A Cuffless Blood Pressure Monitor for Home Healthcare Systems Monitored by Health Professionals

A cuffless blood pressure monitor

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***Abstract*—We tested a new model of healthcare that involves monitoring physiological parameters to improve team-based healthcare. The system consisted of unobtrusive monitoring, a database, and interventions by health professionals. This report discusses the core technologies used, focusing on those involved in monitoring. An unobtrusive blood pressure (BP) estimation system, and web-based care system, including its database, were designed and tested. BP was estimated with a cuffless BP monitor combined with electrocardiography and photoplethysmography. The mean difference (MD) of estimated SBP and reference SBP was 0.2 ± 5.8 mmHg and the limits of agreement ranged from -11.2 mmHg to 11.6 mmHg. The MD of estimated DBP and reference DBP was 0.4 ± 5.7 mmHg and the limits of agreement ranged from -10.8 mmHg to 11.6 mmHg. The estimated BP was enough accurate compared with the cuff-based BP. The core technologies operated well. The proposed system may prove effective for home-based healthcare. Further studies are needed to evaluate the entire care system.**

Keywords-home healthcare; cuffless blood pressure ; decision making system.

I. INTRODUCTION

It is crucial that the healthcare system becomes more effective so that it can meet the needs of the future ultra-aged society. Hospitals can play an important role in the prevention of diseases, but issues related to the increased demand on medical insurance and the decrease in medical personnel are critical challenges for an aged society. Indeed, physicians and their associates working in small communities must not only provide primary care but also keep up with new medical technology. Long-term care facilities have been established and home-based healthcare services have been recommended to reduce the medical costs associated with caring for the elderly.

In Japan, cardiovascular disease and stroke are the second and third leading causes of mortality, respectively; these conditions have high rates of recurrence [1]. Blood pressure (BP) plays an important role in these conditions. Key lifestyle changes and at-home BP monitoring may help patients to avoid another stroke. Indeed, an occasional BP reading at a health checkup may not be a sufficient basis for effective treatment decisions because BP varies. The use of home BP monitors may help those with high BP to better understand their control over this condition; thus, this population should be encouraged to measure and record their BP and share their BP logs with their doctors [1][2].

Results from randomized trials have suggested home BP telemonitoring (HBPT) as a promising tool for improving BP control of hypertensive patients. Most studies have found significant BP reductions in those using HBPT and HBPT interventions. These approaches have also garnered a high rate of acceptance, helped to improve users' quality of life, and reduced the costs of medical insurance. Although HBPT can be advantageous, older patients tend to be less technologically skilled and may require more user-friendly home healthcare technology. Cuff-based BP monitors are commonly used; however, it can be difficult to properly apply these devices in terms of appropriate fitting and identification of the correct measuring site.

Low-cost wireless monitoring has probably led to more data-sharing between patients and clinics. In addition, HBPT may enhance the quality of data reporting and the ease with which the results are interpreted by doctors. A key contributor to the successful management of BP by HBPT is networking among healthcare providers and consultation between doctors and pharmacists or nurses. This process constitutes a new model of care designed to control BP based on telephone/web services. The effectiveness of this model has been demonstrated in several trials [3].

As feedback from doctors is not immediate and evaluation may be time-consuming and inaccurate, a new model of care called e-BP has been proposed [4][5]. There

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is strong evidence that BP can be controlled using a team-based approach involving health professionals, such as pharmacists and nurses. Indeed, the use of team-based care has increased the proportion of individuals whose BP is under control and has reduced both the systolic and diastolic BP, especially when the team included pharmacists and nurses. Implementation of this multidisciplinary approach will require system-level organizational changes and may be an important element of home-based medical care [6][7].

This study examined a new intervention system based on unobtrusive monitoring. First, we developed a healthcare scenario and core technology, mainly unobtrusive monitors, to create a new model of care. The results of this preliminary study will provide information for reconfiguring the system for further research.

II. METHOD

In this section, the propose system is desribed.

