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Building an Inferential Model between Caregivers and Patients by using RFID

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Abstract**—**Nosocomial (i.e., hospital-acquired) infections (NI) is a major cause of morbidity and mortality in hospitals. NI rate is higher in intensive care units (ICU) than in the general ward due to patients with severe symptoms, poor immunity, and accepted many invasive therapies. Contact behaviors between health caregivers and patients is one of the infect factors. It is difficult to obtain complete contact records by traditional method of retrospective analysis of medical records. This paper establishes a contact history inferential model (CHIM) intended to extend the use of Proximity Sensing of rapid frequency identification (RFID) technology to transferring all proximity events between health caregivers and patients into clinical events (close-in events, contact events and invasive events).The results of the study indicated that the CHIM can infer proximity care activities into close-in events and contact events.

The infection control team could redesign and build optimal workflow in the ICU according to the patient-specific contact history which provided by our automatic tracing system.

Keywords**—**Active Radio Frequency Identification, Intensive Care Unit, Nosocomial Infections

I. Introduction

WHO defined that Nosocomial Infections (NI) are infections acquired during hospital cares which are not present or incubating at admission [1]. How to reduce NI and guard the patient safety is the primary goal of medical communities around the world [2] [3]. Medical Providers re-examine the effectiveness and integrity of infection control, and seek useful strategies to complement shortages of traditional methods. There are many factors resulted in Intensive care units (ICU) with highest density of NI in hospitals such as patients with poor immunity, catheter-related infections, invasive treatment, and health caregivers treatments and care patients by contact activities…etc [4]. Hand hygiene has been proven to reduce cross infections from health care workers to patients [5]. The traditional method of trace NI is microbiological laboratory tests and retrospective medical records. Medical records only recorded invasive treatments and routines, but could not record all contact history between health caregivers and patients. Proximity sensing technology can help in capturing and keeping tack on all of the continuity of proximity between patients-specific history and caregivers. Active RFID technology has the features of proximity sensing and person identification [6] [7]; therefore this study can utilize it to trace and active surveillance the patient-specific contact history with caregivers in order to facilitate NI control.

This paper observed health caregivers care patients activities in ICU and definite care activities divided into clinical events: close-in events, contact events, and invasive events and then simulated these activities in Clinical Skill Center and tried to establish CHIM by variables such as length of time, frequency, and number of caregivers-specific. The experiments of this study made three recorders recordings as gold standards compare with CHIM. The results indicated that the sensitivities and specificities were up to 78% to 93%.The evidence indicated the CHIM could infer not only close-in events but also contact events.

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II. Methods

A. Research design

This study consisted of two phases which were designed as follows:

Phase1: This study conducted a CHIM (Contact History Inferential Model). The model could infer the contact history between caregivers and patient-specific.

Phase2: To verify the CHIM, we compared three observers' recordings events as gold standards with the CHIM to compute sensitivity, and specificity to determine the best Cut-off value.

B. System design

The Active RFID system includes the front part, namely, the Active RFID tags and the readers installed in Clinical Skill Center. The middleware of the system can gather the relative information from the front part and store in database.

The system structure of the Active RFID system consists of three parts which is discussed as follows:

1) The 125 kHz Active RFID tag.
2) A RFID reader deployed in Clinical Skill Center.
3) The Application Server, (including RFID middleware), which handles the RFID events, carrying out the extraction

and summary of data.

C. Environment settings

The Active RFID system had a 125 kHz reader that forces tags to transmit in its proximity. An active tag could broadcast within 1.75meters. A RFID reader was adhered to wall above one meter away from a hospital bed without reflecting obstacles nearby in Clinical Skill Center. Caregivers wore the 125 kHz Active RFID tag.

III. Pilot Study

A. Purpose

Based on caregivers care patients behaviors in MICU, The phase aims to test whether the CHIM (Contact History Inferential Model) could further estimate the contact events and invasive events or not.

B. Method

This study observed and inducted caregivers care patient-specific contact pattern in MICU and tried to analysis and definition caregivers care patients behaviors which were divided into three events as follows:

C. Definition of Events

- Close-in Events: Caregivers move close to patient' head plus leg within 1.75meters, and their hands do not touch patient.
- Contact Events: Caregivers' hands touch patient skin, excretion, or pipeline directly.
- Invasive Events: The destruction of normal skin or mucous membrane, or aseptic deep regional of body.

D. These Events were divided into three groups:

- Group1: The group includes close-in events, contact events and invasive events.
- Group2: The group includes contact events and invasive events.
- Group3: The group includes invasive events.

E. Research Steps

1) A Visiting Staff (VS) and an Registered Nurse (RN) wrote common care behaviors scripts (see TABLEI). Caregivers followed the scripts doing care activities according to they general do in MICU. Caregivers wore Active RFID tags. There were two nurses who had worked in MICU for two years and an Intern simulated the script to the CPR Annie in Clinical Skill Center. Meanwhile, there were three observers recorded these caregivers who approached and left RFID broadcast over distance of 1.75 meters, and according to definition of events to determine its close-in, contact or invasive events.

