Feasibility Evaluation of Smart Stretcher to Improve Patient Safety during Transfers

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Objectives: The integration of noninvasive vital sign sensors and wireless sensor networks into intelligent alarm systems has the potential to improve patient safety. We developed a wireless network-based system (“Smart Stretcher”), which was designed to constantly monitor patient vital signs and detect apnea during transfers within a hospital. The system alerts medical staff in case of an emergency through a wireless network.

Methods: A small-scale technical feasibility study was conducted to assess the performance of the system in a simulated hospital environment. Smart Stretcher consists of three components: a small air-mat type pressure sensor measuring respiratory rate and detecting apnea, a patient identification system using RFID technology, and an indoor positioning system using a ZigBee wireless network. In the feasibility experiment, two nurses transferred four subjects who stopped breathing for 10 seconds, after which we calculated the accuracy of apnea detections, repeating this at varying speeds and subject positions. We also performed a subjective evaluation of perceptions and expectations of Smart Stretcher by nurses.

Results: The system could detect apnea in all subjects at a rate of over 90%, patient IDs and locations were correctly detected in real time, and the system could alert medical staff. In addition, the results of nurse’s evaluations were mostly positive.

Conclusions: The technical feasibility experiment and evaluation of Smart Stretcher suggest that the system could play a key role in monitoring patients during hospital transfers.

1. Introduction

Advances in ubiquitous communication technologies, such as radio frequency identification (RFID) and wireless sensor networks, are giving rise to new applications in various fields [1]. In the medical field, particularly in hospitals, these technologies are expected to help prevent medical errors and improve the safety and quality of medical care [2–4]. Wireless technologies have recently been used for monitoring patient physiologic status [5,6] and locating/tracking staff, medical equipment, patients, and drug supplies in a clinical environment [7].

However, these technologies are mostly used separately and, thus, may not be reaching their full potential or most suitable applications in the clinical field. In certain situations, there are limitations in the application of these technologies because of lack of flexibility or restrictions of available resources. To solve these problems, we propose that integrating several sensors and wireless network technologies would make medical applications more flexible to improve patient safety anywhere in a hospital.

For one application of integrated technologies, we focused on emergency management during patient transfers within the hospital. In the current environment, vital signs monitors used in transfers do not transmit data via networks, leaving the burden of detecting and responding to life-threatening events entirely on the personnel that are accompanying the patient. By integrating sensors and wireless networks, we expect to reduce the burden to nurses and facilitate their communication with other staff, especially the anesthesiologists, who are often responsible for patients in transfer. In most hospitals in Japan, although specialized health care providers often accompany transfers between anesthetic rooms and operating rooms or after a surgery, the same may not always be true for transfers to patient wards, the radiology suite or to other areas of the hospital, which increases the risk for the patient [8].

Also, sudden and serious changes in patient physiologic status may remain undetected, and very few systems have addressed the problem of monitoring one critical vital sign: the respiratory rate. Several medical malpractice cases in which medical staff...
overlooked asphyxia after surgery have been reported [9, 10]. Additionally, these reports clarified that the highest risk of asphyxia was during the 12 hours after surgery and after removing monitoring equipment. In fact, a report [10] showed that 55% of all anesthetic malpractice cases occur during this time. Although many preventive measures have been implemented to solve these problems, some early research concluded that disciplinary action alone could not prevent all medical errors [11]. Although a patient emergency can be detected by attached sensors without a communication network, it may be too late to communicate with other staff in real time. In these situations, vital signs detected by sensors are not seamlessly communicated to the appropriate hospital responders. Ideally, medical staff would be notified immediately through wireless networks, without a phone call or page over the hospital system to locate the event and mobilize responders.

In addition to these problems, there have been recent reports of incidents related to mishandled handoffs from a ward to the operating room, miscommunication between medical staff, and misidentification of patients [12]. Other serious medical errors, such as misidentifying patients while transferring them to and from surgery or diagnostic test suites have also been reported [13]. Some cases have been reported in which the wrong patient underwent surgery [14].

