PAPER *Special Section on Data Engineering and Information Management*

A Sensor-Based Data Visualization System for Training Blood Pressure Measurement by Auscultatory Method

Chooi-Ling GOH[†,††a)], ***Nonmember and*** **Shigetoshi NAKATAKE**[†††], ***Member***

SUMMARY Blood pressure measurement by auscultatory method is a compulsory skill that is required by all healthcare practitioners. During the measurement, they must concentrate on recognizing the Korotkoff sounds, looking at the sphygmomanometer scale, and constantly deflating the cuff pressure simultaneously. This complex operation is difficult for the new learners and they need a lot of practice with the supervisor in order to guide them on their measurements. However, the supervisor is not always available and consequently, they always face the problem of lack of enough training. In order to help them mastering the skill of measuring blood pressure by auscultatory method more efficiently and effectively, we propose using a sensor device to capture the signals of Korotkoff sounds and cuff pressure during the measurement, and display the signal changes on a visualization tool through wireless connection. At the end of the measurement, the learners can verify their skill on deflation speed and recognition of Korotkoff sounds using the graphical view, and compare their measurements with the machine instantly. By using this device, the new learners do not need to wait for their supervisor for training but can practice with their colleagues more frequently. As a result, they will be able to acquire the skill in a shorter time and be more confident with their measurements.
key words: *blood pressure measurement, auscultation, Korotkoff sounds, cuff pressure oscillation, data visualization, wireless sensor system*

1. Introduction

Blood pressure (BP) is one of the primary vital signs used to assess the health condition of a patient. The noninvasive auscultatory method for BP measurement has been widely used in clinical practice. The auscultatory method is a method that based on Korotkoff sounds [1], [2]. The Korotkoff sounds are blood flow sounds on the arm which can be listened with a stethoscope during the measurement using a sphygmomanometer. These sounds appear and disappear as the pressure cuff is slowly deflated. There are five phases of Korotkoff sounds.

- Phase I - clear tapping sound (systolic BP)
- Phase II - murmur sound
- Phase III - loud slapping sound
- Phase IV - muffled sound
- Phase V - disappearance of sound (diastolic BP)

The practitioner must recognize the phase I and record the systolic pressure at this point, and when the sound is gone at phase V, it is recorded as diastolic pressure*.

All students from nursing school are required to master the skill of measuring BP by auscultatory method. However, only about 66% of the students could pass the skill test for the first round [3]. Although nowadays many automatic BP measurement devices with reasonable precision are available, manual auscultatory method is acquired by the new nurses. This is because auscultatory method is more accurate, if measured by an experienced observer. Besides, automatic devices are unable to measure accurately blood pressure of patients with arrhythmia, low blood pressure or hypertension, where the correct measurement is highly critical. Furthermore, during disaster when automatic devices are not available, or when the practitioners suspect that the automatic devices did not give accurate values of blood pressure, they must be able to manually measure the patient's blood pressure on the spot. Therefore, learning the skill is mandatory for all healthcare practitioners. However, mastering the auscultatory method for BP measurement is not an easy task. For a beginner, it is difficult to differentiate between the Korotkoff sounds and noises occurred in the stethoscope. Depending on the subjects, the sounds may have different characteristics and may be too soft to recognize. Furthermore, if the deflation of pressure cuff is too fast, they might miss out catching the timing of appearance and disappearance of sounds. Besides, auscultatory method for BP measurement is a complex task of combining a few operations. During a measurement, one needs to deflate the pressure cuff in a constant speed, recognize the Korotkoff sounds on the stethoscope, look at the sphygmomanometer pressure values, all these steps must be carried out simultaneously. If they concentrated on listening to the Korotkoff sounds, they might miss out reading the pressure values. If they concentrated on deflating the cuff pressure, they might fail to recognize the Korotkoff sounds. Therefore, mastering the skill requires a lot of practice and experience. There are models that could be used for learning**, but the models are not real life persons, and could not represent real situation of BP measurement. One can learn measuring BP by using

Manuscript received June 23, 2015.
Manuscript revised November 6, 2015.
Manuscript publicized January 14, 2016.
[†]The author is with the Design Algorithm Laboratory, Waseda University, Kitakyushu-shi, 808–0135 Japan.
[††]The author is with the Information, Production and Systems Research Center, Waseda University, Kitakyushu-shi, 808–0135 Japan.
[†††]The author is with the Department of Information and Media Engineering, University of Kitakyushu, Kitakyushu-shi, 808–0135 Japan.
a) E-mail: goh@da-lab.com
DOI: 10.1587/transinf.2015DAP0010

*It was described by a Russian surgeon, Nikolai Korotkoff, in 1905.
**Such as Atsuhime. https://www.kyotokagaku.com/jp/educational/products/detail02/mw7.html

their colleague as a model, but in this way, a student could not know whether her measurements are correct, unless an experienced nurse is sitting beside her and listening to the same Korotkoff sounds at the same time using a double-tube stethoscope. Since an experienced nurse is not always available for practising, the students face the problems of lack of practice and could not master the skill in a short time.