2) There were totally 40 events in the phase. An analysis who know the scripts established by VS compared observers record events with Active RFID system to established CHIM (Contact History Inferential Model)

TABLE I
THE ONE SIMULATE SCRIPT WHICH WAS DESIGNED FOR 4 HOURS BY VS

Care behaviors	Type of Events
1. Check Vital Sign	Close-in Event
2. Check body temperature with ThermoScan	Contact Event
3. Check heart sounds	Contact Event
4. Foley Catheterization	Invasive Event
5. Intravenous infusion	Invasive Event
6. Abdominal ultrasound	Contact Event
7. Central Venous Catheterization	Invasive Event
8. X-ray	Contact Event
9. Check vital sign	Close-in Event
10.Check body weight	Contact Event
11.Change position and percussion	Contact Event
12.Suction	Invasive Event
13.Arterial Catheterization	Invasive Event
14.Check vital sign	Close-in Event
15.Endotracheal Intubation	Invasive Event
16.Double-Lumen Endotracheal Tube Placement	Invasive Event
17.X-ray	Contact Event
18.Change position and percussion	Contact Event
19.Suction	Invasive Event
20.Assess of amount and color of urine	Close-in Event
21.Change urine bag	Contact Event
22.Invasive of change dressings	Invasive Event
23.Insertion of Nasogastric Tube	Invasive Event
24.NG-feeding for food	Contact Event
25.Check Cuff Pressure	Close-in Event

F. Description of interpretation model

The author named several Registered Nurses (RNs) as RN1, RN2, and named Doctors as Dr1. For instance, Dr1 did an invasive event to a CPR Annie, and RN1 and RN2 assisted Dr1 with contact events (see Fugure1).The analysis were divided into two parts as follows:

- Analysis of individual caregiver: We searched system data for a tag which wore by Dr1 and Dr1 did an invasive event to CPR Annie. In the same way, we also searched system data for tags which wore by RN1 and RN2 and they did contact events to CPR Annie. Every tag is separated to analysis.
- Analysis of multiple caregivers do something-specific event: Dr1 did an invasive procedure and RN1 and RN2 did a contact events to Annie, we recorded as invasive event (the more serious event).

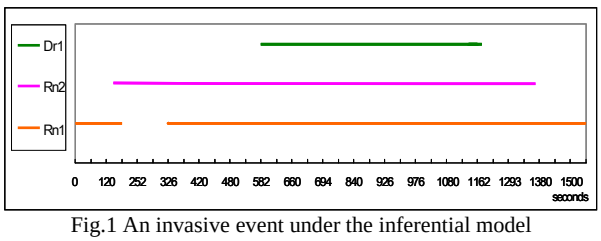

Fig.1 An invasive event under the inferential model

G. Recorder interpretation model

Three observers in this study observed care behaviors under the same circumstance at the same time. The overall reliability of 0.98 showed the three observers record data with high consistency.

The analysis of recorders record data were divided into two parts as follows:

- Analysis of multiple caregivers do something-specific event: For instance, Dr1 did an invasion event to Annie and RN1 and RN2 assisted Dr1 with contact or close-in events to Annie. Meanwhile, there were three observers observe three caregivers. As soon as caregivers left the Active RFID tags broadcast distance, the observers recorded time and determined its an invasion event (the more serious event).If caregivers closed and left tags broadcast distance several times to complete the event ,observers definite an event.
- Analysis of individual caregiver: According to the three observers recorded records, we analyzed individual caregiver behavior.

H. Result

This phase established a CHIM (Contact History Inferential Model) of Analysis of multiple caregivers do something-specific event (see TABLE II) and analysis of individual caregiver (see TABLE III).The cut-off value to determine close-in events and contact events is 21seconds (see Figure2).

After inducted the contact patterns and according to the RFID signals, we conducted a CHIM. The model could infer the contact history between caregivers and patient-specific.

TABLE II
CONTACT HISTORY INFERENTIAL MODEL OF ANALYSIS OF CAREGIVERS TOGETHER DO SOMETHING-SPECIFIC EVENT

Rule	Inferential Model
1. An RN tag or a Dr tag closes to bed less than 21s.	Close-in
2. An RN tag or two RNs tags close to bed more than 21s.	Contact
3. A Dr tag close to bed more than 21s.	Invasive
4. A Dr tag and one to two RNs tags close to bed.	Invasive
5. Tags interrupted signal less than 10s.	Ignore

S: seconds RN: Registered Nurse Dr: Doctor

TABLE III
CONTACT HISTORY INFERENTIAL MODEL OF ANALYSIS OF INDIVIDUAL CAREGIVER

Rule	Inferential Model
1. An RN tag or a Dr tag closes to bed less than 21s.	Close-in
2. An RN tag close to bed more than 21s.	Contact
3. A Dr tag close to bed more than 21s.	Invasive
4. A tag interrupted signal less than 7s.	Ignore

S: seconds RN: Registered Nurse Dr: Doctor

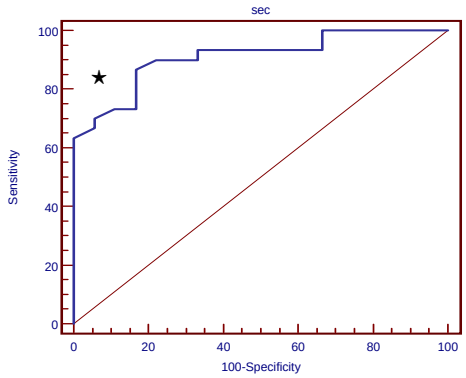

Fig.2 The ROC curves to determine close-in events and contact events. The cut-off value of determine close-in events and contact events is 21seconds, and sensitivity is 86.7 and Specificity is 83.3

IV. Main Study

A. Purpose

To verify the CHIM, we made three observers recordings as gold standards compare with the CHIM to compute accuracy, sensitivities, and specificity to determine the best cut-off value.

