Adopting RFID for Body Parts Tagging: a Local Association Network Approach

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***Abstract*—adopting an innovative technology often requires extensive intelligence research. A major value indicator for RFID Technology adoption is how the potentials of RFID can translate into actions to improve business operational efficiency [1]. This paper presents a Local Association Network (LAN) approach to developing RFID enabled visibility systems for body tagging. On site testing validates the proposed approach. User feedback strengthens our belief that the proposed approach would help facilitate RFID technology adoption in body tagging.**

I. Introduction

RFID as a promising technology to revolutionize the things to be identified and managed, has shown great potentials and has demonstrated good competitiveness in improving visibility on things or items to be managed. The identification power of RFID has been observed from tagging the Internet of Things to human bodies. Possible use of RFID to tag body parts donated to science was already discussed in 2005 [2]. To combat theft of donated body parts, RFID was considered to put in cadavers that can then be read by a handheld device. The U.S. Disaster Mortuary Operational Response Team (DMORT) and health officials in Mississippi's Harrison County were reported to implant human cadavers with RFID chips to help identify victims of Hurricane Katrina. [3]. In Louisiana, it is also expected to begin using the RFID systems to help officials cope with the estimated 500 unidentified bodies in that state [4].

In Hong Kong, there is an increasing interest in tagging human body to help manage the body or body parts either in a hospital or a mortuary. University medical school laboratories are also looking into this potential technology to help track and manage their laboratory body part assets in their everyday operation trainings. Is RFID a feasible candidate in such environment? How shall RFID technology be deployed in such environment? In [1], a key value indicators approach is proposed for performing value analysis in RFID adoption. The key value indicators serve as value metrics to evaluate perceived value from different adoption parties. The key value indicators for RFID technology adoption in body tagging would then relate to metrics indicating its value whether the body parts visibility can translate into actions to improve laboratory operation efficiency and to reduce cost. While the value promised by the RFID technology is eminent, the adoption level very much counts on the perceived value by the potential adoption parties – the labs, hospital, and many others [1].

There are a number of challenges in the value perceived by various stakeholders regarding operational efficiency in respect of body parts visibility, including:

- Functions of medical school training operations are highly fragmented, associating with a very large number of individual training laboratories. Very often they have their own training operation processes. The proliferation of diversified operation processes, if overlooked, makes it difficult for operational efficiency evaluation for RFID adoption in body part tagging.
- There is a lack of quality and consistent information on laboratory training operations (especially from RFID technology experts and laboratory management), leading barriers for setting focus on tackling body parts visibility. This makes it hard to identify how efficient of training operations. This makes it difficult to establish trends, make comparisons and manage cost with respect of RFID adoption in body part tagging.
- Limited information and mechanisms are available for reviewing training operational effectiveness. This would lead to limited adoption scrutiny and cross-checking for operational efficiency and costs savings with respect of RFID adoption in body parts tagging.
- There is a lack of procedures and methodologies in adopting RFID in body part tagging in medical school operation training laboratories, putting cost penalty for the lack of information visibility of body parts. This would result in great barriers in providing greater responsiveness in the provision of laboratory operation training services.

Thus, in this paper, we would tackle the challenges by forming a collaborative team with domain experts related to this RFID adoption in body part tagging, including RFID engineers, medical academics and professionals, and laboratory management teams. A local association network (LAN) approach is adopted to provide a cost effective means to deploy RFID in such a laboratory environment. This LAN

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approach can be generalized for other deployment environment including hospitals or mortuaries.

Organization of this paper is as follows. Section 2 presents the RFID value proposition analysis, conducted through an inquiry into the understanding of end users' expectations. Section 3 is the LAN based approach for adopting RFID in body part tagging. In Section 4, a prototype and solution deployment is described. Section 5 presents the solution validation processes and tests conducted. In Section 6, evaluation of the deployed solution is conducted with users' feedback. Section 7 concludes the paper.

II. Perceived Value Analysis

First step of this LAN approach is to identify the concerns and value of adopting RFID in body tagging by medical professionals and laboratory management. The value proposition comes from the inquiry into understanding of such end user's expectation and concerns.

1) What is normal practice?

The normal practice in taking records of human cadavers and body parts is to physically use a patient tag assigned with the corresponding inventory number. However, these plastic tags have the following disadvantages namely: 1) limited amount of space to input adequate patient information; 2) tags are easily destroyed and subject to lost of information; 3) difficult to track down the location and movements of body parts in particular.

