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Introducing RFID technology in dynamic and time-critical medical settings: Requirements and challenges

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ABSTRACT

We describe the process of introducing RFID technology in the trauma bay of a trauma center to support fast-paced and complex teamwork during resuscitation. We analyzed trauma resuscitation tasks, photographs of medical tools, and videos of simulated resuscitations to gain insight into resuscitation tasks, work practices and procedures. Based on these data, we discuss strategies for placing RFID tags on medical tools and for placing antennas in the environment for optimal tracking and activity recognition. Results from our preliminary RFID deployment in the trauma bay show the feasibility of our approach for tracking tools and for recognizing trauma team activities. We conclude by discussing implications for and challenges to introducing RFID technology in other similar settings characterized by dynamic and collocated collaboration.

1. Introduction

Recent technological advances in the areas of activity, voice, gesture and emotion detection and recognition have opened up new avenues for improving safety and quality of patient care. Among these, radio-frequency identification (RFID) technology is most promising given its unobtrusiveness and relatively easy integration into the healthcare systems. RFID technology also offers several advantages over the existing identification systems. Compared to the widely used barcode system, RFID does not require focused passing of objects over scanners, which minimizes human intervention and interference with task performance. It also enables faster and simultaneous scanning of multiple items, longer read range, and does not require line-of-sight (i.e., radio signal is detectable without direct visibility) [1]. RFID technology is currently used for patient and medical personnel tracking [2,3], resources tracking for rapid use of medical devices [4], and medications tracking for preventing errors and counterfeiting [5]. Although the total cost of adopting RFID in healthcare is still significant, the cost of RFID tags and antennas has been decreasing over the past several years, opening opportunities for broader application [6].

Despite its growing use in healthcare [3,7], RFID technology has not yet been evaluated in time- and safety–critical medical settings, such as trauma resuscitation. The fast-paced, high-risk environment of trauma resuscitation is a challenging domain for introducing RFID technology for several reasons. First, resuscitation rooms are crowded, with many people moving around, causing interference for radio signals. Second, the number of objects—medical tools, supplies and equipment—that needs to be tagged is on the order of 50, requiring many RFID tags, which in turn reduces detecting capacity of tag readers due to longer read cycles and higher probability of collisions. Third, while in use, RFID tags may be covered by providers' hands, which blocks radio signals from tags. Fourth, medical tools are made of different materials and some supplies contain fluids, which may have adverse effects on the radio signal. Finally, some objects come in plastic wrapping and can be tagged only externally; once the wrapping is removed, tracking of the object stops. Initial attempts to deploy information systems to aid trauma teams have been promising, but have shown limited usability [8–10]. The lack of success is due to the challenges of manually entering data from diverse sources in a dynamic environment, the difficulty of synthesizing output and recommendations, and resistance to technology that offered no major improvement.

Our long-term research goal is to develop a context-aware system to provide computerized support for real-time decision making during fast-paced and complex medical events. We envision such system as a combination of different approaches and

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technologies—RFID, digital pen technology, computer vision, and other sensors—that will aid in capturing critical patient information from the environment and be used at different levels of activity recognition to support real-time decision making. For example, information collected and synthesized for a task such as patient intubation could provide feedback to decision makers about the exact timing of the intervention, the time it took to intervene, and if the intervention was done correctly. Alternatively, the system could track the use of different instruments during patient care and provide real-time information about the start and completion of particular tasks (e.g., use of thermometer indicates measurement of patient temperature).

In this paper, we use trauma resuscitation as an example domain and describe the process of deriving design requirements for one component of our future context-aware system, namely, the system for tracking trauma team activities using minimally intrusive RFID technology. Although we recognize the benefits of using several types of sensors simultaneously (accuracy of detecting and recognizing an activity increases with simultaneous use of several technologies), we chose an incremental design approach by which we study system components in isolation to gain the necessary knowledge about design requirements for each component. This incremental approach is also helpful in learning about the effectiveness of individual technologies in capturing, tracking or detecting team activities. To derive design requirements for our RFID system component, we performed an analysis of team activities during simulation in a level 1 (highest) trauma center over the course of 2 years.

