Intravenous Drip Infusion Monitoring System with Body Area Communication Tag

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***Abstract*— Intravenous drip infusion is a common method of administering medication. However, it is difficult for a nurse to continuously monitor the administration since it can take more than one hour. It is difficult to instantly detect problems such as removal of a drip infusion administration set by a patient or an empty bag. We propose an intravenous drip infusion monitoring system equipped with body area communication tags that can instantly detect such incidents.**

Keywords- intravenous drip infusion; body area communication tag; medication; medical administration

I. INTRODUCTION

Intravenous drip infusion is widely used for administering medication in hospitals. However, it is difficult to continuously monitor administration, since it can take more than one hour. Therefore, it is difficult to instantly detect incidents. The following incidents should be monitored.

- Infusion rate: Changing of infusion rate causes insufficient therapy or serious problems.
- Empty medication bag: Empty medication bag sometimes results in a blocked cannula by blood and has to be exchanged with a new one.
- Remaining quantity of medication fluid in the bag: It is possible to estimate changing of infusion rate and empty medication from the remaining quantity of medication fluid.
- Getting the drip administration set off the body: Getting the drip administration set off results in insufficient therapy. In case of administering toxic medication such as anticancer drugs, a skin with which toxic medication oozing through a cannula is stained sometimes becomes necrotic.

Several types of intravenous drip infusion monitoring equipment have been developed. Optical devices, such as Ir-da, are widely used to measure the drip rate [1][2][3][4][5]. Ogawa et al. developed a system for measuring the drip rate using electrodes instead of optical devices [6]. However, the drip rate is not steady, and the size of the drip is not the same [7]. Generally, lower the drip rate, smaller the drip size. For steady and accurate infusion, it is necessary to equip an ordinary administration set with some form of servo-control mechanism. Barros and dos Santos proposed not only monitoring the drip rate but also controlling it to maintain steady and accurate infusion [1]. However, since their system estimates the infusion rate from the drip rate and does not take into account the change in drip size, it is difficult to accurately estimate the infusion rate. On the other hand, Wang and Chen estimated the infusion rate instead of the drip rate using an ultrasonic transducer [8]. Cataldo et al. proposed a measuring scheme to estimate the remaining quantity of fluid in a bag. They used the microwave time-domain reflectometry (TDR) to estimate this [9][10]. Their system can measure the infusion rate from the remaining quantity, not the drip rate. Huang and Lin proposed a warning system using Radio Frequency Identification (RFID) to detect an empty bag [11].

Current systems and tools cannot detect getting the drip administration set off the body. Some cognitively impaired patients consciously remove their drip infusion administration sets by themselves. Hence, a monitoring system that can detect such behavior is needed. We propose an intravenous drip infusion monitoring system that can detect both an empty bag and removal of a drip infusion administration set. We previously presented the results of a feasibility study of our proposed system [12]. We use body area communication tags called the Touch tag to estimate both actions. The Touch tag is developed and supplied by Adsol Nissin Corp. [13].

After related work is discussed in Section II, we describe the basic principle and structure of our proposed system in Section III. The basic characteristics of the proposed system are presented in Section IV. The experimental parameters of the system and evaluations we conducted are described in Section V. The key points are summarized and future work is mentioned in Sections VI.

II. RELATED WORK

In this section, we introduce schemes for detecting the remaining fluid in a bag and body area communication tags, which are related to our system.

A. *Schemes for detecting remaining fluid in intravenous bag*

Cataldo et al. used microwave TDR for a two-strip adhesive probe attached to a bag to estimate the remaining

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quantity of fluid in the bag, as shown in Fig. 1 [9][10]. The TRD value varies corresponding to the remaining quantity of fluid. The measuring accuracy may be acceptable. However, since it requires a TRD measuring instrument, such as a network analyzer, and to measure TRD value vs. remaining quantity of fluid for kinds of bag or medication.