Despite the auscultatory method that has been widely used by healthcare practitioners, most of the automatic BP devices do not follow this approach. The automatic devices use oscillometric method [4]–[6], which is based on the oscillations observed in the pressure cuff during the deflation. The amplitudes of the oscillometric pulses in the pressure cuff varied during the inflation and deflation of the cuff when measuring the blood pressure. Some coefficients that based on the maximum oscillation are used to determine the amplitudes of the oscillations that correspond to the systolic and diastolic pressures. This method is adopted by automatic devices because the oscillations in the cuff pressure are stable and are mostly not affected by external noise. However, it is argued that the accuracy is not as high as using auscultatory method observed by an experienced practitioner.

In this research, we propose an auscultatory based BP measurement training system that can be used to help the new nurses to acquire the auscultatory BP measuring skill. We design this system based on the training method using the conventional sphygmomanometer and the stethoscope currently practised by a local nursing school. We build a sensor-based device that captures the Korotkoff sounds and cuff pressures simultaneously, and send these signals to a tablet using wireless connection such as Bluetooth, and display the changes of the signals as a graphical image on the tablet screen. In this way, the student is able to measure a real person, e.g. a colleague, viewing the sound and the pressure signals on the screen, and obtain the correct measurements from the machine. Thus, they can compare their measurements with the machine measurements instantly. The application can also examine whether the speed of deflation is appropriate, which is 2-3mmHg/s. Without an experienced nurse sitting beside them, they can practise measuring blood pressure anytime and repeatedly as long as they can find a partner to work with. By using this device, we foresee that the nursing students will be mastering the BP measurement skill in a shorter period than the conventional way of learning, and be more confident of their measurements.

This paper is organized as follows. Section 2 introduces some previous work that is related to visualized BP measurement. Section 3 describes our proposed system using a sensor board and a visualization tool, and explain our approach to evaluate the user's measurement and deflation speed. Section 4 shows our solutions to measure the blood pressure automatically using Korotkoff method and oscillation method, and compares their accuracies with the expert measurements. Section 5 describes our development of the visualization tool and its usage, and conducts a survey for the effectiveness of our system at a nursing school. Finally, Sect. 6 concludes our work and proposes some future work to improve the system.

2. Related Work

In order to increase an observer's objectivity for BP measurement, [7] and [8] have introduced Sphymocorder which can record an auscultatory measurement using audio-visual recording technology. However, the technology at that time was not sufficient to produce a user-friendly environment for the usage. The measurement was not done automatically but a human observer determined the BP readings by playing back the audiotape, perhaps repeatedly. With the advances of electronic and computer technology, [9] has produced a visual auscultatory BP measuring system, that can record and capture the signals from the stethoscope and sphygmomanometer, convert them to digital form and display the signals as waveforms on the monitor. Finally, the Korotkoff sound, sphygmomanometer video, cuff pressure and oscillometric pulses will be stored in a database. The database can then be used for various applications such as validating BP measuring devices, testing the effectiveness of a BP measurement algorithm, training new nurses and etc [10].

[11] also developed a playback system which records the Korotkoff sounds and the correspondent cuff pressure. The user can listen to the sound repeatedly in order to obtain satisfied values for systolic and diastolic BP. They have proposed to use the pulse in the cuff pressure to localize the systolic periods between zero crossings, which are then used to determine the appearance and disappearance of Korotkoff sound. Then total power spectrum value for each period is calculated to assess whether there is audible Korotkoff sound or not.

The purpose of having these visualization devices is for substituting of human observers in validation studies of BP measuring devices. [10] suggests applying the monitory system to train new nurses in BP measurement. Since they can capture a database of Korotkoff sounds, they propose to use the stored signal database as the source of training. The advantage is that the database can cover representative measurements of various subjects with specific situations. Using this system, the new nurses can perform conventional auscultatory method by watching the sphygmomanometer video and listening to the recorded Korotkoff sounds. However, there is no sense of presence since the new nurses are working with the machines instead of real human beings. Besides listening to the Korotkoff sounds, they should also practice tying the pressure cuff in proper tightness, inflating the cuff in short period, and deflating the cuff in a constant speed of 2-3 mmHg/s, and have a feel of measuring a real patient. Therefore, a man-to-man measuring support device is more desirable.

3. Proposed System

Our purpose is to help the nursing students to acquire the skill of BP measurement using auscultatory method more efficiently and effectively. In this paper, we propose a visu-

