BioScope: An Extensible Bandage System for Facilitating Data Collection in Nursing Assessments

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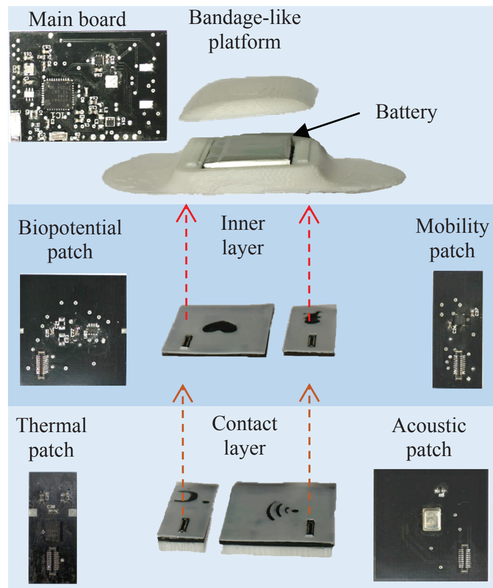
ABSTRACT
To facilitate the collection of patient biosignals, designing extensible sensing devices in which sensor management is simplified is essential. This paper presents BioScope, an extensible sensing system that facilitates collecting data used in nursing assessments. We conducted experiments to demonstrate the potential of the system. The results obtained in this study can be applied in improving the design, thus enabling BioScope to facilitate data collection in numerous potential applications.

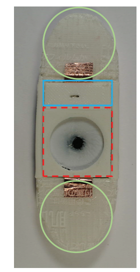
Author Keywords
Extensible bandage; nursing assessment.

ACM Classification Keywords
H.4.m Information Systems Applications: Miscellaneous

INTRODUCTION
Nursing assessments [7] play a critical role in gathering patient-related information that is required to evaluate patient physical and mental health. Conventionally, healthcare workers have collected data from patients by using existing medical instruments that track biosignals obtained from wire-connected sensors attached to the patient. Because these wire-based sensors limit patient mobility, researchers have developed adhesive patch-based solutions (e.g., Vital Connect[1] and MC10[2]) and wearable wireless sensing solutions (e.g., ExG Development Kit[3] and Fitbit Wristband[4]) to monitor data wirelessly through either garment-embedded or body-worn sensors. However, because the mental and physical health of patients fluctuates, these solutions may not enable healthcare workers to simply and effectively affix sensors to patients; healthcare workers may experience difficulties when attempting to fasten sensors to appropriate locations on the body of the patient. In addition, the effort required to manage these sensors increases when the physical or mental states of patients are unstable, such as when patients are in a postoperative phase or have been diagnosed with a psychiatric disorder.



(a) Assembled circuit boards and bandage stacking



(b) Back view of a stacked bandage

Figure 1: Design of the extensible sensing bandage. (a) Four patches with distinctive embossed icons are stacked on the inner and contact layers according to the direction indicated by the red dotted arrows. (b) The sound-collecting structure (box with red dashed border), a thermocouple wire (box with blue solid border), and two electrodes coated with a conductive gel (two green circles) directly contact the patient's skin.

To address these problems, this paper proposes BioScope, an extensible bandage system with components that can be stacked like Lego blocks. Using this system, healthcare workers can simultaneously collect the four most commonly monitored biosignals (i.e., heart rate, body temperature, acoustic signals emitted from the body, and inertial readings of human movement) from multiple bandages to assess and diagnose physical conditions. BioScope extracts the processing and communication functions into a core building block, and hosts the required sensors. Each sensor is affixed as a patch that collects one biosignal. By stacking the required sensors onto a bandage-like platform, healthcare workers can easily

[1]Vital Connect, http://www.vitalconnect.com
[2]MC10, http://www.mc10inc.com
[3]Shimmer, http://www.shimmersensing.com
[4]Fitbit Wristband, https://www.fitbit.com/flex/specs

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create a customized bandage that can be affixed to the skin of the patient. The data collected by the sensors are sent through a Bluetooth interface to the device screen used by the healthcare worker.

The main contribution of this study was the design and implementation of an extensible bandage solution that enables healthcare workers to customize adhesive sensors. We conducted experiments to demonstrate the potential of BioScope and analyzed the results, examining numerous potential applications in which BioScope can facilitate data collection.