A. Proposed system

Fig. 1 shows an overview of the proposed system. The central concept is the use of a team-based care system consisting of three main parts: unobtrusive monitors, a rule-based expert health management system, and interventions by health professionals. Specifically, BP is monitored unobtrusively by cuffless blood pressure which described more detailed at (B); the BP data are automatically transmitted to a server, and health status is ascertained using a ruled-based expert system, which considers data on the estimated BP in the morning and evening, steps walked, weight, and other factors. The expert system automatically generates alerts based on comparisons with predetermined threshold values. When alerts are issued, a health professional calls the client and conducts a clinical evaluation. Based on the findings, the health professional judges the client's health status and decides whether a visit from a clinician is warranted or if a caregiver should be called. Health professionals manage both chronic conditions and emergency situations. Clients can also monitor their health via a browser.

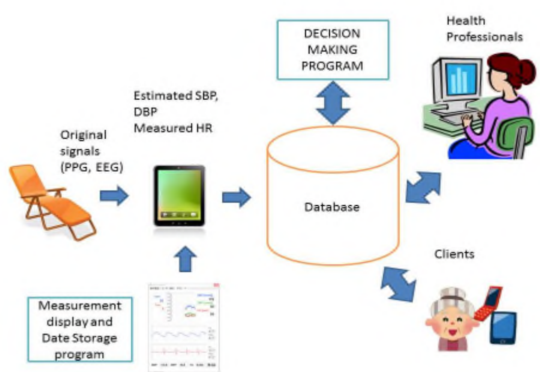

Figure 1. Overview of the system. SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate; PPG: photoplethysmograph; ECG: electrocardiograph.

B. Design of unobtrusive monitoring

The BP was measured with a cuffless BP monitor, a system that was developed in the 2000s [8] and approved as a standard by the Institute of Electronics and Electrical Engineers (IEEE) in 2014 [9]. BP is related to the stiffness of blood vessels: if the blood vessel is rigid, the velocity of the blood is rapid, while if the blood vessel is soft, the velocity is slow. The pulse transit velocity based on the R wave of the electrocardiograph (ECG) and the associated peak of the pulse wave are related to the BP. If we know the calibrated BP, calibrated systolic blood pressure (SBP_{CAL}), and calibrated pulse transit time (PTT_{CAL}) at SBP_{CAL}, the estimated systolic (SBP_{EST}) and diastolic (DBP_{EST}) blood pressures are defined as

$$SBP_{EST} = SBP_{CAL} - \frac{2}{\gamma PTT_{CAL}} \Delta PTT \quad (\Delta PTT = PTT_{MEAS} - PTT_{CAL}) \tag{1}$$

$$DPB_{EST} = SBP_{CAL} - \frac{2}{\gamma PTT_{CAL}} \Delta PTT - (SBP_{CAL} - DBP_{CAL})\left(\frac{PTT_{CAL}}{PTT}\right)^2 \tag{2}$$

where γ is the peripheral resistance, and ΔPTT is the difference between the obtained PTT_{MEAS} and PTT_{CAL} [8][10].

The chair-based system consists of an ECG and a photoplethysmograph (PPG). ECG electrodes are placed on both arms of an armchair and a PPG sensor is placed on one arm of the armchair, as shown in Fig. 2. The client gently touches the electrodes and inserts the index finder in the sensor box. Beat-by-beat signals are then collected to estimate SBP and DBP using the above equations. The algorithm for data collection is shown in Fig. 3.

The device was compared with a simultaneous recording with a beat-by-beat BP monitor (Finometer, Finapres Medical Systems, Amsterdam, The Netherlands) based on the unloading method. The distribution of BP readings and long-term data were also compared with readings using a cuff-based BP monitor (HEM 7510C, Omron Healthcare, Inc., Kyoto, Japan).

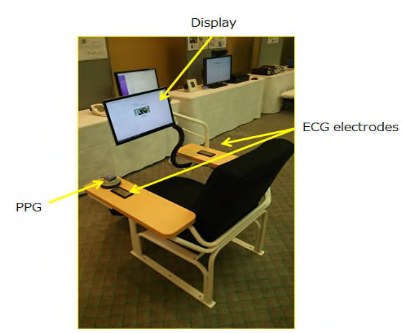

Figure 2. Cuffless blood pressure monitor and chair.