Therefore, we propose using information technology systems to reduce these risks, which lead to a delay in taking action for emergency care, to misidentification of patients, and result in life-threatening conditions. Overall, the system could support medical practices and immediately communicate with an anesthesiologist and other medical staff. We invented a continuous patient monitoring system for transfer by using several sensors and wireless networks.

The purpose of our work was to develop a new system, Smart Stretcher, which uses noninvasive sensors and a wireless network for safe patient transfers in a hospital. Through this system, vital signs, identification, and location data could be transmitted to the medical staff in charge in real time by using a sensor network. This would facilitate clinical response to a serious change in a patient’s physiologic condition during transfers.

In this report, we performed the preliminary evaluation of the system and also validated its effectiveness in facilitating collaboration among medical staff via a sensor network.
2. Methods

2.1 Study Design and Functions of Smart Stretcher

This study was conducted at Tokyo Medical and Dental University in Japan as an industry-university joint research. Smart Stretcher was developed for preventing medical errors, such as overlooking patient status, delay in giving emergency care, and misidentifying patients during patient transfers in a hospital. The system users were nurses who were accompanying patient transfers and also anesthesiologists and other doctors who were in charge of the patient. Our research team consisted of experts in medical engineering and medical informatics. In May 2006, we launched development of a preliminary monitoring system for a stretcher [15]. It was a prototype system and it required significant modifications. Through a series of system tests and modifications, the system was connected to wireless sensor nodes to send detected data wirelessly. The first phase of Smart Stretcher project was finished in March 2007 and updated until March 2008.

Smart Stretcher consists of three components for gathering data: a small air-mat type pressure sensor measuring respiratory rate and detecting apnea; a patient identification system using RFID technology; and an indoor positioning system using a ZigBee wireless network, which tracks the patient’s location during transfers (Fig. 1). The data were integrated through ZigBee wireless nodes, which convert detected data to IP packets and communicate with other connected nodes in the wireless network. The detected data is transmitted to nurse’s PDAs and PCs in a staff room – most importantly, alerts if apnea occurs during patient transfer.

2.1.1 Vital Signs Monitoring System

We introduced a mat-type vital signs monitoring system (developed by Jepico Co.

Fig. 2 Nurse’s PDA, with screen shots. The apnea alert pops up in the monitoring status screen. There are buttons under “vital signs monitoring status”, such as “cancel alert”, which means alert was false positive or there is no need to call other staff, and “emergency alert”, which nurses use to confirm that patient has apnea. The location screen shows the current location of the patient on a hospital map.
A vital signs monitoring system was developed for Smart Stretcher. Apnea status was defined as the amplitude of the respiratory waveform falling below a predetermined threshold (e.g. the standard amplitude corresponding to between 2.5 ± 0.77 V) and continuing for a preset period (5–10 seconds). However, baseline amplitude rose if motion artifacts occurred. Therefore, we developed a dynamic threshold to detect apnea during transfer for more accurate detection. The baseline of the threshold varies based on amplitude data averaged over the last five sampling points [19].

Also, the other system settings for apnea detection were adjusted to a specific environment once beforehand to remove motion artifacts. The system settings consisted of three parameters; duration of apnea (0–20 seconds), sensitivity of detecting signals (V) and signal balance between two air-mat sensors (RMS – root mean square).

The monitoring system of the stretcher not only emitted an immediate audible apnea-warning, but also simultaneously transmitted alerts to the nurse’s and doctor’s PDAs and staff workstations in the ward as soon as the system detected apnea. The screen display of a nurse’s PDA is shown in Figure 2. The patient’s name, time of detection, respiratory rate, physiological status and heart rate are displayed at 15-second intervals. When apnea is detected, a red warning display appears, and
the system emits an audible alarm instantly. After the alert, the nurse can choose to press either “emergency alert” or “cancel alert”, which automatically pops up on the PDA screen. “Emergency alert” is synonymous with “code blue” and patient apnea and location information are sent to not only the nurse accompanying the transport, but also to the anesthesiologist who is in charge of the patient, doctors and other involved staff in the staff room or ER. If the accompanying nurse notices that it is a false positive alert, “cancel alert” can be pressed and deactivate the apnea alert.