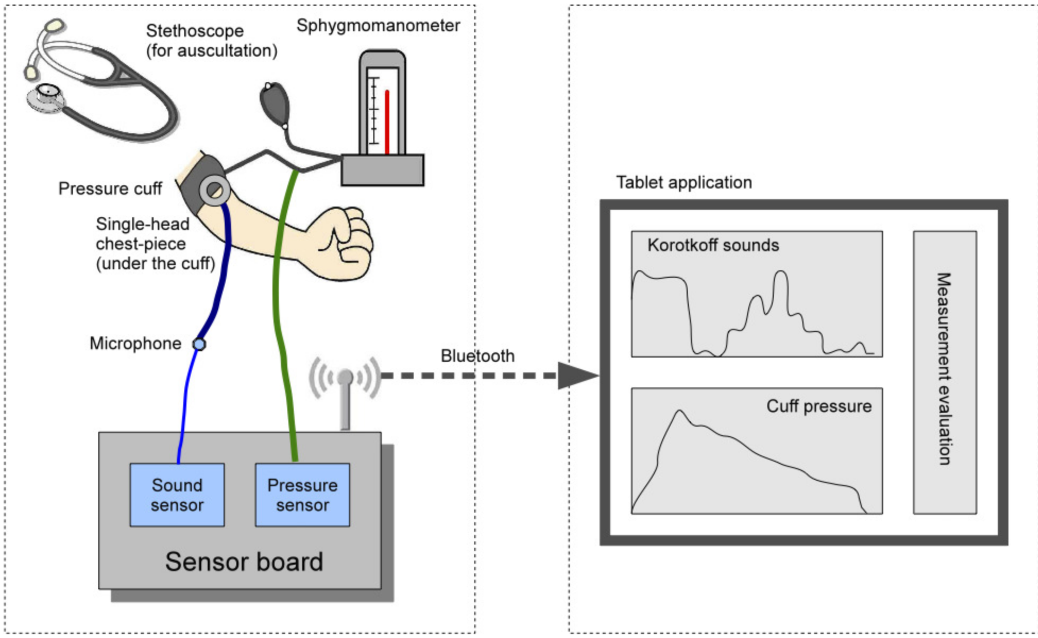

Fig. 1 System overview.

alization system that can capture the Korotkoff sounds and cuff pressure simultaneously during the measurement, and display the movements on a tablet screen. This system consists of two parts: a sensor-based device and a visualization tool on a tablet. Figure 1 shows the system overview. At the end of the BP measurement, the users can visualize the movements of the signals on the screen, and compare their measurements with the machine. Thus, helping them to determine the systolic and diastolic BP with more confidence. Following sections describe the system in more details.

3.1 Sensor-Based Device

The sensor device is based on a design for ECG monitoring system [12]–[14]. In the original design, 8 channels have been used to capture the signals for ECG monitoring. We modify the design to suit our needs, which use only two channels: a channel for Korotkoff sound and a channel for cuff pressure. A pressure sensor is used to detect the cuff pressure by branching the tube of a manual sphygmomanometer. For capturing the Korotkoff sounds, a microphone is inserted into the tube of a single-head chest-piece, which is placed under the pressure cuff during the measurement to record the sounds. For auscultation, a separate stethoscope is used†. Both analog signals are converted into digital signals using an analog-digital converter, and the weak signals are amplified before being transferred wirelessly by a Bluetooth device. The Bluetooth device is set to 9600 baud rate. The digital signals are transferred using two channels: X0 (sound) and X1 (pressure), where each signal is encoded in hexadecimal coding with 6 digits and separated by a newline character. Therefore, one set of signals consists of 18 bytes, and the sampling rate is about 24 sets of signals/second. Our sensor board has a size of 6cm × 10cm, which is small enough to be carried to anywhere.

3.2 Visualization Tool

A tablet application is built to capture the signals from the sensor device through Bluetooth connection and display them on the screen in real time. Figure 2 shows the raw digital signals read from the Bluetooth device. In order for the users to view the signals in a more friendly manner, we only refresh the graphical view every 15 sets of signals read, which is about half a second. For sound signal, we take the difference between the highest and the lowest values read during this period, and for cuff pressure, the average of the 15 values is used. The processed signals are shown in Fig. 3.

3.3 User's Measurement Evaluation

The application system is able to evaluate the measurements taken by the students in two skills. First, whether the student has measured the blood pressure correctly, that means giving correct values for systolic and diastolic BP. Second, whether the deflation speed is appropriate, which should be between 2-3 mmHg/s. A consistent deflation speed is desired as it will help to obtain a correct BP measurement. We will describe both evaluations in the following paragraphs.

Table 1 shows the evaluation for measured blood pressure. Value x is the difference between the human measurement and the machine measurement. If the human measurement is ±4.0 mmHg compared to the machine measure-

†An older version of our system made used of a double-tube stethoscope for capturing the sounds and auscultation. However, we found out that the hand movement of the auscultation caused a lot of noise to the sounds. Therefore, we decided to separate them.

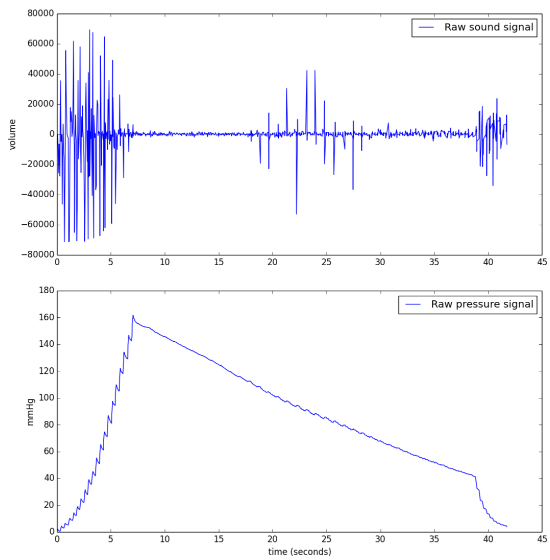

Fig. 2 Raw signals received via Bluetooth connection.