DESIGN CONSIDERATIONS

To determine the considerations for designing an extensible bandage platform that can facilitate data collection, we collaborated with an expert from the Department of Nursing at National Taiwan University, Taipei, Taiwan. Through biweekly meetings with the expert, we first identified the necessity for an extensible sensing device that can assist healthcare workers in efficiently collecting commonly monitored data used in nursing assessments (e.g., monitoring the functional recovery of postoperational patients). Based on input provided by the expert and two experienced healthcare workers (three women, aged 30∼42 years), we explored alternative designs for the extensible sensing device. During these brainstorming sessions, we recorded the ideas of all participants and then organized these ideas by using affinity diagrams to gain a deeper understanding of the primary design considerations, which are summarized as follows.

Sensor extensibility: The system should enable healthcare workers to tailor the sensors to specific assessments. Depending on the diagnostic results, healthcare workers may wish to reassess the patient by collecting additional data. The system should therefore enable preliminary screenings in which the healthcare workers can add or remove sensors to the device.

Accessibility: The system should be efficient and simple to use, even for healthcare workers with no technical background. After determining the types of data required for patient assessment, healthcare workers should be able to easily identify which sensors to add to the device. To enable healthcare workers to attach the required sensors to appropriate locations on the patient, the device should have a compact adhesive design, enabling it to be easily affixed to the skin without undue inconvenience or skin irritation [2].

Long-term monitoring: The system should be able to analyze trends in data that are collected continually over durations ranging from several hours to several days. Healthcare workers can use this long-term data to review and reassess the physical state of patients and identify potential health complications. To continually collect data within a given period, (e.g., half of a day), a fully charged battery should contain sufficient energy to power the sensing device.

BIOSCOPE SYSTEM DESIGN AND IMPLEMENTATION

Based on the design considerations, we designed and implemented the BioScope system. This system consists of (1) an extensible sensing bandage and (2) a monitoring application.

Extensible Sensing Bandage

To create an extensible system, we designed a device with two distinct modules (Figure 1): (1) the basic bandage platform and (2) sensor patches.

The bandage-like platform resembles an adhesive bandage. We drew a 3D model of the platform and then printed it using a 3D printer and elastic filaments. Figure 1(a) depicts the platform, in which a hollow space is reserved to encase the customized sensing patches. To provide processing and communication capabilities, we designed a customized circuit board, called the main board, that could be mounted in the hollow space. The main board and the stacked sensor patches are powered by a 130-mAh Li-ion battery situated in the upper layer of the platform. On the main board, a Microchip PIC32MX150 microcontroller receives data from the sensor patches through board-to-board connectors, and then relays the processed data to the monitoring screen through a Texas Instruments CC2451 Bluetooth module. To collect biosignals, such as electrocardiogram (ECG) signals, two preallocated electrodes (i.e., two conductive copper areas situated 6.4 cm apart at opposite ends of the bandage) are coated with a thin layer of electrical gel (Figure 1(b)).

The sensor patches, consisting of small sensor boards sandwiched between two thin layers of 3D-printed elastic filaments, are mounted on the bandage-like platform using connectors. To demonstrate this system, we designed four types of patch — biopotential, thermal, acoustic, and mobility patches — to collect the most commonly monitored data in nursing assessments (e.g., biosignals). Figure 1(a) illustrates these patches stacked in two layers in the hollow space of the platform; temperature and microphone sensors directly contact the skin to collect high-quality signals. The designs of the four patch types are described in the following subsections.

Biopotential patch: This 23 mm $\times$ 24 mm patch, stacked in the inner layer, amplifies and filters ECG signals to enable continual cardiovascular monitoring. Cardiac activity, which can be characterized by ECG signals, is a crucial biosignal for assessing the cardiac functions of patients. By amplifying the electrical potential difference measured between the two electrodes by using a Texas Instruments ADS1115 analog-to-digital converter on the patch, ECG signals can be monitored by allowing the passing of low-frequency signals from 0 to 100 Hz [1] by using a low-pass filter. A pulse can be identified by detecting spikes in the signal, thus enabling healthcare workers to assess patient heart and respiratory rates.

Acoustic patch: This 24 mm $\times$ 24 mm patch, stacked in the contact layer, records acoustic signals emitted by the patient's body or while the patient is phonating. By identifying the unique sound patterns that the body's organs generate, healthcare workers can assess patient conditions. Furthermore, patients' phonation can indicate social interaction, according to which healthcare workers can assess whether patients are depressed or impaired cognitively. To clearly record the internal sounds of the body, a mediating instrument (e.g., a stethoscope) is required. Inspired by the design of electronic stetho-