Huang and Lin used RFID to detect an empty bag [11]. A RFID tag is attached to the bottom of an intravenous bag. They argued that a tag reader could read a RFID from a few meters during fluid level was under a RFID tag, as shown in Fig. 2. However, they did not provide practical experimental data on if a tag reader could read RFID.

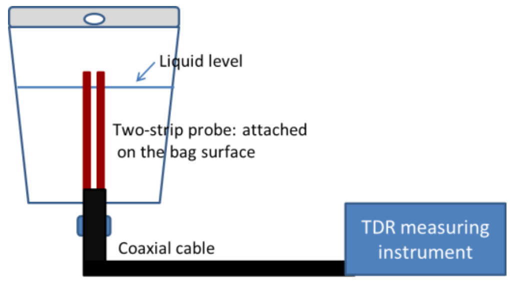

Figure 1. Scheme for measuring remaining liquid quantity using TDR

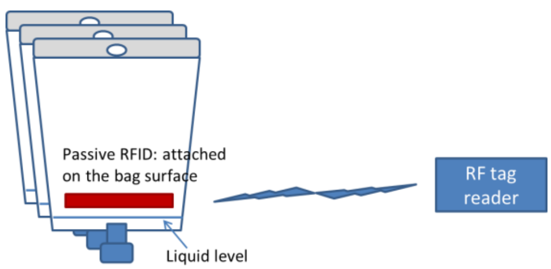

Figure 2. Scheme for detecting an empty bag using RFID

B. *Body area communication tag*

There are two types of body area communication systems [14]. One involves the human body as a data-bus between devices attached to the body. The other involves a radio system used as a communication system between devices attached to the body. The first type was invented by T. G. Zimmerman in 1996 [15]. His body area communication system used the variable of the electric field on the body of which the frequency range was from 0.1 to 1 MHz. He built a prototype operating at 330 kHz. However, since he chose a frequency range from 0.1 to 1.0 MHz to suppress electric-field emissions, probably it was difficult to achieve stable communication because of the significant ambient noise. Ambient noise usually presents itself at frequencies below 1 MHz. When the transmission signal is strong enough to maintain stable communication, there is no difference between his system and existing near-field communication systems such as WiFi and Bluetooth. Ultimately, Zimmerman stopped developing this technology and chose the second scheme.

Panasonic Electric Works Co. Ltd. developed a touch communication system using the variable of the electric current in a body instead of the electric field to avoid the ambient noise in 2004 [16].

Yuichi Kado evolved Zimmerman's body area communication system [17]. He selected the frequency band from 5 to 10 MHz to avoid the ambient noise and developed a modulation scheme to efficiently modulate the electric field near the body and receiver circuits which reduce ambient noise such as electrical hum.

Our partner, Ad-Sol Nissin Corp., introduced a semi-active scheme to improve the battery life cycle of tags used in evolved electric field schemes [13]. It is possible to use a tag for a few years without having to replace the battery. We chose Ad-Sol Nissin's Touch tag to develop a medication error protection system [18], since it is possible to communicate over clothes or shoes and the life cycle of the tag is long. The Touch tag was used for verifying the relationship among an intravenous bag, patient, and nurse. We noticed that the received signal level when the Touch tag was touched directly was different from the level when the tag was touched through an intravenous bag.

III. BASIC PRINCIPLE AND SYSTEM STRUCTURE

A. *Basic principle*

Our system uses Touch tag features to detect an empty intravenous bag and a removal of a drip infusion administration set. The Touch tag reader sends a calling signal over the electric field for the Touch tag to send a reply message. The tag that received the calling signal sends a reply message including its ID over the electric field. Therefore, the tag reader can read the ID in a tag a few centimeters away from it without requiring any media. In addition, when there are ionized media, such as isotonic sodium chloride solution, in a tube between a reader and tag, the distance from where the reader can read the tag becomes longer. When a person touches the tube between a reader and tag, the communication length becomes very short. The reason is that the electric field generates between a tag and the ground via a person in addition to a section between a reader and tag, and the strength of the electric field between a reader and tag weakens.