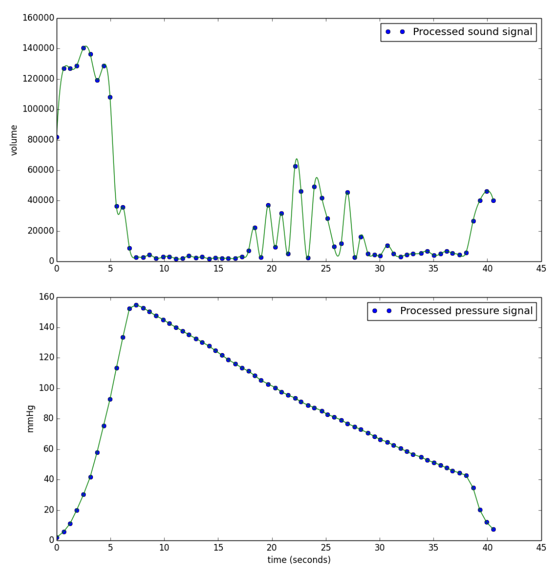

Fig. 3 Raw signals after processing.

Table 1 Evaluation of blood pressure measurement, where x is the difference between the machine measurement and the human measurement.

Good	$-4.0 \le x \le 4.0$
OK	$-6.0 \le x < -4.0$ or $4.0 < x \le 6.0$
Poor	$x < -6.0$ or $x > 6.0$

ment, it is considered as a *Good* measure. Else, if it is ±6.0 mmHg, it is considered as *OK* and *Poor* for the rest. During blood pressure measurement test of a nursing school, the students' measurements must not differ from the examiners' by 4 mmHg in order to pass the practical test [3]. However, besides the *Good* level, we also provide *OK* level, in order to let the students know that their skill is not far from the passing level.

Moving speed is used to calculate the speed of cuff deflation, which is based on simple moving average concept.

Table 2 Evaluation of deflation speed, where *speed* is in mmHg/s.

Good	$2.0 \le speed \le 3.0$
OK	$1.0 \le speed < 2.0$ or $3.0 < speed \le 4.0$
Poor	$speed < 1.0$ or $speed > 4.0$

Moving speed is calculated for every 5 readings (around 3 seconds), as shown in Eq. (1), where *BP* is in mmHg and *Time* in milliseconds, for all samples read during deflation†. Table 2 shows the conditions for speed evaluation. The perfect speed of deflation is between 2-3 mmHg/s. The deflation speed (all moving speeds calculated) must be consistent all along the way during deflation in order to be in that category. For example, even if only one calculation falls in the lower category (too fast or too slow), the result will be the lower category. This evaluation is strict so that the new nurses can be trained to deflate constantly and correctly. The consistent deflation will also guarantee proper amplitude of oscillation which is used for automatic BP measurements. We also provide 3 categories of results as shown in Table 2: *Good* (between 2-3 mmHg/s), *OK* (between 1-4 mmHg/s), and *Poor* (for the rest). We also calculate the average speed for the whole deflation period but it is not applicable for evaluation because even the average is within the perfect speed, if it is not consistent, it is still considered as poor deflation.

$$Speed = \frac{BP_{x-5} - BP_x}{Time_x - Time_{x-5}} \times 1000 \quad \text{mmHg/s} \tag{1}$$

4. Blood Pressure Measurement by Machine

The system must be able to estimate the systolic and diastolic BP automatically, as they will be used to evaluate the observer's measurements. We try to estimate the measurements using both conventional methods namely auscultatory method that based on Korotkoff sounds and oscillometric method that based on cuff pressure oscillations.

4.1 Korotkoff Method

We use a microphone to record the Korotkoff sounds that passed through a chest-piece. An analog-digital converter is used to convert the analog sound to digital signal, and the signal is transferred by Bluetooth wireless connection to the tablet. These signals will be refreshed on the screen for every 15 samples read. At the end of the measurement, the application will calculate the systolic and diastolic BP based on the sound volume. Our maximum sound volume is set to 14×10^4 units. A threshold of 2×10^4 units + lowest volume is found to be the existence of Korotkoff sound. However, if the (maximum Korokoff sound - lowest volume) is less than 6×10^4 units, then the threshold will be set to $\frac{1}{3}$(maximum Korotkoff sound - lowest volume). This could happen sometimes when the recorded Korotkoff sound is too weak. Besides, the lowest volume of a measurement depends on the

†The averaged pressure readings as in Fig. 3 are used in this calculation.

environment noise and could be varied. We found that the noise occurred before systolic BP and after diastolic BP is different. Usually, the noise is louder after diastolic BP. Therefore, we set the average of first 5 samples after deflation as the lowest volume for detecting systolic BP and the average of last 5 samples before end of deflation as the lowest volume for detecting diastolic BP. The threshold is half of the value for detecting diastolic BP as the difference between the sound and the noise has become less.