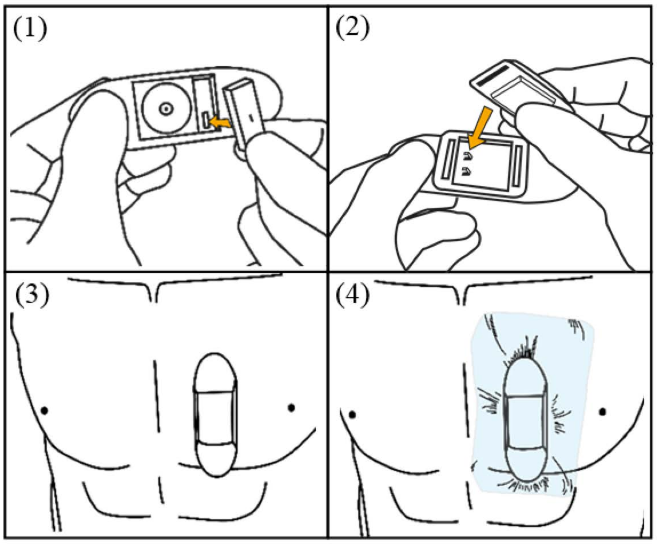


Figure 2: Four steps for applying bandages.

scopes[5], we designed and attached a small sound-collecting structure (Figure 1(b)) on the patch that effectively amplified acoustic signals from the body and occluded environmental noise. Above the sound-collecting structure, an opening is aligned with the receiving hole of an InvenSense INMP441 microphone on the main board to guide sound waves towards the hole. In this study, we detected patient phonation, which reflected social activity, by analyzing the frequency components of the collected sound.

Thermal patch: This 10 mm $\times$ 24 mm patch is stacked in the contact layer and measures the skin temperature, which can indicate patient health. Healthcare workers can evaluate a patient by identifying abnormal or varying temperatures [5]. A Maxim MAX31850 K-type thermocouple-to-digital converter detects body temperature through a thermocouple wire that protrudes from the covering elastic material to contact the skin of the patient (Figure 1(b)).

Mobility patch: This 11 mm $\times$ 24 mm patch, stacked in the inner layer, monitors the mobility level of a patient. To prevent complications caused by reduced mobility levels and assess functional recovery, healthcare workers must track the mobility level of patients. On this patch, a Bosch BMA250 accelerometer is used to collect acceleration readings, which indicate whether the patient is moving or stationary. The mobility level can be derived by calculating the percentage of time a patient is moving.

To create accessible patches for the healthcare workers, each patch was punched with a representative icon on both sides of the covering material (Figure 1(a)). Figure 2 illustrates the BioScope application process: (1) A healthcare worker selects the appropriate patches (or dummy patches) by using the embossed icon as a reference, stacks the patches on (or filling in empty spaces that are originally occupied by unused patches on) the platform, (2) inserts a battery and closes the protection cap, (3) affixes the bandage to the patient's chest, and (4) covers the entire bandage with transparent film dressings.

[5]Thinklabs One — Digital Stethoscope, http://www.thinklabs.com

BioScope Monitoring Application

To summarize the data collected using the bandages, we developed a monitoring application that operates on an Android mobile device. A mobile device on which the BioScope monitoring application is installed displays the results obtained by analyzing data collected through a Bluetooth connection from nearby bandages. In future studies, we will evaluate and improve the user interface design, which was not a focus of the present study.

EXPLORATIVE EXPERIMENTS

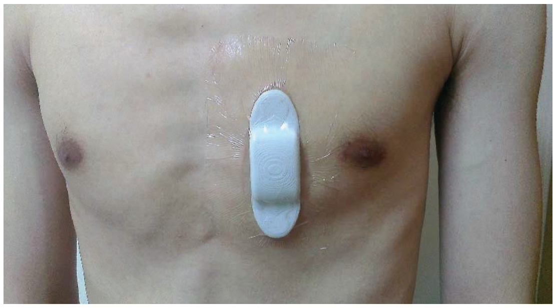
Experimental Setup

To validate system functionality, we scripted a sequence of activities to simulate conditions arising when a patient with basic functional mobility is hospitalized. Two volunteers performed the specified activities while wearing bandages equipped with all four patches on their chests, enabling us to collect data (Figure 3(a)). The simulations were conducted for 10 and 30 minutes in the cases of the first and second participants (P1 and P2), respectively. Activities comprised (1) lying down on a bed, (2) having a phone conversation, (3) watching TV, (4) having a face-to-face conversation, and (5) performing walking. In the experiments, the data captured were heart rate, skin temperature, received acoustic signals, and mobility indicators.

