, the introduction of interactivity can not only increase user engagement and acceptance, but also make interventions more precise and effective through personalized feedback and adjustments.

Case Study 4: Enhancing Workplace Well-being: Integrating Physiological Data into Aromatherapy through Calm Technology

This study aims to develop a smart aromatherapy device to enhance workplace well-being by applying the principles of calm technology (Wang et al., 2023) . The device automatically starts diffuser based on physiological data collected by a wearable wristband to relieve anxiety and enhance office vitality, thereby improving productivity (see Figure 3). The study recruited 90 participants, divided into three groups of 30 people each. Anxiety was induced by the Kraepelin test (arithmetic task), and aromatherapy was performed using lavender essential oil and coconut oil, while the blank group served as the control group.

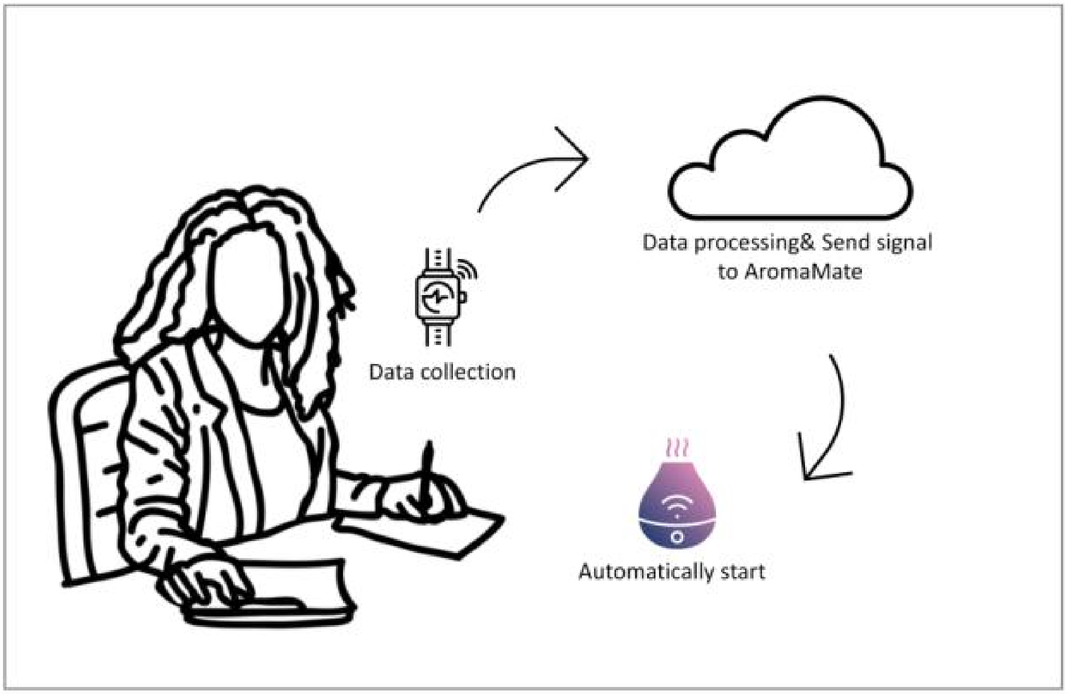

Figure 3: Design Concept

The experimental results showed that the anxiety level of participants using lavender essential oil was significantly lower than that of the control group. This study highlights the potential of smart diffusers as a natural intervention for stress management and vitality enhancement, and is in line with the principles of calm technology. This study lays the foundation for further development and improvement of smart aromatherapy devices to improve work and life quality.

Integrating physiological data from wearable devices can achieve more accurate and personalized stress intervention. Combined with the concept of calm technology, the user experience can be improved through automated and non-intrusive methods, reducing interference with users' daily activities. The experiment verified the effectiveness of aromatherapy in relieving stress, making it more convincing and possible in practical application. These insights will help us design a more comprehensive and effective intervention system to improve mental health and well-being in the workplace.

Relaxation Rate Scale(RRS)

DIRECTIONS:

Please rate your relaxation state at this moment.

NOT RELAXED	1	2	3	4	5	6	7	8	9	TOTALLY RELAXED

Questions of **State-Trait Anxiety Inventory**

DIRECTIONS:

Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel *right now, that is, at this moment.* There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	Not at all	Somewhat	Moderately so	Veyr much so
1.I feel calm..	1	2	3	4
2.I feel secure..	1	2	3	4
3.I am tense..	1	2	3	4
4.I feel strained..	1	2	3	4
5.I feel at ease..	1	2	3	4
6.I feel upset..	1	2	3	4
7.I am presently worrying over possible misfortunes............	1	2	3	4
8.I feel satisfied..	1	2	3	4
9.I feel frightened..	1	2	3	4
10.I feel comfortable..	1	2	3	4
11.I feel self-confident..	1	2	3	4
12.I feel nervous..	1	2	3	4
13.I am jittery(anxious and nervous).....................................	1	2	3	4
14.I feel indecisive..	1	2	3	4
15.I am relaxed..	1	2	3	4
16.I feel content..	1	2	3	4
17.I am worried..	1	2	3	4
18.I feel confused..	1	2	3	4
19.I feel steady..	1	2	3	4
20.I feel pleasant..	1	2	3	4

Interview Questions

1. Collective stress perception

Did the AromaHub system help you become more aware of collective stress in the workplace? Please specify the reasons for the changes or lack of changes you perceived.