It is possible to detect an empty bag by changing from able to read a tag to unable to read a tag derived from fluid in a tube being empty.

The removal of a drip infusion administration set is detected by changing from unable to read a tag to able to read a tag, because of the patient removing the tube and the tag together with the cannula. The tube was attached to an arm or other body parts of a patient before removing. It is difficult to detect if a patient removed only the cannula. However, we believe that a cognitively impaired patient may remove the tube and tag together with the cannula.

B. *System structure*

The structure of our proposed system is shown in Fig. 3. A tag reader is attached to a tube beneath a chamber, Tag_1 is attached to the tube at longer than the longest position that a reader can read a tag's ID when there is no fluid in the tube

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(L_1), and Tag_2 is attached to the tube between the shortest position that a reader cannot read a tag's ID when a person touches it (L_2) and the longest position that a reader can read a tag's ID when there is fluid in the tube (L_3). L_1, L_2 and L_3 are lengths from a reader. An arm is attached to the tube at a position near Tag_2. Not reading Tag_1 means the amount of fluid in the tube is nothing; and reading Tag_1 and Tag_2 simultaneously means the tube was removed from an arm. When a PC detects no amount of fluid in a bag or a tube has been removed, it sends an alert to the nurses' station. Only Tag_1 is needed for detecting only an empty bag. On the other hand, only Tag_2 is needed for detecting a removal of a drip infusion administration set.

One of the advantages of the proposed system is that installation is very easy. Attaching an electric-probe or an RFID on a bag is not necessary. Installation only involves fastening an electrode of a reader and one or two tags to a tube. For this research, the electrode of a reader was fastened using magic tape and a tag was fastened using a rubber band, as shown in Fig. 4. Fastening becomes easier to change them to clipping type.

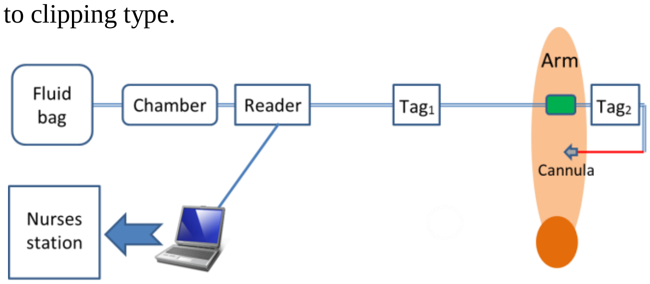

Figure 3. System structure

IV. BASIC CHARACTERISTICS

A. *Humidity*

Since the touch tag is an electric-field-type tag, we assumed L_1, L_2 and L_3 would be affected by humidity. We measured the relationship between L_1, L_2, L_3 and humidity for two tags on three different days, as shown in Fig. 4. This photo shows when measuring L_2. We used a bag filled with an isotonic sodium chloride solution.

An electrode of the reader was attached to a tube beneath a chamber with magic tape. A tube was attached to a patient's arm between an electrode and a tag with gummed tape, and Touch tags were attached to the same tube with a rubber band to easily change their positions. Since a reader can surely read a tag at less than or equal to L_1 or L_3, the measured data were of the longest length on which a reader can read a tag continuously 10 times. The other hand, since a reader surely cannot read a tag at longer than or equal to L2, the measured data were of the shortest length on which a reader cannot read a tag continuously 10 times.

The measurement data of L_1, L_2, and L_3 are shown in Figs. 5, 6 and 7, respectively. We could not find any effects of humidity on the readability of touch tags. The reader could not read a tag 18 cm away, when there was not fluid in a tube, as shown in Fig. 5. Therefore, Tag_1 must be attached to a tube more than 18 cm from the reader-electrode. The reader could not read a tag's ID more 60 cm away, when someone touched the tube, as shown in Fig. 6, but it could read the tag within 84 cm, when there was fluid in a tube, as shown in Fig. 7. From these experimental data, Tag_2 must be attached to a tube between 60 and 84 cm from the reader-electrode.