2) Are there any measures for good practices?

The measures put in place to ensure that accurate information of the human cadavers' body parts are kept properly are: 1) input of the inventory number with photographs of the human cadavers and body parts ; 2) input of additional information such as the causes of death, source, status of the endpoint whether the human cadavers need to be returned as a whole or be cremated for collection of the relatives or not and any special signs of the any parts of the body ; 3) Input to where the human cadavers or body parts are kept in the laboratory; and 4) regular check of the inventory at least once a year for accuracy and replacement of deteriorated tags,

3) Are there any pain points?

There are some serious problems with the existing system such as labor intensive in implementing the measures for good practices since the amount of human cadavers and body parts are increasing on the yearly basis. In spite of these investment, there are occasions where inaccuracy of the labeling the body parts and difficulty in tracking the movements of human body parts after being used. The other important issue is the security of the body parts after they are being used for teaching or display.

4) Are you aware of any help envisioned by adopting RFID?

The RFID will definitely solve a major part of the problems mentioned in no.3. RFID can also handle large volume of information with accuracy and NOT increase the cost of human resources. RFID will also increase the degree of the security in the mortuary and laboratory.

III. LAN based approach

In a laboratory environment, operation automation and efficiency improvement demands good position sensing technologies to track and manage body and parts. Like any technology or solutions, their adoption is very often under scrutinized with performance consideration for trade offs balancing out the cost reduction and operational efficiency. Performance consideration is one of the key performance indicators for RFID and other technology adoption exercises. Cost reduction often leads to a "line of sight" RFID implementation. That is, when you see, you can then approach and read. This would often lead to missing items difficult to locate when they are misplaced. Further, body parts and other laboratory items could be placed around any area in a laboratory. They can be moved and replaced as well. In order to track all the items where they could reach in such an environment, area of coverage becomes a concern, which is directly linked with network deployment cost. The needed area coverage and positioning accuracy for laboratory operation automation often comes with a corresponding level of expenditure for positioning network and RFID technology deployment to cover the laboratory premise.

A. Local association network

Thus, we adopt the Local Association Network (LAN) approach developed in E-Business Technology Institute, the University of Hong Kong to develop cost effective technologies and solutions for body parts tagging to facilitate laboratory automation, improve operational efficiency and help cost reduction. In this LAN approach, the tracking accuracy delivery could be further optimized by balancing the cost considerations and often expected operational efficiency.

We tackle the line of sight vs. cost/performance barrier mentioned earlier by establishing a Local Association Network (LAN) for tracking the body parts and laboratory items. The LAN, which covers a small area within the line of sight, would greatly reduce the tracking cost by requiring much cheaper technologies which can function reliably by sensing items in this line of sight or short range coverage area. Further, an association based tracking method will be adopted for recording pickup and drop-off during item movement in the laboratory, registering whereabouts by reference with the placing tool's position, by which the body parts are placed or carried. This association based tracking method will promise a good visibility on those body parts, together with their association with laboratory operation training processes and management systems. The LAN could also employ multi-sensing capabilities, leveraging technologies including RFID, Wi Fi, and other positioning method for establishing the associations.

B. Body part tracking

Operation counters or tables would act as placing tools where body parts are placed or by which body parts are carried. They will form a local association network. With these tools, association based tracking method will be able to locate a body part through the placing tools. That is, by tracking the placing tools, positions of the body parts placed on or carried by the tool will be known. The following is the association based tracking for such position sensing of body parts.

- The LAN would be able to identify the placing tool by the ID in the RFID tag.
- The LAN then associates the tag with the RFID reader in the LAN.
- The RFID reader will be able to read all the body parts with RFID tags placed or carried.
- The LAN then will associate the placing tool with those RFID tagged body parts placed or carried.
- The LAN then can calculate the placing tool's position leveraging available positioning infrastructure, e.g. provided by RFID.
- The position information will then be applied to all those items placed or carried.

When a body part is put into the placing tool, an association action will be detected. The position of the placing tool will be calculated to record the position where the body part is put into the placing tool. Then the position of the body part will now be associated with the placing tool. When a body part is removed, a disassociation action will be detected. The position of the body part now is taken out and disassociated from the placing tool. The position of the Placing tool will then be calculated to record the position where the body part is removed. This position will be used to update where the body part is being placed thus the whereabouts of the body part is known.