2.1.3 Auto-recognition of Patient ID

For auto-detecting a patient who was lying on a stretcher and matching monitoring data to patient data, we used a passive RFID system (Takaya, TR3, Japan [23]). The patient ID information was stored in a passive RFID tag attached to the left wristband, and an RFID reader that recognizes the patient’s ID was located on the left side of the stretcher. Other patient information was not directly stored in the RFID tag, but rather retrieved from the database of the hospital information system using the tag’s unique ID (UID).

The RFID reader began reading the patient’s ID when the contact sensor that was attached to the stretcher detected that a patient was lying on the stretcher. If the patient’s ID was successfully detected, the RFID reading device emitted a beep and showed data on a PDA. If a reading error occurred, such as when no ID information was detected, or if two or more different IDs were read within the first 30 seconds of a scanning period, the system emitted a continuous beep tone to alert the medical staff of the need for re-reading.

The RFID reader used a polling mode, whereby the data of a tag were read only within a fixed period, usually set to 30 seconds. If the reader failed to detect the patient’s ID, it attempted to read it again in the following 30 seconds. The patient ID detection worked as a trigger to start monitoring of the patient. The patient information was also visible on a PDA screen to facilitate double confirmation. In addition to vital signs data, the detected patient ID was also transmitted by a ZigBee network.

2.1.4 Identifying Patient Location

A wireless ZigBee network was implemented not only to transmit patient data but also to detect the location of the patient and of the stretcher in real time and to pass this information to other medical staff in the event of an emergency. Compared with other wireless technologies, such as wireless LAN or Bluetooth, ZigBee was shown to be more compatible when connected to other devices and to easily enable wireless communication [24]. A Received Signal
Strength Indicator (RSSI) system was employed, which estimated the location on the basis of the intensity of the signal received by the ZigBee location routers distributed along the hospital corridors. These routers were capable of detecting the location of a tag within a 15-meter radius. A wireless ZigBee tag attached to the stretcher transmits a unique ID to all ZigBee location routers at 10-second intervals. Each of the routers received the signals from the ZigBee node of the stretcher and transmitted the corresponding tag ID, intensity of the signal received from the ZigBee node, and its own ZigBee router ID, to the ZigBee gateway and hospital LAN. The patient’s location was estimated by identifying the ZigBee router that had recorded the greatest signal intensity. The ZigBee routers constituted an ad hoc mesh network that transmitted reliable and accurate location information to the gateway.

### 2.2 Clinical Feasibility Experiment and Evaluation

#### 2.2.1 Experiment Methods

We conducted a feasibility experiment of Smart Stretcher in a simulation setting at TMDU Hospital (801 beds). We used the 16th floor of the hospital, which had the same structure as other general wards. To confirm that a whole system could correctly work in terms of alerting without delay when apnea occurred and evaluating accuracy of an apnea alert function during transfers in the hospital, we measured the apnea of four subjects: two males and two females. Each wore a strain sensor on his/her abdomen and a pulse oximeter on one ear lobe for obtaining respiration and heartbeat reference signals. We also implemented an on/off button that subjects pressed during a simulated period of apnea in order for us to measure the time of the simulated apnea.

### Table 2 Detection rate for apnea (FN: false negative, FP: false positive)

| Subject (weight in kg, gender) | Semi-sitting position | | | | | | | | | Supine position | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sensitivity (%) | Specificity (%) | FN alert (times) | FP alert (times) | Sensitivity (%) | Specificity (%) | FN alert (times) | FP alert (times) |
| A (50, F) | 89.4 | 99.9 | 1 | 0 | 79.7 | 100.0 | 1 | 0 |
| B (55, F) | 90.5 | 100.0 | 0 | 0 | 100.0 | 97.0 | 0 | 0 |
| C (65, M) | 90.1 | 98.4 | 1 | 0 | 100.0 | 91.6 | 0 | 0 |
| D (70, M) | 100.0 | 92.0 | 0 | 0 | 94.8 | 94.8 | 0 | 0 |
| Overall | 92.0 | 97.4 | 2 | 0 | 93.8 | 95.7 | 1 | 0 |

