RFID, Wi-Fi, RTLS, medical applications,
clinical path visualization, quantitative data analysis,
time pattern analysis, increasing efficacy of healthcare

Shikha NAYYAR[1], Marina GAVRILOVA[1], Alecia GREENOUGH[1], William GHALI[1]

EXPLORATION OF SPATIAL-TEMPORAL PATTERNS IN HEALTHCARE IMPLEMENTATION OF RFID INDOOR NAVIGATION SYSTEM

The development of advanced spatial-positioning systems for medical monitoring and emergency response using RFID and Wi-Fi technologies is a current research focus of many healthcare organizations. The goal of such system is to support real-time location tracking of medical equipments and personnel in hospital settings using RTLS technology. This paper presents a spatial-temporal data analysis based on data collected at the W21C of Foothills Hospital, Calgary, Canada. The collected data, comprising real-time observations and tracking paths, has been used to perform advanced statistical pattern analysis and visualization of work-flow patterns in health care system. From this analysis, we bring forward some insights into medical resource, asset and facility utilization in a clinical care ward of a regional healthcare organization. This gained knowledge could be used as one of the inputs in improving patient care, responsiveness, and infection control practices.

1. INTRODUCTION

The development of biomedical devices supporting non-invasive medical monitoring is an active domain of research, with significant human health implications and exceptional technology transfer potential. One of the new areas of research in healthcare, which make use of such innovative devices, is Real-Time Location Systems (RTLS). This technology aims at integration of radio frequency identification (RFID) and Wi-Fi technologies into applied clinical care setting and exploration of the potential impact of location tracking system on safety and quality of care. In order to study effectiveness, utility and potentials of this technology, a prototype system has been setup at Foothills Hospital, Calgary [8].

Primary focus of this research paper is to present analysis and visualization of real-time observational and location measurements obtained by RTLS system. The data includes time and location observations of assets, equipment or clinical paths, collected in accordance with protocol for Ethical Review of Clinical Trials at W21C. This spatial-temporal data is used for subsequent data analysis and visualization, which assists in further exploration of capabilities of RTLS in healthcare. *The rest of paper is organized as follows. Section 2: Brief Overview of Background Literature, Section 3: Methodology, Section 4: Summary, Section 5: Bibliography.*

2. BACKGROUND LITERATURE

Location-based tracking is a new area of application and research in healthcare, addressing patient safety. Most location based tracking technologies to date focus on RFID, further with the emergence of Wi-Fi tracking technology (802.11 wireless standards) it has gained more momentum [9]. RTLS technology which uses active RFID tags and Wi-Fi has a capability to store both real-time and historical data for analysis and reporting purposes without any noticeable changes required in infrastructure [12]. Traditionally, location based tracking was primarily used for inventory management, planning and military operations, but later its utility was extended to various other domains, one of which is in healthcare [14, 15].

In healthcare it is used for “real-time identification of assets, such as infusion pumps or medicine carts and there are number of such successful examples [2, 15, 16]. However, the potential exists to apply Wi-Fi location-based tracking for improving quality and addressing patient safety [5, 1]. In some

[1] University of Calgary, 2500 University Drive NW, Calgary, AB, T2N 1N4, Canada.

instances, location-based tracking of human resources such as physicians and nurses can provide insight that could contribute to improving patient safety and quality of care [7]. Spatial-temporal data collected using these technologies can be further utilized to understand workflow of medical professionals and usability of high value medical assets [13]. The quantitative research methodology is shown to be an effective way to quantify observation and analysis outcomes in many different domains of research, one of which being healthcare [3].

3. METHODOLOGY

This section is divided into three sub-sections. First sub-section explains how technology was implemented in real time healthcare settings. Design of the clinical path visualization system is elaborated in the second sub-section. The last sub-section describes collection and processing of real time spatial temporal data.