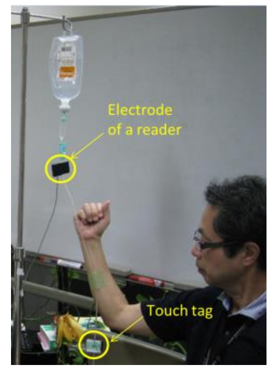

Figure 4. Photograph of measuring L_2

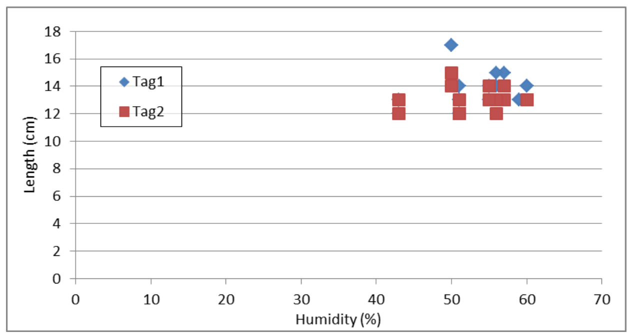

Figure 5. Measurement results of L_1

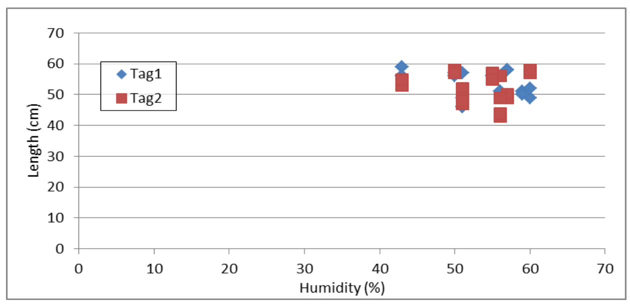

Figure 6. Measurement results of L_2

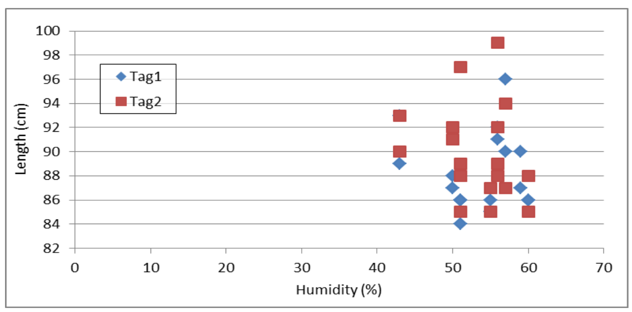

Figure 7. Measurement results of L_3

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B. Angle between reader-electrode and tag

The electrode of a touch tag reader and a touch tag is designed to generate an electric field on the surface of the body. Therefore, they have directional characteristics. We measured the received signal strength for a tag of which the direction increased 15 degrees from 0 to 315 degrees. The measurement conditions were as follows;

- There was fluid in the tube, or it was empty.
- Distances between the reader and a tag were 5 and 10 cm.

We used an intravenous bag filled with an isotonic sodium chloride solution.

The data were averaged over ten received signals. The measurement data are shown in Fig. 8. When there was fluid in the tube, the directional pattern was omni-directional. On the other hand, when there was not fluid in the tube, the received signal strength was stronger in the same or opposite direction between the reader-electrode and tag.

For detecting the removal of a drip infusion administration set, since there was fluid in a tube, a nurse did not have to focus on the attaching angle of Tag_2. On the other hand, L_1 has to be considered. However, when we measured L_1 (Fig. 5), the angle between the reader-electrode and tag varied every time. We believe the measurement data include this variation.