Only sounds recorded during deflation period are taken into consideration. The first sound that is higher than the threshold is considered as the systolic BP. The algorithm continues to detect volume that is higher than the threshold until the end of deflation. The last detected sound is considered as diastolic BP. However sometimes there exists sound gaps† in the detection. The gaps may be caused by the malfunction of the microphone or any other possibility, or it could be the noise that comes after the Korotkoff sounds. Therefore, empirically, if the systolic and diastolic period lasts longer than 12 seconds or the difference between the systolic and diastolic BP is more than 30 mmHg, we consider that it is the end of Korotkoff sounds. If not, we continue to detect the sound after the gap, and set the diastolic to the end of the next last detected sound.

From our experience, we found that it is difficult to differentiate between the Korotkoff sounds and noise effectively. Although Fig. 2 shows a clean picture of Korotkoff sounds, in reality, we could not obtain such clean signals all the time. Beside the Korotkoff sounds, the microphone also records the normal heart beat sounds, noise of the movement of stethoscope, echo inside the tube and etc. Currently, we still do not have a better solution, therefore, we need another method to measure the blood pressure more accurately.

4.2 Oscillation Method

Most of the automatic BP manometers nowadays adapt the concept of oscillations in the cuff pressure as the measurement for blood pressure. It is because the oscillations in the cuff pressure produce less noise compared to Korotkoff sounds. Usually, even noise exists in the Korotkoff sounds but the oscillations in the cuff pressure are not affected. Therefore, measurement by oscillation in the cuff pressure is more stable and convincing. Although the accuracy is said to be lower than auscultatory method using a mercury sphygmomanometer [15], it is acceptable for measuring a healthy person. Since our recorded Korotkoff sounds could not give satisfied BP measurement results, we also consider the automatic measurement using oscillations in the cuff pressure. Oscillations are found in the cuff pressure during deflation, as shown in the bottom waveform of Fig. 2.

The amplitude of oscillation will determine the systolic and diastolic BP. In [6], it is said that oscillations at cuff pressure equal to systolic A_s and diastolic A_d are near fixed ratios of the maximum oscillation A_m, where $A_s/A_m = 0.55$ and $A_d/A_m = 0.85$. In their method, the cuff pressure is high-pass filtered at 0.5Hz so that the oscillations can be clearly seen such as shown in Fig. 4. However, in our approach, we do not implement the high-pass filter, and the oscillations are found directly from the cuff pressure readings. We set the difference between the lower peak and the higher peak in a pulse as the oscillation amplitude. In our preliminary experiment, the ratios used in [6] was not applicable as the range is too small. Most of the time, we obtained lower systolic values and higher diastolic values. Based on our experiment with the expert nurses in Sect. 4.3, we had an average ratio of $A_s/A_m = 0.520$ and $A_d/A_m = 0.566$, but we decided to set our ratios as $A_s/A_m = 0.50$ and $A_d/A_m = 0.50$ as they gave the best results for our experiments.

† That means the system could not detect any sound during a period of time. The gap is allowed for 6 seconds empirically.

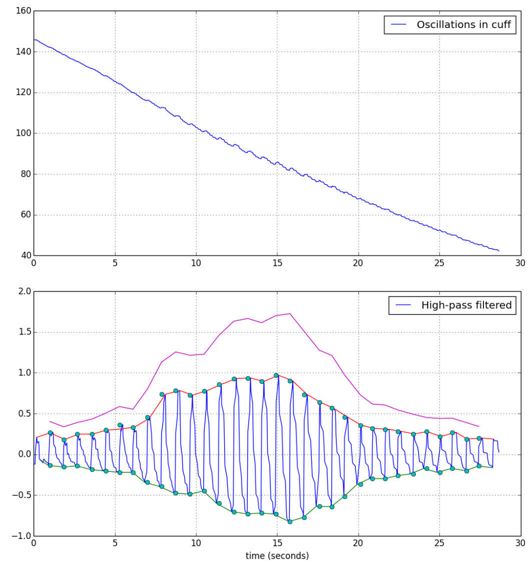

Fig. 4 Cuff pressure oscillation and its amplitude.

Table 3 Mean and standard deviation (SD) of differences between expert measurements with our Korotkoff and oscillation methods.

Method	Systolic BP *mean ± SD*	Diastolic BP *mean ± SD*
Korotkoff method	5.82±6.19 mmHg	13.98±8.36 mmHg
Oscillation method	3.77±4.59 mmHg	5.36±4.58 mmHg
Hybrid method	2.41±2.74 mmHg	4.86±4.25 mmHg

4.3 Machine Measurement Evaluation

The accuracies of our algorithms for Korotkoff method and oscillation method are tested using 22 subjects. The subjects are of 18 males and 4 females, with a range of ages between 18 and 44 years old. Each subject is measured twice by two expert nurses. Therefore, we have 44 measurements in total for calculation.

The mean and standard deviation (SD) of all the differences between the expert measurements with our Korotkoff and oscillation methods, $|ExpertBP - OurMethodBP|$, are calculated. The results shown in Table 3 imply that the oscillation method measures more accurately as the mean±SD

Table 4 Grading criteria used by the British Society of Hypertension. All three cumulative percentages of readings falling within 5 mmHg, 10 mmHg, and 15 mmHg of the mercury standard, must be greater than or equal to the values shown for a specific grade to be awarded.