RFID is a broad term representing a set of technologies that offer an automatic identification system to enable transfer of information through radio frequency system. RTLS technology, on the other hand, facilitates real time locating and tracking of mobile assets or resources. RTLS uses RFID to identify assets and algorithm to triangulate and determine the location of the asset based on the interaction between RFID tag and readers. Active tags are attached to mobile assets or resources for real time tracking. These tags are battery powered and auto-initiate data transmission with reader.

Typical commercial use of RFID (shown in Figure 1) involves an active RFID tag being adhered to an item. This tag is normally small in size. Exciters then read the tag to identify the item, without a direct line of site. Integration of RFID and Wi-Fi technologies allows the tags to be read from a Wi-Fi network, without the need for an intrusive separate network. Exciters are installed in the ward and their beacon rates are set to a very small interval. Spatial temporal data served two purposes - first to real time visualize mobile assets on the floor map and second to process this data for workflow analysis. Mobile assets were referred to as tags. No permanent connection was established between assigned tag number and mobile asset, making the entire process fully anonymous. Moreover, the same tag number could be assigned to different asset on a different date. All observations were conducted under ethics umbrella obtained prior to studies.

3.1. CLINICAL PATH VISUALIZATION

Clinical path visualization plays a significant role in understanding work patterns and resource utilization. In this context, we developed an innovative, interactive, path visualization system with added benefit of data analysis.

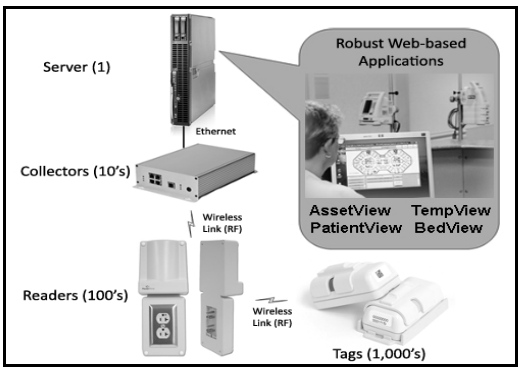

Fig. 1. Working process in RTLS [16].

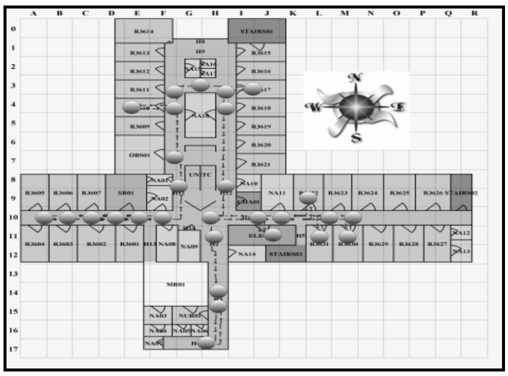

Fig. 2. Clinical path visualization system.

The goal behind development of this visual system has been to provide a convenient, easy to use interface that enables users to visualize clinical pathways, execute date/time filters, perform basic statistical functions and provide user customization options [8]. Figure 3 shows system interface.

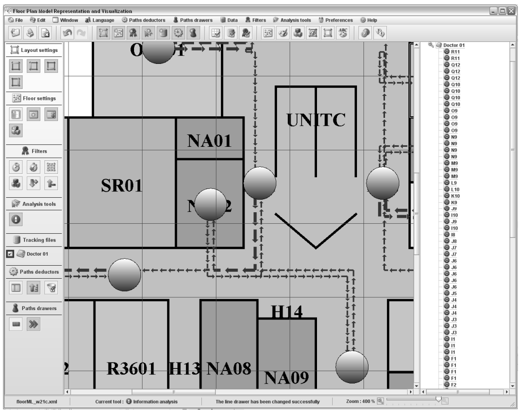

Fig. 3. Example of system interface.

3.2. DATA COLLECTION AND PROCESSING

Real time tracking of the tags and dynamics involved in health care environment lead to a large point location dataset. This dataset was further synchronized with reference to the coordinate system of the hospital floor plan, so that automatic allocation of room numbers and wing can be performed.