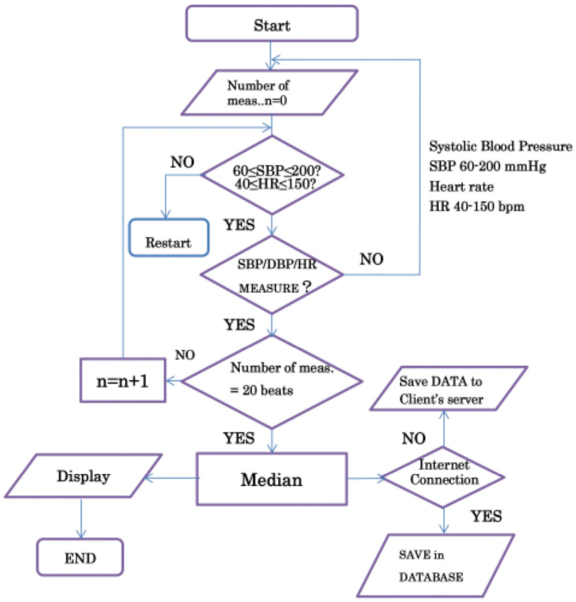

Figure 3. A flow chart of decision making program

The accuracy and validity of the setup were tested in ten normal young males (age, 24.1 ± 5.4 years) who sat in the chair while the BP was measured.

C. Database

A database was created from information obtained from clients, including the estimated BP and heart rate. All data were uploaded to the server, and a health professional checked the continuity of data collection. The database software included an expert system and verified client participation. A health professional was encouraged to monitor the status of clients who did not participate in this system. At the same time, the clients checked their own health status via the Internet.

D. Expert system

A problem-solving expert system is useful for managing the healthcare of individuals. Home monitoring depends on patients measuring their BP regularly, recognizing when readings consistently exceeded the target values, understanding the need for the intensification of treatment, and visiting their physician for review and appropriate management. Therefore, we developed criteria to enable the expert system to generate alerts when values exceeded the predetermined values listed in Table 1. The criteria have been made by guidance of physicians. If the client's health is relatively good, then a message saying "fine" is automatically transmitted to him or her. When alerts are generated, the alerts are sent to a health professional and not to the client, who instead receives a message saying, "Your data are being checked by a health professional who will reply shortly."

TABLE 1 ALERT CONDITIONS OF THE EXPERT SYSTEM.

Items	Conditions
SBP	>160 mmHg
DBP	>95 mmHg
Pulse pressure (SBP – DBP)	>50 mmHg
SBP (morning – night)	>±30 mmHg
Spontaneous SBP	>160 mmHg
Continuous SBP at successive three days	>150 mmHg
Changes in the average SBP over 1 month	>30 mmHg
Heart rate	<40 or >120

SBP: systolic blood pressure; DBP: diastolic blood pressure

E. Intervention by health professionals

After receiving an alert, the health professional calls the client to make relevant clinical inquiries. Initially, information is obtained regarding life-threatening conditions, such as stroke and heart failure. After collecting physiological data and completing the medical inquiries, the health professional decides whether to arrange for a clinician to visit the patient or to contact the patient's caregivers. For our trial runs, we recruited and trained retired register nurses to serve as the health professionals, and the system was tested on healthy subjects.

F. Experimental set-up

Total system was operated for a healthy young male. The subjects sat down the chair and touched the electrode on the chair arm. The experiments were performed two months to check the reliability of expert system as well as the operation of intervention.

III. RESULTS

Results show the accuracy of developed cuffless blood pressure monitor and a preliminary result of a long term recording for daily life.