Fig. 4 Results of FFT analysis shown in Figure 3. These spectrums underwent FFT analysis and were compared to reference data for both heartbeat and respiration.
First, the subject, in semi-sitting position (45 degree angle), was transported on the stretcher at a speed of approximately 4.5 km/h (= 1.25 m/s = 4.1 ft/s), estimated by the length of the corridor and the elapsed time. The subject was asked to stop breathing twice per minute to verify whether the monitoring system would detect apnea in spite of the movement of the stretcher. If apnea was detected, a warning signal was subsequently emitted. In this experiment, the complete measurement duration for all subjects was 120 seconds. We usually need at least 60 seconds of normal respiration period before detecting apnea. Therefore, we asked subjects to stop respiration after a respiration time of 60 seconds. We set up the apnea detection time (threshold) at 10 seconds and defined the apnea period as that with the output level of the respiratory sensor within the range of 0.23 to 0.32 V in this setting. The percentage of alerts for all apnea events was calculated.

Similarly, we conducted the same test with a supine position and repeated this ten times for each subject.

We compared the respiratory rate and heart rate calculated by the air-mat type sensor with those of reference data obtained from conventional monitors. The original data underwent a Fast Fourier Transform (FFT) analysis, which disassembled the temporal vibration signals into a sum of the oscillatory components at various frequencies. Subsequently, frequency components corresponding to heart and respiratory rates were filtered. The baseline data was set to the following: in a normal subject, heart rate frequency is predominantly within 0.5–2 Hz, and respiratory rate is within 0.1–0.5 Hz. Also, we calculated the correspondence rate, whether the highest peaks of respiratory and heart rates in FFT analysis corresponded with reference data or not. Moreover, we calculated the sensitivity and the specificity for the accuracy of detected apnea in Smart Stretcher.

Similarly, to clarify the influence of transferring speed, we conducted the same test to detect apnea but continually increased the speed of the transfer by 2 km/h. This test was repeated ten times for each subject and also conducted in both semi-sitting and supine positions.

Second, the readability of the patient ID wristband on Smart Stretcher was examined. All subjects wore an RFID wristband on their left arm for identification. The specification of all equipment is shown in Table 1. The distance at which the patient wristband ID could be recognized by the RFID reader, which was located on the left side of the stretcher, was measured. We varied the reading conditions – such as the types of tag, position of the RFID reader antenna, and patient posture – and measured the maximum readable distances from the reader antenna in each of the cases.

Lastly, in the experiment area, we installed five ZigBee routers at 10-meter intervals on the ceiling of a hospital corridor. The equipment is shown in Table 1. The hospital ward was U-shaped, with two corners. The routers were connected to a single gateway. Two nurses moved the subject on Smart Stretcher down the corridor for a distance of 80 meters. During this transfer, two observers followed the moving Smart Stretcher, one taking a video and the other giving the current location over a wireless phone to a person who was watching a location map on screen at the staff station. After the experiment, we compared the system log file of the ZigBee location to the video which the observer took.

### 2.2.2 Evaluation Methods

After examining the clinical feasibility of Smart Stretcher, we obtained a subjective assessment by asking 30 registered nurses with 1–12 years of clinical experience to fill a questionnaire that evaluated the usability of this integrated Smart Stretcher system. Before giving the questionnaire, we demonstrated Smart Stretcher in an experiment room and a corridor and explained how to use it. After that, nurses tried out the system using a subject who stopped his respiration. It took about one hour for each nurse to evaluate the system including the demo and trial use. In this usability assessment, we investigated four parameters, i.e., perceived usefulness, operability, efficiency, and effectiveness of the system. These items were scored from 1 (poor) to 5 (excellent). The questionnaire consisted of 20 items. The questionnaire was evaluated by ten co-researchers, including physicians and nurses, before the nurse evaluation. We calculated mean values and standardized deviation of the scores for each parameter.

![Fig. 5 Results of the experiment at different speeds](image-url)
3. Results

3.1 Measurement of Vital Signs and Detection of Apnea

One example of the vital sign waveforms (heart rate and respiratory rate) from the experiment is shown in Figure 3, and their FFT analyses when subject A was transferred at a speed of 4.5 km/hr is shown in Figure 4. Measured vital sign waveforms and their FFT analysis data should be consistent with reference data if the system can correctly detect the respiratory and heart rates. In FFT analysis with the semi-sitting position, the correspondence rate for respiration was 90.0% and for heartbeat 60.0% (n = 20). With the supine position, it was 90.0 and 50.0%, respectively. However, some of the heart rate did not correspond to the highest peaks in the reference data, but rather with the second highest peaks.