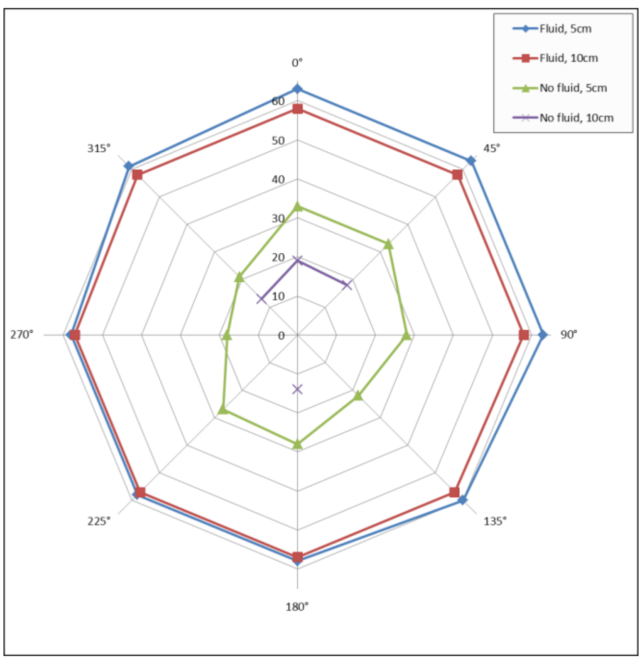


Figure 8. Directional characteristics of angle between reader-electrode and tag

C. Touching tube between reader-electrode and tag

An electric-field-type body area communication tag and reader-electrode generate an electric field between them and the earth via the human body when a person touches a tube between a reader-electrode and a tag, as shown in Fig. 9. Therefore, the received signal strength from a tag to the reader weaken when the person touches the tube. We measured how much the received signal strength was affected when someone touched the tube between the reader-electrode and tag, as shown in Fig. 9. The length between the reader-electrode and tag was 40 cm. There was fluid in the tube, which was attached to an arm with gummed tape. We used an intravenous bag filled with an isotonic sodium chloride solution. The measurement data are shown in Fig. 10. The received signal strengths for Tag_1 and Tag_2 were roughly the same and always steady when a tube was removed from an arm. On the other hand, the received signals for Tag_1 and Tag_2 varied by about 5 dB, when a participant touched the tube. There was not big difference between values for each tag. There was a 15 – 20 dB difference between when a participant touched the tube and did not. Since the signal strength at 25 cm for both tags was weak and varied like a sine-wave, we estimated there was a standing wave on the tube. However, we miss-estimated since the frequency of the touch tag was 3.2 MHz .

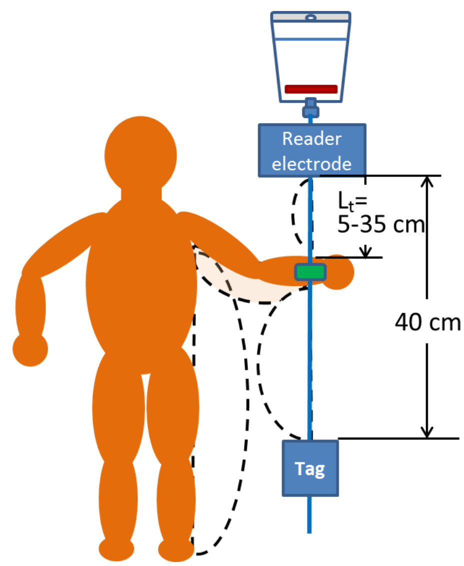


Figure 9. Image of electric-field between reader electrode, tag and earth via human