C. *Proposed solution framework*

The solution for adopting RFID in body part tagging in laboratory environment is constructed with a LAN. Multiple LANs can then be integrated to form a whole solution for body part tracking in a laboratory environment. Thus the solution would have three components:

- The LAN
- The LAN integration
- LANs visibility

The LAN would be basic unit for providing positions of body parts. When RFID is used for the positioning purpose, a positioning Grid [9] would be set up for the LANs. The LAN integration will then link up all the LANs in a laboratory to form a complete laboratory body part tracking and management network. A mobile asset tracking method [7] is adopted in the LAN integration. In an RFID only environment, a mobile handheld can also be utilized to track those parts on the move. A signing up and off protocol is also developed for tracking those body parts being transferred from one LAN to another based on delay tolerant routing mechanisms [7]. Interferences among different LANs are resolved via data processing and in a collision avoidance manner [6, 8, 10]. The LAN visibility will then link the body part visibility with laboratory operation processes and management systems.

IV. SOLUTION PROTOTYPING AND DEPLOYMENT

A prototype of the solution is developed and deployed. The following is the figure (Figure 1) which shows a typical operation training environment in a medical laboratory.

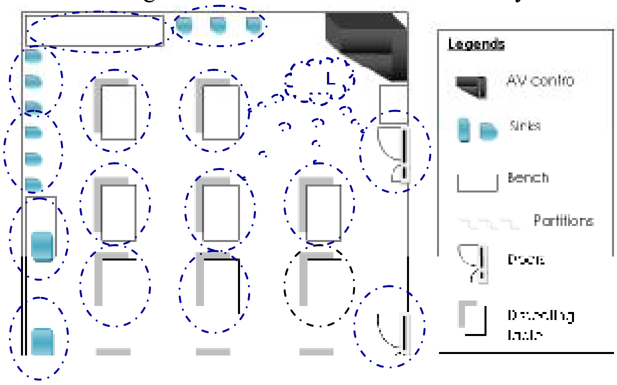

Fig. 1. Dissecting room layout

Figure 1 also shows a typical dissecting room layout (a partial drawing, 8m*35m) with LAN setup. The main checking zones are the dissecting tables, doors, sinks and benches. Each checking zone could form a LAN. Different LANs integrated would form another larger local laboratory LAN. The LAN is also able to set up as a mobile LAN. That is, a LAN can be moved to RF scan another checking zone.

The body parts, RFID tagged, will be read by the LAN, establishing the belonging association relationships with the LAN. The LAN will also form an association with the trainee according to the operation training schedule. Those associations are kept and managed by the LAN visibility module, integrated with the laboratory management systems.

V. SOLUTION VALIDATION

Our proposed solution is validated on site in the laboratory of the Department of Anatomy, LKS Faculty of Medicine, The University of Hong Kong. Areas of concerns for establishing the associations in a LAN are the following:

- Body part to tag. The part of the body to tag would affect the solution performance.
- Orientation. This orientation includes the body parts and the RFID reader.
- Distance. To construct a LAN, effective reading distance is a key performance indicator.
- Room environment. The room environment for operation and for storage will have impact upon the solution performance.

A. *Available validation scenarios*

Thus, the validation scenarios can be described as a combination of possible factors affecting the test result that is of interest to us. As the test objective is to see how RFID tag can help us to track bodies or body parts in the working environment, we mainly want to measure how well the RFID performs in reading RFID tags under different environmental conditions. As such, the factors, derived from the area of concerns, are:

- RFID reader and antenna
- RFID tag, model of chip used, packaging material
- Room temperature and humidity
- Position and orientation of RFID antenna
- Part of body tagged.
- Position and orientation of RFID tag relative to the dead body and the metal tray
- Room environment, including neighboring metal door, metal cabinet door, concrete wall, etc.
- Distance between RFID tag and antenna
- Storage condition of bodies

B. *Validation planning*

The validation is planned with the following factors being considered.

1) RFID reader and antenna

We tested EPC Class 1 Gen 2 RFID tags using compatible readers and antennae. The following equipments are used.