Absolute difference between test device and mercury standard (%)			
Grade	≤5mmHg	≤10mmHg	≤15mmHg
A	60	85	95
B	50	75	90
C	40	65	85
D		Worse than C	
Korotkoff method			
B (SBP)	63.6	81.8	90.9
D (DBP)	13.6	38.6	61.4
Oscillation method			
A (SBP)	79.5	88.6	95.4
A (DBP)	63.6	86.4	97.7
Hybrid method			
A (SBP)	88.6	97.7	100.0
A (DBP)	70.5	90.9	97.7

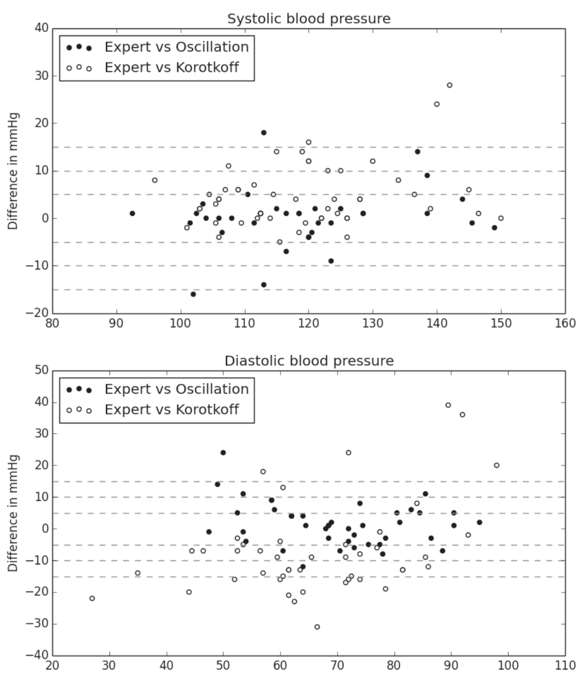

Fig. 5 Bland-Altman plot showing the differences between the expert and the machine measurements.

of differences is much lower than the Korotkoff method. In order to fulfil the standard set by the US Association for the Advancement of Medical Instrumentation (AAMI), a test device must not differ from the mercury standard by a mean difference greater than 5 mmHg or a standard deviation greater than 8 mmHg [16]. In our case, the oscillation method has almost fulfilled the standard but not the Korotkoff method. Besides, based on the grading criteria used by the British Society of Hypertension (BSH) [16], our oscillation method has grade A for both systolic and diastolic BP as shown in Table 4. Figure 5 shows the Bland-Altman plots of the differences between the expert and the machine measurements. Most of the differences for oscillation method fall within ±5 mmHg. Therefore, in our evaluation with the human measurement, we select oscillation method as the measurement standard for comparison as the Korotkoff method does not give satisfactory results if there exists noise during the measurement. Tables 3 and 4 also show the results of a simple hybrid method, where the best BP values between the two methods compared to the expert are used for calculation. These results show that we still have potential to improve the accuracy by combining both methods in the future.

5. Tablet Application

We build our application on Android environment. SQLite database system is used to store the user identity, subject information, Korotkoff sound and cuff pressure digital signals and BP measurement records. All the operations on the data are manipulated using standard SQL queries. The users can add new measurement, delete measurement, view previous measurement, and download/upload the measurement history to/from a text file. The application is built on Java, using Android Development Tools on Eclipse platform.

Figure 6 shows a screenshot of the main screen of display on a tablet. This screen is displayed at the end of a measurement. However, during the measurement, the graphs are refreshed as the signals are received periodically. When the deflation is over and the receiving of signals is terminated, the users can input their BP measurements. Then, the application will compare their input measurements with the methods described in Sect. 4. The evaluation results are displayed on the right of the screen. For machine measurement, we display both measurements by oscillation method (O) and Korotkoff method (K) for their references, although we use only oscillation method for evaluation. The human measurement and its evaluation are displayed below, and the deflation speed evaluation comes after. Three symbols are used to show the measurement results: ◯ for *Good*, △ for *OK*, and × for *Poor*, as described in Sect. 3.3 (refer to Table 1). For speed assessment, we show the minimum, maximum and average speed of the deflation, and evaluate the speed according to Table 2. We also draw lines for systolic and diastolic BP (red bars on pressure graph) and highlight their correspondent Korotkoff sounds (red dots on sound graph). Furthermore, the straight yellow line on the pressure graph shows the perfect deflation speed, 2.5 mmHg/s, beginning from 2-3 seconds after the deflation started. From this screen, the users can know immediately whether their BP measurement is correct and how much is the difference with the machine measurement, whether the deflation speed is appropriate and consistent, or whether it is too fast or too slow. Finally, we also calculate the subject's pulse rate and show it on the screen. The users can repeatedly use this system to practise measuring BP as long as they could find a partner to be the subject.

5.1 Scenario of Using of the System

We propose using the system with the procedure below.