A robust database was needed for storage of spatial temporal information related to tag positions. Extensive data normalization and cleaning was required to improve the efficiency of the system. The software system also performed data analysis. It calculated frequency at given location, time spent by mobile asset in different facilities/wings and Euclidian distance traveled over given time frame.

3.3. QUANTITATIVE DATA ANALYSIS

This section provides an example of quantitative data analysis. Note that due to technical settings and existing infrastructure, the recorded location observations were imprecise for the same tag even when the tag was stationary. The recorded range was within 2 meter radius from the absolute tag location. This imprecision, fully discussed in the project report, does not allow exploring fully all the benefits of the prototype system. However, the goal of this paper is to report on potential uses of technology, if and when it becomes precise enough.

Below is the list of sample questions that potentially could be answered using subsequent data analysis:

- Are workflow patterns different among mobile assets?
- Do work patterns vary with time/day of week?
- Where was most of the time spent by resource?
- What is the distance traveled by each resource?
- How often was specific facility visited by resource?

3.3.1. STATISTICAL ANALYSIS

The analysis presented in this section is based on the subset of data related to tag spatio-temporal locations. For example, Figure 4 compares Euclidian distance traveled by two resources.

Subject	Euclidian Distance
Resource 02	206.18
Resource 01	1111.21

Fig. 4. Comparison of Euclidian distance.

Similar analysis can be used to visualize differences in workflow.

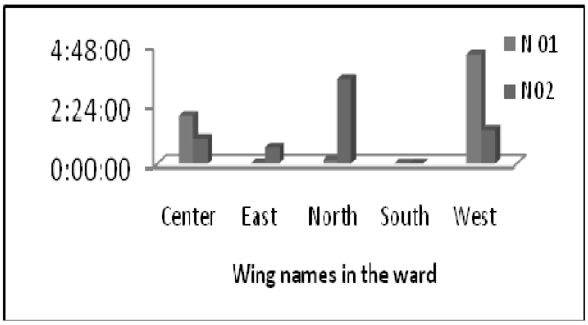

Fig. 5. Comparison of wing visit frequency by resources.

Statistical results presented above can be used to answer questions such as when, where and how much time resource spent in different facilities or wings of the ward which will differentiate work pattern. Figure 4 informs that two resources traveled significantly different distance. Figure 5 indicates most high traffic and least high traffic areas, which can be further used to improve ward space utilization or infection control practices (such as installing more hand washing stations in the high traffic areas).
Also, understanding reasons behind high use areas could be beneficial to further optimize resource utilization. Center wing is a highly used wing (Figure 5) because it is reception and most of the computer terminals for charting. In addition, questions based on workflow pattern can be answered, for example 1) Which wing is highly used; 2) Which roms are over/under utilized; 3) Comparison of work patterns in different wings. The similarity or difference between work patterns could be observed, which varies with job responsibilty or work flow pattern variation.
Another possible analysis is comparison of time spent and frequency of visits to different patient rooms, if this data becomes available. These and other question can be answered if precise technology for data collection becomes available.
Additional analysis can provide insights on weekly facility utilization. From figures 6 and 7 it can be inferred that Mondays and Fridays are the busiest days when resources travel considerably more distance in the ward as compared to other days of the week. Also, analysis of most frequently visited ward locations can be done from Figure 6.

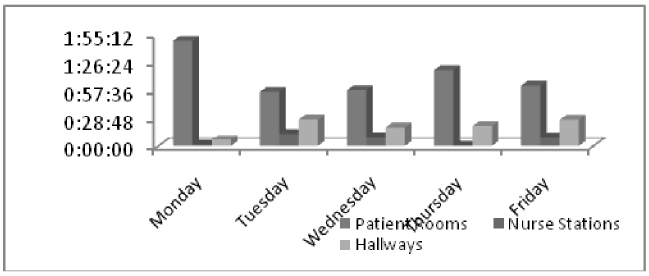

Fig. 6. Comparison of total time spent.

