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Smart Elderly Pillow That Can Improve the Quality of Nighttime Nursing

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Abstract: The collection of sleep information based on the smart pillow helps to analyze the sleep quality of the elderly and improve the nighttime nursing level of relevant institutions. This study, combined with existing medical research results, analyzes and summarizes the information requirements for monitoring the sleep quality of the elderly, and proposes and verifies a low-cost implementation scheme based on Arduino. Specifically, this scheme uses a thin-film pressure sensor to monitor the number of times the elderly turn over in real time to evaluate their sleep quality; a heart rate sensor is adopted for real-time heart rate detection and to issue an alarm in case of sudden situations such as myocardial infarction and palpitation; and an air quality sensor is used to detect the sleep environment. The prototype is developed based on the Arduino smart hardware platform. This study provides new information and equipment support for nighttime nursing of the elderly, which helps to improve the full-time monitoring system, reduce the difficulty of nursing work, and enhance the nursing quality.

Keywords: Geriatric care, Nighttime health monitoring, Sleep quality detection, Air quality testing.

1. Introduction

With the changes in the global population age structure, the elderly care industry is booming, posing more demands and challenges for smart devices. The elderly face more difficulties in night care. This study focuses on the solution of intelligent pillows, hoping to realize the functions of health detection and sleep environment detection during sleep of the elderly by transforming the common home pillows. When the elderly have sudden diseases, it can alert their families in time, grasp the golden time of night rescue of the elderly, and reduce the night mortality rate of the elderly as much as possible.

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2. Analysis of collection requirements for key physiological indicators

2.1. Nighttime monitoring of cardiovascular and cerebrovascular diseases

The physiological characteristics of elderly patients with coronary heart disease led to a higher likelihood of unexpected occurrences during quiet nights compared to during the day. According to the data presented in the article [1]"Nighttime Observation and Nursing of Elderly Patients with Coronary Heart Disease" in the journal “Inner Mongolia Journal of Traditional Chinese Medicine”, among the elderly patients with coronary heart disease in a certain hospital department, 67% of the patients with changes in their condition occur at night, and nighttime deaths account for 82% of the total number of deaths [2].

Recent studies have emphasized the role of wearable technologies in detecting nocturnal arrhythmias and hypoxemia among elderly patients. For example, research by [3] demonstrated that non-invasive smart textiles embedded with ECG and SpO_2 sensors significantly improve early detection of sleep-related cardiac events in aged populations [4]. Moreover, AI-powered predictive models have shown promising results in real-time monitoring of atrial fibrillation risks during sleep, aiding in automated emergency response.

The normal heart rate for a healthy person is between 60 and 100 beats per minute. However, for the elderly during sleep, the heart rate is slower, and a heart rate below 60 beats per minute is also considered normal. Once the heart rate drops below 45 beats per minute, there is a risk of danger. The normal range of oxygen saturation for the elderly is between 95% and 98%. If there are abnormal conditions, immediate medical treatment is required [5]. When the heart rate of the elderly is below 45 beats per minute or the oxygen saturation is below 95%, this smart pillow will issue a reminder and warning.

2.2. Nighttime monitoring of the sleep environment

Numerous studies have shown that the quality of sleep is affected by the indoor physical environment, and the degree of this influence is related to factors such as age and region. Therefore, to understand the current situation of the sleep environment and sleep quality of the elderly population, I obtained the influence rules of sleep environment parameters on the sleep quality of the elderly through research and data analysis, providing a reference for improving the sleep quality of the elderly by enhancing their sleep environment.

Recent advancements in indoor environmental sensing have led to more refined models for understanding how variables like CO_2 concentration, humidity, and ambient noise influence elderly sleep cycles. For example, [6] developed a machine learning framework using IoT sensors to predict poor sleep episodes based on combined indoor air quality and humidity data. This supports the integration of real-time environmental sensors in smart pillows for precision elder care.

I mainly investigated papers such as [7] "Characteristics of the Sleep Environment of the Elderly in Xi'an and Its Impact on Sleep Quality", [4] "The Relationship between the Nighttime-Daytime Sleep Patterns of Middle-aged and Elderly People in China and the Prevalence of Hyperlipidemia", and "Research on the Sleep Quality of the Elderly and Its Related Factors", and conducted a summary and analysis. The conclusions are as follows:

1.The higher the average relative humidity before going to bed, the easier it is to fall asleep [8].

2.The higher the average relative humidity during sleep, the longer the sleep duration [9].

3.The higher the average CO2 concentration during sleep, the shorter the sleep duration.

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2.2.1. Research on air quality evaluation grades

This section should describe the exact methods for integrating sensors into the pillow, including sensor specifications, integration process, positioning rationale, and initial testing methods.

2.2.2. Reference for AQI levels

As shown in the figure, the AQI levels are divided into 5 levels from 1 to 5. Among them, Level 1 and Level 2 are suitable for living [10]. Therefore, when the AQI level is greater than 2, users should be reminded to strengthen ventilation to ensure the sleep quality of the elderly at night.