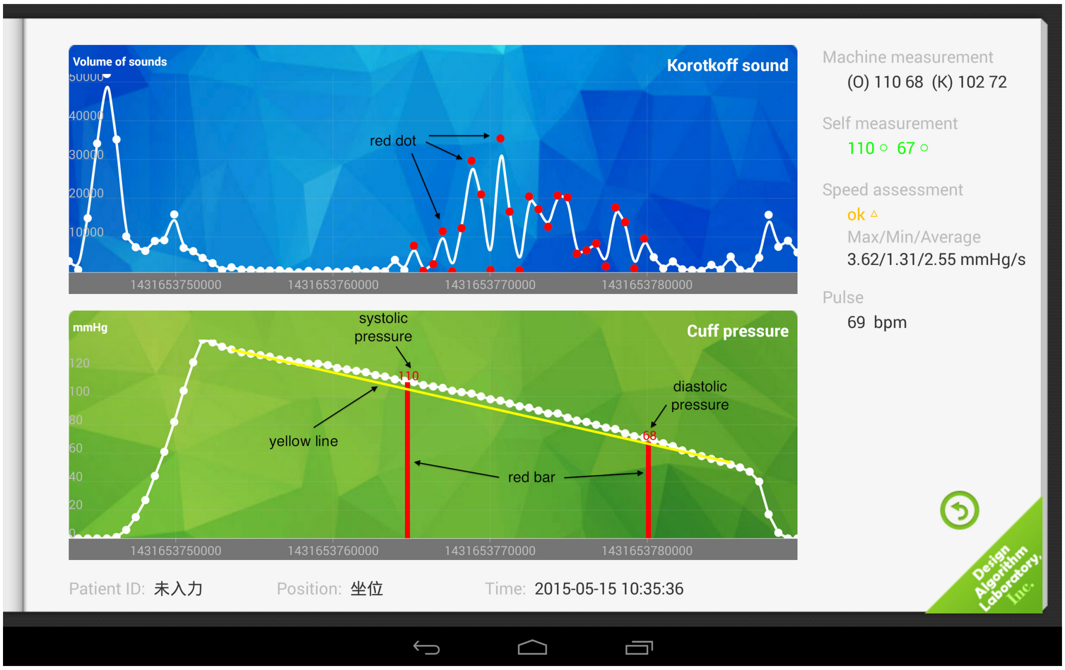

Fig. 6 A screenshot of the signals captured on the tablet, and its evaluation on the right.

1. Practise controlling deflation speed using a fake arm such as a plastic bottle, until the speed assessment is at least OK.
2. Measure a human and look at the tablet screen to confirm the appearance (Phase I) and disappearance (Phase V) of Korotkoff sounds.
3. Measure as usual without looking at the tablet, but look at the sphymomanometer and get the readings for systolic BP and diastolic BP values. Finally, compare the readings with the machine measurements and verify the deflation speed.
4. Verify own mistake and weakness, and repeat steps 1-3 until satisfied.

In this way, the students can first learn measuring BP with the aid of the tablet, and finally they can measure as usual without looking at the tablet, but just confirm the measurements with the machine.

5.2 Survey at a Nursing School

We have run a survey at a nursing school regarding the effectiveness of our system. We obtained the test run results from two groups of students. The first group consists of 13 students where they have never used our system before. The second group consists of 19 students where they have used our system for practising during the course. At the end of the semester, we asked them to use the system for three times, and then a practical test was carried out with the supervisor using a double-tube stethoscope. For the first group, only 5 (38%) of them passed the test, whereas the second group, 12 (63%) of them passed the test. This shows that our system has improved learning the skill compared to conventional way of learning. Based on a questionnaire done by 18 students, 67% of them think that the system is useful to learn measuring BP and 33% think that may be it is useful. Besides, 44% of them feel that they are more confident after using the system. However, none of them thinks that the system is not useful at all. Most of the students like the idea that the deflation speed can be seen on the screen and they could adjust their speed more correctly. Besides, it is helpful that they can compare their measurements with the machine and try to improve the skill based on the machine measurements. In addition, the supervisors of the nursing school are satisfied with the usage of our system and they have decided to use it for training their students in the future.

6. Conclusion

This system aims to aid the nursing students to learn measuring BP using auscultation method more efficiently and effectively. During the measurement, the Korotkoff sounds and cuff pressure signals are captured using a sensor device and sent via Bluetooth connection, and the movements of the signals are displayed on a tablet screen. By using this system, the students are not only listening to the sounds and looking at the sphymomanometer scale, but also viewing the signals on the screen at the end of the measurements. With the graphical view and the machine measurements given, they can judge their measurements more confidently and more correctly. The merit is that the students do not need to have their supervisors sitting besides them to practise measuring, which usually is not practical as the supervisors are not always available, but can practise with their colleagues more frequently using this system.

Since we are still facing the problem of noise in the

Korotkoff sound signals, as future work, we will look into some solutions, either on the hardware side or the software side, so that a clean sound graph without noise can be obtained. Consequently, BP measurement using Korotkoff method will be more convincing and more suitable for our initial intention of training by auscultation method. Eventually, a hybrid method that combines the Korotkoff sounds and the oscillations will be considered in order to further improve the accuracy of our machine measurements.

Acknowledgments

We would like to express our deepest gratitude to Ms. Kodama Hiromi, Ms. Hagiwara Tomoko and Prof. Takai Kiyako from Division of Nursing Science and Arts, School of Health Sciences, University of Occupational and Environment Health, Japan, for their helps on conducting the survey on the usage of the system on their students and evaluating our system accuracy. This survey has passed the ethical committee of their university. We also thank them for their continuous discussions, feedbacks and suggestions to improve our system.