B. Method

The third trial were totally 60 events that an analyst who did not know the script established by VS compared three observers recordings as gold standard with CHIM to determine close-in events, contact events and invasive events

The analysis of events illustrated as follows (See Figure3):

- There is an overlap event between gold standard and CHIM; we interpreted the event as TP (True Positive).
- There is no overlap event between gold standard and CHIM; we interpreted the event as TN (True Negative).
- If the event was not recorded by recorders, it was recorded by CHIM. We interpreted the event as FP (False Positive).On the Contrary, we interpreted the event as FN(False Negative)
- If gold standard recorded an event, CHIM interpreted two events. There are overlap events between gold standard and CHIM; we interpreted the event as a TP and a FN.

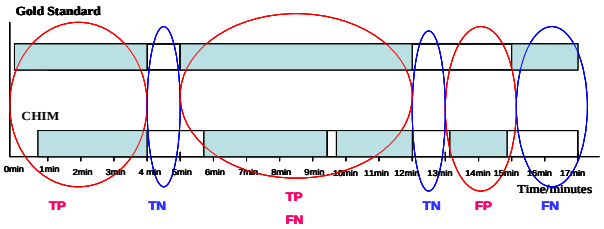

Fig. 3 Gold Standard vs. CHIM

C. Result

- Analysis of multiple caregivers do something-specific event

There are 12 close-in events, 38 contact events, and 10 invasive events.

TABLE IV
THE SENSITIVITIES AND SPECIFICITIES IN ANALYSIS OF MULTIPLE CAREGIVERS DO SOMETHING-SPECIFIC EVENT

Type of Group	Sensitivity	Specificity	numbers
Group 1	0.83	0.93	N=60
Group 2	0.78	0.87	N=48
Group 3	0.68	0.76	N=10

- Analysis of individual caregiver

TABLE V
THE SENSITIVITIES AND SPECIFICITIES OF ANALYSIS RN1

Type of Group	Sensitivity	Specificity
Group 1	0.70	0.93
Group 2	0.71	0.90
Group 3	0	1

TABLE VI
THE SENSITIVITIES AND SPECIFICITIES OF ANALYSIS RN2

Type of Level	Sensitivity	Specificity
Group 1	0.74	0.93
Group 2	0.58	0.91
Group 3	0	1

TABLE VII
THE SENSITIVITIES AND SPECIFICITIES OF ANALYSIS DR1

Type of Group	Sensitivity	Specificity
Group 1	0.73	0.88
Group 2	0.66	0.90
Group 3	0.78	0.76

The result showed that sensitivity and specificity of analysis of multiple caregivers do something-specific event were higher than analysis of individual caregiver (TABLEIV-VII).The analysis of individual caregiver method interpreted lower sensitivity and specificity resulted from tags interfered with each other. The sensitivity and specificity of group1 and group2 of Analysis of multiple caregivers do something-specific event were up to 78% to 93%.The evidence indicated the CHIM could infer not only close-in events but also contact events.

V. Discussion

Active RFID tag interferes with each other tags, if more than one caregiver who wears tags takes care of a patient, signal transmissions will stop few seconds. This constraint could be modified by rules.

Three health caregivers in accordance with normal work habits and behaviors, but not every person care with the same model, the model rules can be adjusted in the different circumstances.

The variances of the length of time and particular numbers of health caregivers establish the interpretation of patterns, there are still shortcomings, such as ultrasound is a nurse and a physician or a physician operation, it is easy to judge this event as intensive events; one to two nurses do Foley Catheterization to female patients easy to misjudge the invasive to contact events. There is a nurse doing suction to a patient, and it is easy to misjudge the invasive event to contact events. This is why the lower sensitivity and specificity of invasive events.

VI. Conclusion

Active RFID timely records the all contact events with proximity sensing, this study establish a CHIM to estimate health caregivers and validate CHIM. This study tried to provide a way distinguishing the use of interpretation of the rules for infection control. They will be able to have easy access patient-specific and caregiver-specific contact history. It is difficult to obtain complete contact records by traditional method of retrospective analysis of medical records. By this method would help infection control to access new discoveries in hospitals. In the future, it can be provided to establish risk model of Nosocomial infections by using automatic detection and risk profiling.

Wireless technology offers ubiquitous computing, u-computing service in hospitals. The providers and healthcare workers expect to provide higher quality of health care, effective, and flexible to achieve their goal by using information technology in the future.

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