The apnea detection method worked correctly, as can be seen in the respiratory waveforms during the transfer (Figure 3). The measured respiratory waveforms indicated apnea by flattening out for few seconds.

The results are summarized in Table 2. Events of apnea for subjects in a semi-sitting position, B and D, were thoroughly detected (with, respectively, 90.5 and 100.0% sensitivity). However, one false negative apnea alert for each A and C occurred, resulting in 89.4 and 90.1% sensitivity, respectively. On average, apnea could be detected with 92.0% sensitivity and 97.4% specificity of total apnea seconds for all subjects. In the supine position, out of the 20 episodes of apnea, the system did not emit apnea alerts one time (79.7%) for subject A. Except for that, all apnea alerts were accurate and overall sensitivity was 93.8% and specificity 95.7%. Additionally, at this conservative threshold, there were no false positive alerts. The delay of the alert in Smart Stretcher was about 0.9 seconds (stdv = 1.2) according to a comparison with reference data.

The results are summarized in Figure 5. The 80 episodes of apnea for all subjects at the speed of 2–6 km/h were detected at an average of 95.6%. Considering the posture of patients, there were slight differences between supine positions – 93.8% – and semi-sitting positions – 97.5%. However, the detection rate at the speed of 6 to 8 km/h dropped to 83.8%.

The actual detected apnea was shorter than reference data by 0.6 seconds (stdv = 1.27) on average, at the speed of 2–6 km/h. As for the results at different speeds, again no false positive occurred. However, a false negative occurred four times at the speed of 4–6 km/h and eleven times at the speed of 6–8 km/h.

Table 3 Results of readable distance limits of patient ID

<table>
<thead>
<tr>
<th>Tag type</th>
<th>Maximum readable distance</th>
<th>RFID antenna On left side</th>
<th>Under the mat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tag A (size: ϕ 10 mm)</td>
<td>~60 mm</td>
<td>60 mm</td>
<td>12 mm</td>
</tr>
<tr>
<td>Tag B (size: 42.5 × 54 × 0.45 mm)</td>
<td>~250 mm</td>
<td>128 mm</td>
<td>73 mm</td>
</tr>
<tr>
<td>Tag C (size: 85 × 54 × 0.76 mm)</td>
<td>~350 mm</td>
<td>135 mm</td>
<td>80 mm</td>
</tr>
</tbody>
</table>

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speed of 6–8 km/h for all 80 episodes of apnea.

Unlike current monitoring systems, the signals were transmitted through the ZigBee wireless network, and the patient’s name, respiratory rate, and heart rate could be correctly displayed on a remote PC and PDA instantly. The apnea-warning alert and warning screen on the PC and PDA were also displayed with no delay.

3.2 Readability of Patient ID

In most cases, the RFID was recognized within 15 seconds after the reader started, and the patient ID was displayed on the monitoring screen in real time. Readable distances from the RFID antenna (left side of the stretcher and under the mat) are shown in Table 3. Mat thickness was 55 mm. The readable distance limit for patient ID increased with tag size. There was no difference in readable distances between patients in supine and semi-sitting positions. The readable distance of the RFID reader placed on the left side of the stretcher was much higher than when it was under the mat. Patient identification was most reliable when the patient’s hand wearing the RFID wristband was positioned straight, along the edge of the stretcher. Patient identification was somewhat difficult when the hand was in any other position.

3.3 Detection of Location of Smart Stretcher

The location detection system (Fig. 6) could provide the correct location in real time. The location of Smart Stretcher based on the video file was compared to the detected location of the system log file of the ZigBee location system. Radial range of location detection was 15 m, and the range of error was ± 10 m. We could detect the accuracy of location continually as the stretcher passed through each room. Critical errors and delays in the display of the detected location were not observed in this experiment.