References

[1] Y.L. Shevchenko and J.E. Tsitlik, "90th anniversary of the development by Nikolai S. Korotkoff of the auscultatory method of measuring blood pressure," Circulation, vol.94, no.2, pp.116–118, 1996.
[2] G.M. Drzewiecki, J. Melbin, and A. Noordergraaf, "The Korotkoff sound," Annals of Biomedical Engineering, vol.17, no.4, pp.325–359, 1989.
[3] T. Hosoya and S. Miura, "Nursing students' awareness of, and approaches to, a test of their technique in blood pressure measurement," Medical and Health Science Research, vol.5, pp.159–168, 2014. (in Japanese)
[4] L.A. Geddes, M. Voelz, C. Combs, D. Reiner, and C.F. Babbs, "Characterization of the oscillometric method for measuring indirect blood pressure," Annals of Biomedical Engineering, vol.10, no.6, pp.271–280, 1982.
[5] F.K. Forster and D. Turney, "Oscillometric determination of diastolic, mean and systolic blood pressure—A numerical model," Journal of Biomedical Engineering, vol.108, no.4, pp.359–364, 1986.
[6] G.M. Drzewiecki, R. Hood, and H. Apple, "Theory of the oscillometric maximum and the systolic and diastolic detection ratios," Annals of Biomedical Engineering, vol.22, pp.88–96, 1994.
[7] E. O'Brien, N. Atkins, F. Mee, D. Coyle, and S. Syed, "A new audiovisual technique for recording blood pressure in research: The Sphygmocorder," Journal of Hypertension, vol.13, no.12, pp.1734–1737, 1995.
[8] N. Atkins, E. O'Brien, K.H. Wesseling, and I. Guelen, "Increasing observer objectivity with audio-visual technology: The Sphygmocorder," Blood Pressure Monitoring, vol.2, no.5, pp.269–272, 1997.
[9] Y. Wang, J. She, H. Xiang, Y. Li, J. Liu, D. Li, and M. Yu, "Improving auscultatory blood pressure measurement with electronic and computer technology: The visual auscultation method," American Journal of Hypertension, vol.22, no.6, pp.624–629, 2009.
[10] Y. Wang, H. Xiang, Y. Li, and M. Yu, "Application of the visual auscultatory blood pressure measuring system," The 9th International Conference on Electronic Measurement & Instruments, pp.322–325, 2009.
[11] D.K. Park, H.S. Oh, J.H. Kang, I.Y. Kim, Y.J. Chee, and J.S. Lee, "Novel method of automatic auscultation for blood pressure measurement using pulses in cuff pressure and Korotkoff sound," The 35th Annual Conference on Computers in Cardiology, pp.181–184, 2008.
[12] H. Kim, S. Kim, N. Van Helleputte, A. Artes, M. Konijnenburg, J. Huisken, C. Van Hoof, and R.F. Yazicioglu, "A configurable and low-power mixed signal SoC for portable ECG monitoring applications," IEEE Trans. Biomed. Circuits Syst., vol.8, no.2, pp.257–267, 2014.
[13] H. Yang and J. Chai, "A portable wireless ECG monitor based on MSP430FG439," International Conference on Intelligent Computation and Bio-Medical Instrumentation, pp.148–151, 2011.
[14] K. Soundarapandian and M. Berarducci., "Analog front-end design for ECG systems using Delta-Sigma ADCs," Tech. Rep., Texas Instruments Application Report, 2010.
[15] J. Landgraf, S.H. Wishner, and R.A. Kloner, "Comparison of automated oscillometric versus auscultatory blood pressure measurement," The American Journal of Cardiology, vol.106, no.3, pp.386–388, 2010.
[16] E. O'Brien, B. Waeber, G. Parati, J. Staessen, and M.G. Myers, "Blood pressure measuring devices: Recommendations of the European Society of Hypertension," British Medical Journal, vol.322, no.7285, pp.531–536, 2001.

Chooi-Ling Goh received the M.E. and Ph.D. in information science from Nara Institute of Science and Technology, Japan, in 2003 and 2006, respectively. Later, she had done her post-doctoral research (ATER) in Caen University, France. She had been a researcher in Advanced Telecommunications Research Institute International (ATR) and National Institute of Information and Communications Technology (NICT). Currently, she is a researcher at Design Algorithm Laboratory, Inc. and a visiting researcher of IPSRC, Waseda University in Kitakyushu, Japan. She is a member of ANLP. Her main research interests include natural language processing, data visualization, and sensor-based system.

Shigetoshi Nakatake received B.E. degree from Tokyo Institute of Technology in 1992, M.S. degree from Japan Advanced Institute of Science and Technology in 1994, and D.E. degree from Tokyo Institute of Technology in 1999. He had been a research associate in department of electrical and electronic engineering of Tokyo Institute Technology from 1996 to 1999. Then, he moved to the University of Kitakyushu, and was an associate professor in the department of information and media engineering from 1999 to 2011, and he is a professor since 2012. His research interests are mainly focusing on VLSI physical design and analog mixed signal LSI design.