- One model of handheld reader (Psion Teklogix WorkaboutPro)
- One model of fixed reader and antenna (CSL CS461)

2) RFID tag

Tags from one brand are tested (Avery Dennison AD-826). The tag has been packaged in a special format to allow it to attach to either the wrist or ankle of the body and stay in an almost upright position. This allowed us to easily test different orientation on dead bodies, and also allow us to somehow stay away from the metal tray below the body.

3) Room temperature and humidity

As room temperature and humidity of the validation lab is controlled. We only tested one set up based on actual lab environment. These are recorded as environmental factor.

4) Position and orientation of RFID antenna

The orientation is facing the metal tray, firing RF signal horizontally from around 1 m above ground.

5) Part of body tagged.

We plan to test body neck, wrist and ankle.

6) Position and orientation of RFID tag relative to the dead body and the metal tray

We plan to test the following:

- Tag above body (about 10cm separation from metal tray, edge of tag touching the body, tag parallel to antenna plane)
- Similar to a, with tag laying down, forming an angle greater than 70 degree (estimated) from the antenna plane.
- Tag lying on metal tray.
- Tag with one edge touching metal tray.

7) Room environment, including neighboring metal door, metal cabinet door, concrete wall, etc.

We avoided facing squarely on a large metal surface, such as metal door of the cabinets and freezers. The path between antenna and the dead body were not obstructed. There is either a concrete wall or at least 2 meter of free space on the other side of the body. Due to difficulty in moving dead bodies around and setting up different room environment, only normal room environment would be tested.

8) Distance between RFID tag and antenna

The distance is adjusted on the fly to capture the maximum reading distance in each test case.

9) Storage condition of bodies

We tested bodies stored in 4 degree Celsius and -25 degree Celsius.

C. *Validation to carry out*

The following factors are decided to carry out the solution validation.

1) RFID reader and antenna

The RFID reader and tag chosen represent typical EPC RFID implementation.

2) RFID tag

The special tag packaging allows us to test the RFID tag in simulated working condition when attached to dead bodies. Metal tags are considered but was not made available during the validation period.

3) Room temperature and humidity

As we want to perform test in actual working environment, we are not allowed to adjust the temperature and humidity of the validation area. Although only one parameter is available, this represents common working condition of similar institutions.

4) Position and orientation of RFID antenna

The tested orientation is typical of real life installation. However, installation of reader under the ceiling, facing directly downward; and also at about 2 meters above ground level, facing downward at an angle; are also considered. These orientations were not tested due to difficulty in setting up the antenna in the lab of the department.

5) Part of body tagged.

The three body parts are the positions of our interest, where tag can be secured attached and easily reached by fixed and mobile reader.

6) Position and orientation of RFID tag relative to the dead body and the metal tray

The tag position was adjusted by hand to represent different ways the tag ends up after the dead body is moved in and out of the cabinet for some time.

7) Room environment, including neighboring metal door, metal cabinet door, concrete wall, etc.

We were limited to the set up of the room where validation was conducted.

8) Distance between RFID tag and antenna

The distance recorded represents the longest reading distance. It also represents how good the tag was detected by the fixed readers in real life operation and shows the feasibility of using the tag in each case.

9) Storage condition of bodies

The two tested conditions are typical of storage conditions of similar institutes, such as public mortuary.

D. *Validation results*

The validation result is shown in the following table. Number equations consecutively with equation numbers in parentheses flush with the right margin, as in (1).