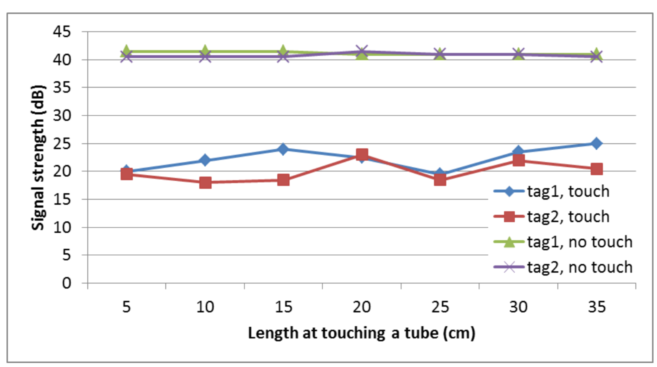


Figure 10. Effect of participant touching tube between reader and tag

D. Simultaneously reading two tags

The Touch tag uses the semi-active method. The tag responds to a compellation of a reader to suppress electricity consumption of the battery in a tag. Therefore, the reader sometimes fails to read when two tags send a response at the same time. We measured the characteristics for reading two tags simultaneously. Tag_2 was attached to a tube 80 cm from the reader and L_r at which Tag_1 was attached changed from 20 to 70 cm, as shown in Fig. 11. We used an intravenous bag filled with an isotonic sodium chloride solution. The number of continuous miss-readings for each tag is shown in Fig. 12. In this figure, L_r is 20, 50 and 70 cm. The number of tag readings was 237 at 20 cm, 171 at 50 cm, and 253 at 70 cm. The values in Fig. 12 were corrected to normalize 100 readings.

A reader could read Tag_1 every time from L_r=20 to 40 cm. Since there is not a big difference between L_r=20 and 40 cm, the figure at 40 cm is not presented. The reason the reader could perfectly read Tag_1 must be due to the fact that the signal strength from Tag_1 is much stronger than that from Tag_2. Hence, when L_r was 70 cm, the number of continuous miss-readings for Tag_1 was the same as that for Tag_2. We believe the number of continuous miss-readings for Tag_1 and Tag_2 being completely the same must be a coincidence. When a reader does not read Tag_1, the tube must be empty, or the reader or tag is broken. The proposed system can instantly detect when a tube is empty.

No more than nine miss-readings occurred at every L_r. when the drip infusion administration set was removed, our system must detect it within at least of ten trying to read a tag after removing occurence. It is possible to detect such actions within 10 sec., when the reading period is 1 sec.

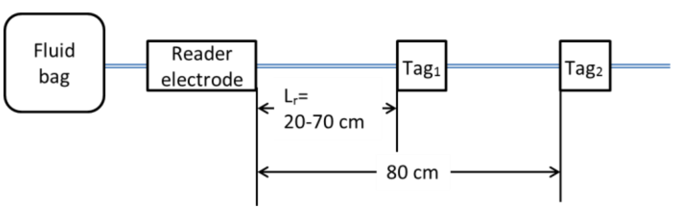
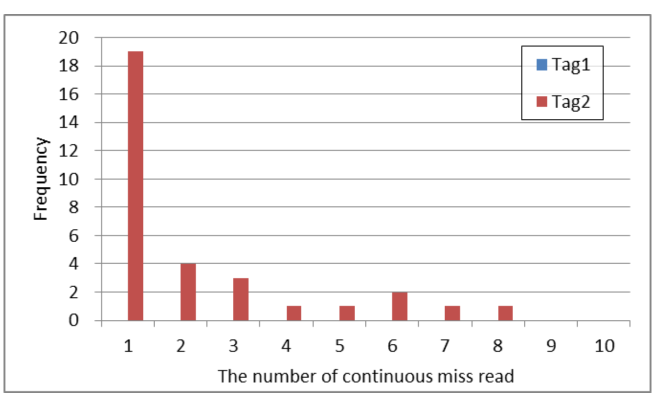
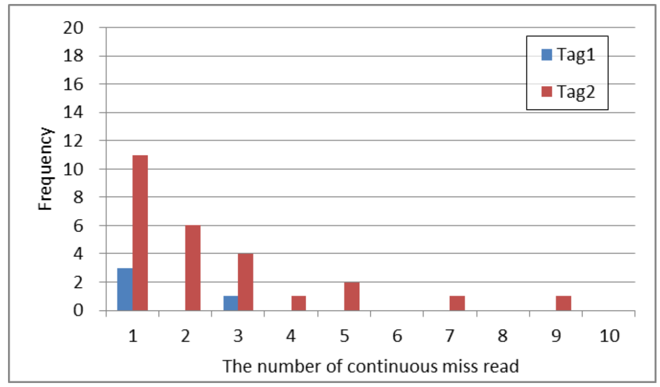