A. Unobtrusive monitoring of BP

Fig. 4 shows the distribution of the BP values obtained from ten subjects in different environments. The mean difference (MD) of estimated SBP and reference SBP was 0.2 ± 5.8 mmHg and the limits of agreement ranged from -11.2 mmHg to 11.6 mmHg. The MD of estimated DBP and reference DBP was 0.4 ± 5.7 mmHg and the limits of

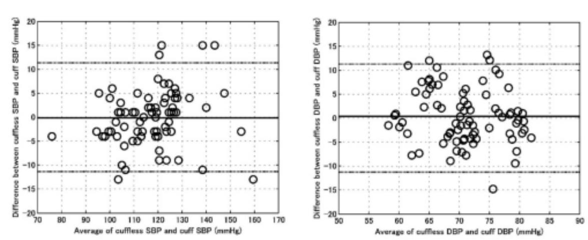

Figure 4. Bland–Altman plots of systolic blood pressure (SBP, left) and diastolic blood pressure (DBP, right).

agreement ranged from -10.8 mmHg to 11.6 mmHg.

B. Database and intervention system

The database stored information on the estimated BP. Figure 5 shows the screen display that a health professional would see. Red indicates outside the normal BP range. When red values were seen on the screen, the health professional contacted the client and asked about various medical conditions before making a decision.

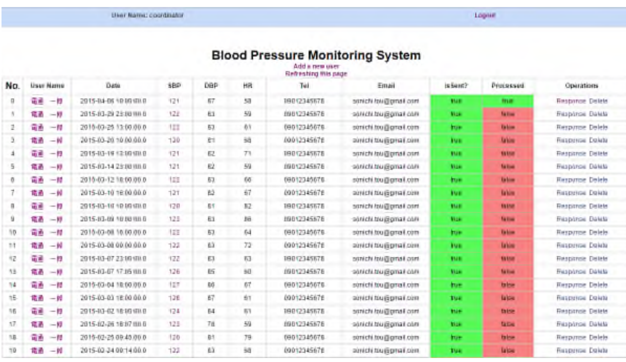

Figure 5. Screen display for the health professional.

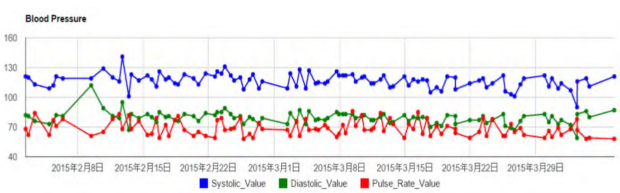

Figure 6. Example of long-term BP recordings.

The success of this intervention was tested using long-term BP monitoring, as shown in Fig. 6.

IV. DISCUSSION

We developed and tested a model to be used as a new healthcare system. The novel elements of this approach are that it involves unobtrusive monitoring and a team-based healthcare system, which operates efficiently due to its simplicity.

Based on our preliminary trial, the following problems remain to be solved. In terms of unobtrusive monitoring, further studies are required to determine how to eliminate unreliable signals caused by motion artifacts or other factors. Cuffless monitoring was performed according to the IEEE standards, and measurements obtained while the client sits in a chair are relatively reliable because they are taken at rest. Although the error was within the standard deviation, the interval of calibration and measurement site warrant additional consideration to increase the accuracy of the measurements.

Furthermore a monitoring device was battery- operated and client safety is satisfied

The effectiveness of an expert system rests on the development of a set of rules that produce clinically relevant alerts that ensure client safety. The existing team-based care depends on physiological data, such as the BP and ECG, but the monitoring depends on the clients. Our system measures physiological parameters without interrupting the daily lives of the clients, and beat-by-beat information is more accurate than spot monitoring.

The innovative aspect of this system is related to the interventions and consultations provided by professional nurses and medical staff. Although physicians may be too busy to review all records, health professionals such as registered nurses can help to diagnose patients and interpret the BP data obtained in the morning and evening. It is also important to provide relevant education for health professionals, including registered nurses, registered dieticians, and pharmacologists, and to identify the experience and skills that should be required of professionals involved in this system.

The final goal should be cost-effective eHealth imitative in daily home healthcare and practice [11] and we collect data of many clients to prove the system.

V. CONCULUSION

We proposed a team-based healthcare system. The core technologies operated without any trouble. We obtained long-term BP records smoothly and automated decision making system worked to classify either normal or abnormal values. The next step will involve testing the entire system in a home-based healthcare setting. In addition, other cardiovascular parameters such as ECG and respiratory rate should add for better description of medical service.

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