Body	Tag age (day) **	Body temp (℃)	Body part where tag attached	Tag position and orientation *	Reader	Distance (cm)
08-16	0	4	Neck	3	Fixed	180
08-16	0	4	Wrist	1	Fixed	190
08-16	0	4	Wrist	1	Handheld	70
08-16	0	4	Wrist	2	Fixed	180
08-16	0	4	Wrist	2	Handheld	12
08-16	0	4	Ankle	1	Fixed	116
08-16	0	4	Ankle	1	Handheld	50
08-16	0	4	Ankle	4	Fixed	60
X	0	20	Wrist	1	Fixed	250
X	0	20	Wrist	1	Handheld	100
X	0	20	Wrist	5	Fixed	80
X	0	20	Wrist	5	Handheld	40
09-37	0	-25	Neck	1	Fixed	240
09-37	0	-25	Neck	1	Handheld	50
09-37	0	-25	Neck	2	Fixed	200
09-37	0	-25	Neck	2	Handheld	20
09-37	0	-25	Wrist	1	Fixed	200
09-37	0	-25	Wrist	1	Handheld	80
09-37	0	-25	Wrist	2	Fixed	140
09-37	0	-25	Wrist	2	Handheld	20
09-37	0	-25	Ankle	1	Fixed	200
09-37	0	-25	Ankle	1	Handheld	10
09-37	0	-25	Ankle	2	Fixed	120
09-37	0	-25	Ankle	2	Handheld	20
08-16	11	4	Neck	3	Fixed	170
08-16	11	4	Neck	3	Handheld	30
08-16	11	4	Wrist	1	Fixed	170
08-16	11	4	Wrist	1	Handheld	40
08-16	11	4	Wrist	6	Fixed	No signal
08-16	11	4	Wrist	7	Fixed	No signal
08-16	11	4	Ankle	2	Fixed	170
08-16	11	4	Ankle	2	Fixed	40
X	11	-25	Wrist	5	Fixed	200
X	11	-25	Wrist	5	Handheld	40
09-37	11	-25	Neck	2	Fixed	200
09-37	11	-25	Neck	2	Handheld	30
09-37	11	-25	Wrist	2	Fixed	200
09-37	11	-25	Wrist	2	Handheld	30
09-37	11	-25	Ankle	1	Fixed	200
09-37	11	-25	Ankle	1	Handheld	30

* Tag position on and orientation

1. upright, parallel to antenna
2. lay down, not parallel to antenna
3. lay down, with space between tag and chest
4. lay down, touching metal tray (which is covered by plastic body bag)
5. between wrist and trunk, not touching tray, almost parallel to antenna
6. reading tag on opposite limb (antenna on right hand side of body trying to read tag on left hand)
7. tag lying down on metal tray

** Tag age

- *number of days after tagging of body*

VI. Solution Evaluation

While the solution is validated by performing on site testing, user feedback on validation results of the proposed solution is also used for evaluating the solution. We have asked the following questions requiring users to respond.

A. *Are we focusing on the right problems to solve?*

We are focusing on the right problems. The main factor that contributed to the reading performance difference is the position and orientation of the tags. Tags generally perform poorly when putting near to or touching a metal surface, or when touching the dead body, especially on the chest. Test results show what is possible and what is not in actual usage of the technology in mortuary operation environment.

B. Are we able to plan the test smoothly?

As validation was done in an actual operation environment, the environmental parameters that we can adjust are very limited. It is also hard to control test parameters to repeat same test cases. For example, tag orientation and position cannot be prepared and recorded at a very high accuracy as if it was performed in a lab. On the other hand, the data that we collected represents what is happening in typical working environment where dead body is stored and processed.

C. Does the solution validation deliver good results?

The test result is very good. It shows where and when the technology works and also shows its limitation under certain conditions.

D. Are there any experiences to learn?

We understand more about the amount of detuning effect when the RFID tag is placed near the human body and the metal tray.

Things that we wished to perform in subsequent tests will be to test the tag and reader in real life situations where the dead body is moved in and out of the chamber multiple times, and measure the reading performance for a longer period and for more reading events. We would also like to test whether more expensive metal RFID tags can alleviate the difficulty of reading the attached tag in the awkward positions, such as when the tag is put between the body and the tray.

As automatic reading is not always possible, due to the high variation of reading performance of tag position and orientation, other measures, such as tag packaging design and operational procedure design may also help to adopt the technology to actual mortuary operation. Nevertheless, the automatic data capture capability of RFID is found to be a suitable technology to be deployed to help tracking dead bodies in laboratories, hospitals and mortuaries.

VII. Conclusion

In this paper, we study the feasibility of body tagging in a local laboratory in Hong Kong. A solution is proposed based on a Local Association Network (LAN) to develop the laboratory visibility system and tools to facilitate automation and operation efficiency improvement by tagging the body parts. The solution, prototyped through RFID only enabled system and tools, is validated via on site testing. Results from the validation show that the proposed approach and solution are feasible, supported by a number of available RFID readers and tags in the market.

Current ongoing work is focused on two fronts: 1) the change management in laboratory automation, process improvement by introducing the proposed solution for body tagging, and 2) testing of the data processing techniques for data filtering in a dense RFID or sensor deployment environment [8, 10]. Real time tracking under Wi-Fi and other wireless infrastructure (e.g. ZigBee, UWB) will also be tested and validated on a site implementation. Focus will then be on deployment efficiency/convenience and cost/performance considerations.

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