The goals of the current research were threefold. First, we studied domain tasks and procedures to identify activities and objects that require tracking. Second, we used the results from tasks and procedures analysis, and from laboratory experiments to find the optimal placement for RFID antennas and tags in the environment. Third, we developed guidelines for interpreting radio signals from tagged objects, i.e., whether an object is stationary, carried from one place to another, or in use. To deduce team activities based on radio signals, we analyzed work practices and providers' interactions with objects. Our description of the requirements gathering process and preliminary results from RFID technology deployment offer valuable insight into challenges to introducing RFID technology in dynamic work environments.

The contributions of this paper are:

- Identification of tasks and objects that require tracking for real-time support of decision making during fast-paced and complex medical activities, such as trauma resuscitation.
- Strategies for placing RFID tags and antennas in the environment for optimal tracking and activity recognition.
- Guidelines for interpreting radio signals from tagged objects for accurate task detection.
- Initial results from the system deployment at a trauma center during simulated resuscitations with trauma team members.
- Challenges to introducing RFID technology in time- and safety critical medical settings.

1.1. Context-aware systems and RFID technology in dynamic work settings

Prior research on context-aware systems has shown feasibility of using sensors for studying complex activities in dynamic work environments [5,11–21]. To detect and track objects or people, these systems have used different types of sensing technologies and approaches, including computer vision, accelerometers, ultra wide band (UWB) sensors, active RFID tags, passive RFID tags, keyword spotting and digital pen technology. Context-aware systems have the potential to support work of interdisciplinary medical teams in fast-paced and unpredictable medical domains, where context refers to the currently performed activity.

Trauma resuscitation tasks are dynamic activities and consist of many body movements (e.g., walking, bending down, raising arms, moving fingers) and manipulations (e.g., interactions with objects and patients). While simple activities, such as walking or raising arms can be recognized by body motion sensing through computer vision or body sensor networks [22], complex activities require high-level cues, including spoken words, body location, or objects in use [23]. Vankipuram et al. [13] and Kannampallil et al. [14] used active RFID tags to deduce coarse-grained activities of clinicians in a trauma unit, including their location and movement. Our research extends this prior work by exploring the use of passive RFID tags for detecting and interpreting finer-grained tasks, such as those performed on patients. We focus on analyzing the use of medical objects and tools rather than clinicians' location and movement patterns. Because objects are uniquely associated with different tasks, they can serve as reliable indicators for current tasks and team activities. For example, the use of manual blood pressure (BP) cuff implies that blood pressure is being measured.

High-level cues such as spoken words and objects in use have already been applied for tracking medical activities, including drip injection tasks [24], classification of surgery phases [12], and maintaining situation awareness during surgery [16]. To detect such activities, researchers have used wearable RFID readers or barcodes. Although these near-field technologies yield high accuracy in interaction detection, they require that providers remember to attach readers to their gowns or body parts—a requirement that may be highly intrusive in critical-care settings. Because our plan is to evaluate the feasibility of our approach through continuous experiments in the actual setting of the trauma bay, we needed to ensure that the placement of RFID tags and readers is minimally disruptive to team members' activities. To accomplish this goal, we used passive RFID technology.

1.1.1. Passive RFID: Advantages and disadvantages

Compared to active RFID tags and other sensing technologies, passive RFID technology offers several advantages, making it a suitable solution for highly dynamic and crowded medical settings. First, passive tags do not require special maintenance because they have their own energy source and operate without batteries; they receive energy from RFID readers and then use this energy to send signals back to the reader. Second, passive RFID tags are smaller, which makes them convenient for attaching to small medical objects and usable at the item level. They can also be used for disposable items such as intravenous catheters and tubes; using motion sensors or active RFID tags for disposable items is not feasible. Third, RFID data contains little or no personal information, making this technology an ideal solution for capturing information in medical settings. Although computer vision offers most of these advantages, its use is limited by privacy concerns as cameras provide a permanent visual record of people and their activities. Finally, passive RFID tags are cheaper compared to other tracking technologies, which is an important factor if the amount of objects that need tagging exceeds 100. Accurate detection of objects during resuscitation events often requires tagging more than 100 objects per resuscitation, showing the feasibility of using passive RFID tags.

Despite these advantages, long-range passive RFID technology has received limited attention in activity recognition community due to its performance limitations. Compared to active sensors with read range up to tens of meters, passive RFID tags have a much shorter read range, up to 4 m. Although a significant disadvantage for a hospital-wide tracking applications, this limitation