![Diagram](https://example.com/diagram.png)

**Fig. 7** Results of the subjective evaluations. The responses were set to the following scale: 5 = completely agree/excellent, 4 = mostly agree/good), 3 = can’t decide/fair, 2 = somewhat disagree/poor, and 1 = disagree/bad. In this figure, average scores of each item are shown (μ: mean value; δ: standard deviation).
3.4 Subjective Evaluation by Nurses

The results of the average evaluation score for each item are summarized in Figure 7. Questions were based on the same five aspects of the four criteria in Figure 7.

Regarding perceived usefulness, the questions received predominantly positive responses, with combined averages of 4.8, except for the location detection system. This item’s average (4.5) was slightly lower than that of any other item. Overall, we concluded that Smart Stretcher was perceived as sufficiently useful for the practicing nurses.

Regarding efficiency, the average score for all the items (4.0) was a little lower when compared to that of other categories. The lowest averages, ranging from 3.8 to 3.9, were related to the patient ID recognition function, which reflected the fact that patient ID reading required periodic checks by the staff who were unfamiliar with indoor positioning systems. The averages for the answers related to the vital signs monitoring function ranged from 4.0 to 4.4, and indicated that the system was considered efficient, but not completely unobtrusive.

As for operability, such as measuring vital signs and recognizing patient RFID, the combined average score for all items was 4.2. The system was considered to be reasonably user-friendly.

Finally, in terms of effectiveness as a medical safety measure, questions related to patient ID recognition and vital sign monitoring received very high scores, but the apnea alert function showed relatively less positive results, 4.3. This indicates that, although the participants of this experiment appreciated the utility of the alert system, as shown in the evaluation of other functionalities, they believed that the present alert system required improvements to be effective as a medical safety measure. Although the average for the effectiveness of the entire stretcher system was 4.8, the response to improvement over current patient safety measures was not as high, at only 4.1. This result indicated that the medical staff had a very high expectation for the performance of Smart Stretcher in improving patient safety over the current systems.

4. Discussion

4.1 Factors Influencing the Measurements

Our feasibility experiments showed that information on patient vital signs, ID, and location could be obtained in real time during transfers using Smart Stretcher.

Respiratory rate was correctly detected in over 92.0% of the transfers at the speed of 4.5 km/h even when some motion artifacts were present. When speed was increased, the rate of detection dropped. However, assuming that walking speed is about 4 km/h and, when transferring a patient on a stretcher, it is slower, we analyzed only data between 2 and 6 km/h. Therefore, we used 4.5 km/h as a basic stretcher speed based on the walking speed.

Regarding the influence of the patient positions, there was not a big difference between semi-sitting and supine positions. However, if the speed was over 4–6 km/h, the detection rate was slightly decreased with a supine position. Apnea detection seems to be more accurate with a semi-sitting position. At this point, we have not been able to find the reason, but we should clarify the relationship between position and speed. Additionally, we found that the variable of patient weight was more of an influence than position. We assumed that because heavier weight pressed the sensor mat more firmly, there was greater accuracy of measuring vital signs. The results of these refinements of the noise filter and the shock absorber are reported in [20]. The accuracy of measuring apnea in regard to weight variables before introducing the noise filter and the shock observer was not high enough [15]. However, we confirmed that after these improvements, we could get higher accuracy of apnea detection regardless of subjects’ characteristics. Also, although we introduced the shock absorber to reduce the effect of weight, we might have to consider modifying the current shock absorber for general use in all stretchers.

4.2 Issues Noted during the Experiments

Some false negatives did occur in the experiment. The fact that subjects were only able to hold their breath for a short time, approximately 10 seconds, contributed to this issue, and it is possible that the system would not have these false negatives in a longer apnea interval, such as asphyxia. It is possible to decrease the rate of the alert delay by adjusting system settings of sensitivity and time of apnea detection (10 seconds in our experiment), but there are trade-offs in terms of false positives, which are a known problem in monitoring systems. It is important to eliminate false negatives but, at the same time, we have to consider false positives. False positives often result in reduced vigilance by staff, and even eventual discontinuation of the system if nurses are pulled away from other work to investigate frequent false alarms. For this reason, before conducting this experiment, we did several test runs to find an ‘optimal’ setting for the test environment. This parameter tuning phase may be necessary in every new environment and therefore our results may not carry over to other clinical settings. However, it would be difficult to change settings each time. Therefore, we are considering the development of an auto-optimization algorithm.