2.2.3. Reference for eCO2/CO2 concentration

As shown in the figure, according to the eCO2/CO2 reference standard, when the eCO2/CO2 concentration is >800, it is considered relatively high. In this case, users can be advised to open windows for ventilation to ensure air quality for the elderly during sleep [11].

2.2.4. Reference for TVOC concentration

As shown in the figures, according to the TVOC concentration reference, a TVOC level below 50 is considered normal. Therefore, when the TVOC concentration exceeds 50, measures should be taken to ensure air quality for the elderly during sleep [12].

To summarize, the smart pillow should issue an alert in the following cases:

(1) When TVOC concentration > 50

(2) When eCO2/CO2 concentration > 800

(3) When AQI level > 2

3. Prototype design and development

Based on the above concept, the required functionality can be achieved by modifying a standard pillow.

An Arduino Uno core control board and a display screen are installed on the left side of the pillow to show real-time sensor readings. A long strip-shaped thin-film pressure sensor is embedded into the pillow surface to monitor the sleep quality of elderly users, while an air quality sensor is placed on the right side of the pillow to detect their sleep environment conditions.

3.1. Control system and key sensors

Arduino is open-source electronics prototyping platform that offers a wide range of flexible and easy-to-use smart sensors.

The RP-L flexible thin-film pressure sensor consists of a flexible film and a pressure-sensitive layer on the top, with another flexible film and conductive circuitry on the bottom. When installed on the pillow surface, it has minimal impact on comfort. When pressure is applied to its sensing area, it can precisely detect pressure distribution, providing data support for algorithms detecting movements like turning over or getting up.

Common heart rate and blood oxygen sensors are only about the size of a thumb and can monitor changes in heart rate and SpO2 levels. Since many smart wristbands already include these functions, the smart pillow only needs to provide neck measurements as supplementary data.

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The ENS160 air quality sensor from ScioSense is specifically designed for indoor air quality monitoring. It can directly output multiple IAQ metrics (including TVOC, eCO2, and AQI), supplying the smart pillow with real-time sleep environment air quality data.

3.2. Prototype development

To validate and demonstrate the design concept of this solution, we modified a household pillow by securing the hardware components using a steel ruler, scissors, and hot-melt adhesive [13]. The control system was programmed with Mind+ software, employing a rising-edge detection algorithm to process pressure sensor data for roll-over motion monitoring show in figure 1 below. Additionally, threshold analysis was applied to data from the air quality sensor and heart rate/blood oxygen sensor, with real-time data and alert information displayed on the screen.

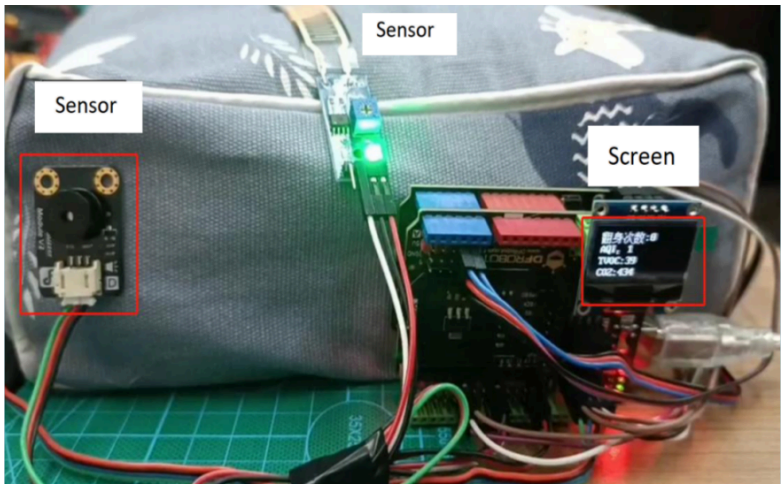

Figure 1. Prototype setup showing integrated sensors and display mounted screen on the smart pillow for real-time monitoring

As shown in the figure above, we installed a strip-shaped thin-film pressure sensor on the upper surface of the pillow, while an air quality sensor, Arduino Uno control board, and display screen were mounted on the side of the pillow [14]. The Arduino can process information in real time to record rollover movements and analyze both physiological and environmental data, with results displayed instantly on the screen.

4. Summary

This project addresses the nighttime care needs of elderly individuals by designing and demonstrating a smart pillow prototype. The pillow monitors vital signs, sleep quality, and sleeping environment, assisting in emergency response while providing comprehensive overnight monitoring and feedback effectively reducing the risk of sudden nocturnal fatalities among the elderly population.

While the current implementation already demonstrates practical value, the smart pillow retains significant potential for functional expansion and optimization. Future iterations could incorporate more advanced sensor arrays and sophisticated AI algorithms to deliver more efficient and comprehensive sleep monitoring solutions for geriatric care.

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