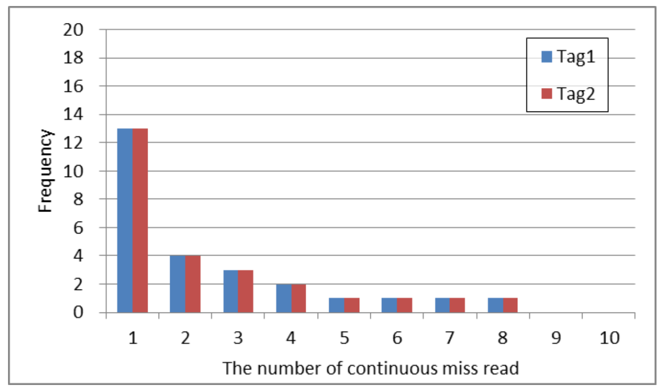
Figure.11 Positions at Tag 1 and Tag 2 for measuring characteristics for reading two tags simultaneousl



(a) Distance from reader L_r=20 cm



(b) Distance from reader L_r=50 cm



(c) Distance from reader L_r=70 cm

Figure 12. Miss-readings for two tags simultaneously

V. EXPERIMENTAL EVALUATION

From the results discussed in Section IV-A, we attached Tag_1 20 cm from the reader and Tag_2 70 cm from the reader, as shown in Fig. 3. The proposed system could detect an empty intravenous bag and a removal of a drip infusion administration set. We used an intravenous bag filled with an isotonic sodium chloride solution. The evaluations conditions were as follows.

- When bag was empty: was continuously unable to read Tag_1 10 times. We decided this condition to get certainty.
- Removal of the drip infusion administration set: instantly could read Tag_2. The reason we used this condition was that the reader may read Tag_2 ten times to detect if an administration set was removed, derived from the results in Fig.12 (a). This means the detection speed was very slow.

In our prototype system, an alert message for each incident was presented on a PC display. We determined if the bag was empty by pulling a tube off the bag instead of running fluid out of the bag. The reasons were that we did not have enough bags filled with the isotonic sodium chloride solution and it took too much time to measure. We did not connect a cannula to the tube. As a matter of course, we did not insert a cannula into a participant's arm. There were seven participants.

We measured five times whether the proposed system could detect an empty bag and removal of a drip administration set or not for each participant. The proposed system could perfectly detect both types of incidents.

From the results in Fig. 12 (a), not being able to read 10 times is too severe for detecting if a bag is empty. In fact, the system presented an alert message for an empty bag being just after pulling the tube off the bag during the experiments. This judgment condition will have to be changed in a commercial system.

VI. CONCLUSION

We developed an intravenous drip infusion monitoring system using the Touch tags, a type of body area communication tag. This system can detect an empty infusion bag and removal of a drip infusion administration set by a patient. Unfortunately, this system cannot detect whether a cannula got off from the blood vessel or not, if the cannula is on or under the skin, because of the tube attached to the skin which prevents a reader to read the Tag_2 keeping on the skin.

One of the advantages of the proposed system is that installation is very easy. Installation only involves fastening an electrode of a reader and one or two tags to a tube. There also is no need to change an existing a drip infusion administration set. This system is applicable not only for standard gravity infusion administration sets but also a pump infusion administration sets.

We have already demonstrated this system at an exhibition for medical and welfare appliances and no miss-readings occurred. Since there is currently no monitoring system that can detect if a patient has removed his or her drip infusion administration set from his or her arm, our system was highly rated by participants such as nurses, doctors and medical equipment providers.

We could not evaluate the proposed system in a real-world situation for this research. Before evaluating the proposed system in such a situation, such as a hospital, we would like to change the design of the touch tag and electrode of the touch tag reader so that it can be easily attached to a tube, and transfer the decision function to a tag reader from a PC. We also plan to evaluate it in a real-world situation such as in a hospital.

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