Another problem was that it was somewhat difficult to obtain the correct heart rate in our experimental setting; the heart frequency band was similar to the frequency band of the stretcher’s motion artifacts. Even though we only focused on detecting apnea at that point, the mat–type vital signs monitoring system could also monitor heart rate if the stretcher was at rest. Currently, for sensing heart rate during transfer, a pulse oximeter is used. However, if Smart Stretcher can detect both respiratory and heart rates, it would be more useful and convenient. Considering the result of the experiments, the precision of detection of heart rates is likely to improve in the near future with the introduction of more improved noise filters or dampers. Therefore, although the apnea detection was relatively reliable, we conclude that the system does not yet perform favorably when compared to the monitoring systems we tested, but
4.3 Perceptions of Nurses for Using Smart Stretcher

Results of the subjective evaluations showed that the stretcher system might be well accepted in medical practice. However, although the nurses appreciated the potential usefulness of this system, they also expected the system to be much more “easy to use,” “efficient,” and “reliable.” To measure real effectiveness of Smart Stretcher, such as the accuracy of detecting apnea, we should conduct a cohort study, which compares before and after implementation of the system in a hospital. At this point, the proposed system monitors the patient’s state automatically, without a need for trained staff to attach medical devices to the patient, so it may prove useful in situations in which there is a scarcity of medically trained personnel.

4.4 Strength of Smart Stretcher System Compared with Related Work

In our study, ZigBee technology was chosen for detecting location instead of wireless LAN or other wireless networks. Although popular, these detecting location systems, mainly using Wi-Fi technology, are likely to pass the signals through walls and ceilings, which results in the inaccurate detection of location. The big advantage of ZigBee was not only in sending data but also detecting location in the same sensor network.

4.5 Future Work

In terms of the system integration with hospital information systems, it is possible to integrate Smart Stretcher with current hospital information systems. Through a system developer, the Smart Stretcher system can be coordinated with both Wi-Fi networks for hospital information systems and ZigBee networks, and communicate with them using a gateway server. Through the wireless networks, Smart Stretcher would be able to get patient ID or medical order information from hospital information systems. Furthermore, in the future, this system could be applied to wheelchairs inside the hospital, and connected to other sensors, such as a blood pressure monitor. In fact, we have conducted preliminary trials to find out whether we can detect apnea in wheelchairs. Results so far have been mixed, particularly due to the difficulties in accommodating all necessary equipment in the wheelchair. These integrations and applications with other medical equipment would complete our final research aims.

Our study corresponds to the first phase of clinical trials for evaluation of new drugs and medical devices. This is one of the processes of clinical trials which has to be conducted to obtain approval for clinical use under the Pharmaceutical Affairs Act in Japan. Clinical trials involving new drugs and medical devices are commonly classified into four phases. In Phase I trials, small pilot studies or experiments are conducted with healthy subjects to gain insights into the design of the clinical trial. As positive safety and efficacy data is gathered, patients can be involved in the next step: Phase II trials.

Our study corresponds to the first phase of the research, which is testing of healthy subjects (usually between around five and 20 people). At this point, the research could not involve patients in a real clinical situation. It would be necessary to conduct the research with a larger number of patients. After obtaining approval from the institutional review board, patients can be involved in the research; we will proceed to this second phase and continue to do experiments toward a practical use of Smart Stretcher.
5. Conclusions

Through the technological feasibility experiment and evaluation of Smart Stretcher, we confirmed that Smart Stretcher has great potential in improving patient safety during transfer and stimulating collaboration among medical staff. At this point, it is still difficult to detect heart rate, but we could detect apnea. Through our new approach, integrating all sensors and networks, we could develop a new system which could solve the patient safety problem during transfer. Moreover, we concluded that this system can help to detect patient emergency status and be used to monitor patient conditions without increasing staff workload. Still, it was a preliminary experiment and evaluation; we have to conduct a large-scale experiment in the near future.

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References