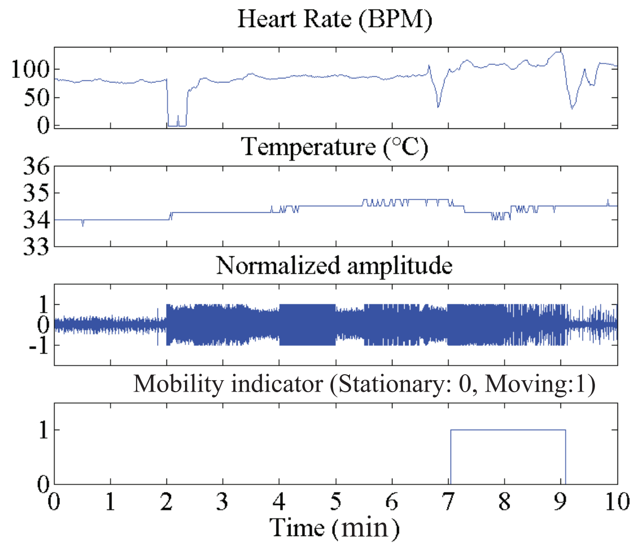
Examining the Data Collected Using BioScope

Figure 3(b) shows the results obtained by analyzing the data collected from P1. The readings obtained from the mobility patch indicated that P1 moved between the seventh and ninth minutes; this was an accurate assessment of the patient's behavior during that time. While walking, P1's heart rate increased relative to that while stationary between the start and the seventh minute. When the posture of the patient drastically changed, such as when P1 stood up near the second, seventh, and ninth minutes, the ECG signals were distorted [3], producing a dip in the calculated heart rate. The sounds generated by clothes rubbing against the bandage when P1 moved adversely affected the quality of detected internal sounds, causing the amplitudes to increase between the seventh and ninth minutes. After filtering out sounds generated by movement, however, we could still detect when P1 phonated between the second and seventh minute. Based on the vocal resonance of the body [4], we detected phonation by identifying the frequency components of sounds higher than the 0- to 3-kHz frequency range of the human voice [3]. Finally, the body temperature varied minimally (34°C $\sim$ 35°C) and was near the normal skin temperature of the human chest [5]. Overall, the results accurately reflected the activities performed by the participants.

To examine whether the system can detect reasonable values for the average heart rate, total moving duration, average skin temperature, and total phonating time, we analyzed the data collected from P2 over 30 minutes. The total moving duration was determined to be 7.2 minutes (actual value: 6.9 minutes), with an error of 4.0%. The average heart rate was 81.5 and



(a) Stacked bandage affixed to patient's chest



(b) Results from data collected by BioScope

Figure 3: Experimental setup and results.

100.3 beats per min (BPM) when P2 was stationary and moving, respectively. Because P2 did not perform intensive exercise, the average temperature did not vary significantly, remaining near 33.9°C. By identifying the high-frequency components embedded in the high-pitched sounds collected when P2 was stationary, P2 was determined to have phonated for 635.5 seconds (actual value: 564.0 seconds), with an error of 12.7%.

DISCUSSION AND FUTURE WORK

Major Factors Affecting Sound Quality

The acoustic patch was enhanced using a sound-collecting structure to increase the signal-to-noise ratio and record sounds emitted from the body in high quality. In this study, a sound-collecting structure similar to the bell structure of a stethoscope was incorporated to boost the magnitude of body sounds. Although the hollow space within the bell structure slightly increased the thickness of the acoustic patch, the magnitude of the body sounds was substantially magnified. These magnified body sounds, however, interfered with environmental sounds because the low-density platform was printed with elastic filaments. The acoustic signals were easily corrupted if the sounds of interest (e.g., acoustic signals emitted while the patient is phonating) shared a frequency band with the environmental noise; this corruption can be reduced considerably by using acoustic isolation materials. Future prototypes will be covered with hard and dense materials (e.g., brushable silicone [6]) to reduce noise.

Long-term Field Trials to Validate BioScope

This study was a short-term explorative study that could only show the potential and feasibility of BioScope. Before applying this system in healthcare facilities, several design aspects must be carefully evaluated through long-term field trials. For example, because of its limited battery life, BioScope can transmit only a fraction of the collected data through its Bluetooth interface for visualizing on a mobile device or for storing at a remote healthcare data center. Future studies should consider optimizing battery life to prolong the operation time of the bandage.

Potential Applications

Our aim in developing BioScope was to assist healthcare workers in collecting commonly monitored biosignals used in efficiently tracking or roughly diagnosing hospital patients. In addition to applying BioScope in nursing assessments, we hope to apply it to other situations, including (1) ambulatory care for monitoring outpatients, and (2) on-demand support for tracking individuals, e.g., children or elders, and their wellbeing in daily life.

CONCLUSION

In this study, we developed BioScope, an extensible sensing system designed to facilitate data collection in nursing assessments. Experiments were conducted to demonstrate the potential of the system, and the results indicated that the system is efficient. We identified numerous potential applications of BioScope that can be explored in future research.

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