2. Intervention effectiveness

How did AromaHub's intervention methods (including visual and olfactory) affect your stress levels? Please specify what worked and what didn't.

Do you think the system's multi-sensory interventions helped you with your overall stress management? Please describe your experience and observations.

3. System improvement suggestions

Based on your experience, what features or design aspects of the AromaHub system need to be improved? Please provide specific suggestions, such as visual design, fragrance selection, stress detection accuracy, etc.

4. Other comments

In addition to the aspects discussed above, did you have other observations or experiences while using AromaHub? For example, the stability of the system, ease of use, or any functional issues not mentioned.

5. Overall satisfaction

Overall, how satisfied are you with the AromaHub system? Please consider the overall functionality, design, and actual results of the system, and provide specific reasons for satisfaction or dissatisfaction.

CURRICULUM VITAE

Qiurui Wang recieved her Bachelor's degree in English from Beijing City College in 2007 and a Master's degree in Industrial Design Engineering from Zhejiang University in 2020. With extensive experience at the China Industrial Design Association, she has honed her skills in design innovation and project management. Her notable achievements include leading collaborative design cooperation and international exchanges that have set new benchmarks in the industry. In 2022, she joined the collaborative PDEng project "Designing with Connectivity for Office Vitality," a joint effort between Eindhoven University of Technology and the Guangzhou Wanqu Cooperative Institute of Design. Her role in this project aligns with the institute's strategic focus on smart design and health interventions. Her work on the AromaHub project, particularly her contributions to multi-sensory design and stress management, has been crucial in advancing research. Her efforts are aimed at providing innovative solutions to enhance workplace health and productivity, demonstrating her commitment to improving office environments through effective design collaboration.

List of Publications

Conference Proceedings

- Wang, Q., Liu, Z., He, C., & Hu, J. (2022, October). Effects of Dynamic Digital Art with Audio-visual Emotional Congruence on Relieving Stress. In *Proceedings of the Tenth International Symposium of Chinese CHI* (pp. 222-226).
- Wang, Q., Liu, Z., & Hu, J. (2022, October). Effects of color tone of dynamic digital art on emotion arousal. In *International Conference on Entertainment Computing* (pp. 363-371). Cham: Springer International Publishing.
- Wang, Q., Hu, J., Liu, Z., & He, C. (2023). The Effects of Happy and Sad Dynamic Digital Art on Relieving Stress. *Human Interaction & Emerging Technologies (IHIET 2023): Artificial Intelligence & Future Applications*, 111(111).
- Wang, Q., He, C., & Hu, J. (2023, November). Enhancing Workplace Well-being: Integrating Physiological Data into Aromatherapy through Calm Technology. *In Proceedings of the Eleventh International Symposium of Chinese CHI* (pp. 455-460).
- Wang, Q., Streithorst, L., He, C., Feijs, L., & Hu, J. (2023, November). Calm Digital Artwork for Connectedness: A Case Study. *In International Conference on Entertainment Computing* (pp. 461-470). Singapore: Springer Nature Singapore.
- Wang, Q., He, C., & Hu, J. (2024, March). Calm Digital Art Installation for Alleviating Sedentary Anxiety: A Case Study. In *2023 International Symposium on World Ecological Design, ISWED 2023* (pp. 1197-1206). IOS Press.
- Liu, Z., Yao, C., Wang, Q., & Ying, F. (2023). AffectiveTree: Visualizing Collective Stress Amongst Chinese Telecommuters through Dynamic Painting. *Human Interaction & Emerging Technologies (IHIET 2023): Artificial Intelligence & Future Applications*, *111*(111).
- Liu, Z., Wang, Q., He, C., Yao, C., & Ying, F. (2024). Effects of Auditory Integration Training Combined with Music Therapy on Children with Autism Spectrum Disorder. In *International Symposium on World Ecological Design* (pp. 223-232). IOS Press.
- He, C., Wang, Q., Lou, J., Liu, Z., & Ying, F. (2024). Real-Time Physiological Signal Feedback for Anxiety Intervention Music System for Postpartum Women. In *International Symposium on World Ecological Design* (pp. 378-386). IOS Press.

- Jansen, A., Leborgne, F., Wang, Q., & Zhang, C. (2024, May). Contextualizing the "Why": The Potential of Using Visual Map As a Novel XAI Method for Users with Low AI-literacy. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems* (pp. 1-7).

Exhibitions

- Dutch Design Week 2022 *Digital Art of Anxiety and Stress*

Group Standard

- *T/EI 6501-2024* 智能室内氛围系统设计

  Intelligent Indoor Atmosphere System Design

- *T/EI 8301-2024* 高校计算机电子信息工程线上线下混合教学实践基地建设

  College Computer Electronic Information Engineering Online and Offline Mixed Teaching Practice Base Construction

- *T/EI 7501-2024* 数字文化艺术产业园区建设规范

  Specifications for Digital Culture and Art Industrial Park

- *T/EI 7402-2023* 服务机器人模块化设计

  Design of Modularity for Service Robot

- *T/EI 8801.1-2022* 数字化艺术与设计价值评价体系第 1 部分：通则

  Digital Art and Design Value Evaluation System Part 1: General Principles

Software Patent

- *2024SR0700708* 智能区域氛围管理平台 V1.0

  Intelligent Atmosphere Management Platform V1.0

- *2024SR0700724* 实时生理信号反馈信息处理分析平台 V1.0

  Real Time Physiological Signal Feedback Information Processing And Analysis Platform V1.0