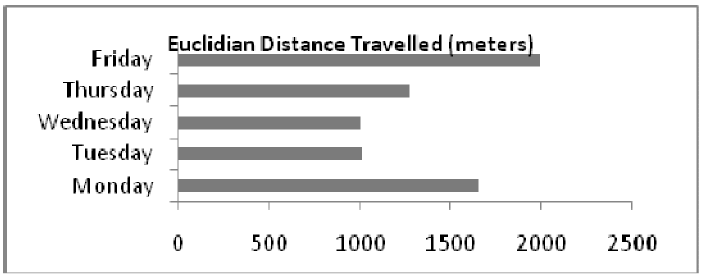

Fig. 7. Comparison of Euclidian distance travelled.

3.3.2. CORRELATION IN VARIABLES

In this section we investigated if there any relationship between total time spent and frequency of visits to respective facilities of the ward with two random sample data sets. Null Hypothesis: There is no correlation between total time spent and frequency of visits in different facilites.

```
*** Correlations for data in: SAMPLE 1    *** Correlations for data in:  SAMPLE 2
      Count      Time                           Count      Time
Count 1.0000000 0.9867939                     Count 1.0000000 0.9971425
Time 0.9971425 1.0000000                      Time 0.9867939 1.0000000
```

Fig. 8. Correlation data example.

Interpretation: The correlation coefficient informs that time and frequency are very closely associated to each other (using Pearson table, see Figure 8). For sample 1, Level of significance (using Pearson table) is *r*. 27 is Degree of freedom; r=0.98 for 27 degree of freedom; α =0.367 (0.05) and β=0.471 (.01) ($r(27)$ =0.98, $p< 0.01$). For sample 2 Degree of freedom is 35. Calculated value of r = 0.99 in our samples and it is higher than (alpha 0.05, 0.325 and alpha 0.01, 0418) ($r(37)$=0.997, p<0.01). Hence we reject the null hypothesis.

3.4. SUMMARIZING KEY OBSERVATIONS

Above analysis demonstrates that RFID data can be used for expoloration of workflow analysis even with technology limitation observed and reliability of recorded observations. Below is the list of some of observations that can be drawn using above statistical analysis.

3.4.1. RESOURCE UTILIZATION

- There is significant difference between various resoruce utilization, this difference could be subsequently analyzed to improve resource utilization.
- Patterns vary from resource to resource.
- Reception area (center wing) which has most of computer terminals is a highly used area of the ward. Time spent here and type of work performed in this area of the ward can be used as one of the measures to understand productivity.

3.4.2. FACILITY UTILIZATION

- Hallways are frequently used, to carry medical carts etc . So, for easy workflow and access, special consideration should be paid to design facilites.
- Allocation of patient rooms to medical eprsonnel may have impact on productivity. This is very important observation because it plays vital role in optimal utilization of resources and can be verified using RTLS technology.
- Usage of wings is normally directly proportional to numebr of patient rooms. Wings with less patient rooms have lesser frequency of visits.

3.4.3. INFECTION CONTROL

- It is very useful to have location of sanitization units in areas of high utilization.
- Based on observations, central wing has the highest traffic area and potentially most vulnerable for infection. To prevent contagious diseases, more sanitizing units should be installed here.
- Wings with most of patient rooms have highest traffic, which makes them more prone to spread of infection. In W21C, north wing has most of the patient rooms and is also the largest wing in the ward so more sanitization facilities should be installed there.

4. SUMMARY

To summarize, we conclude that spatial temporal data analysis is an effective way for understanding medical workflow with the goal of reducing patient waiting time and increasing utilization of medical facilities. This paper paves a feasible way towards facility redesign so that critical facilities are ideally located in clinical care settings. Moreover, workflow analysis informs about which areas of the ward are high traffic and hence prone to more infection. Like any other evolving technology, RFID has some technological, privacy, security and other constraints that need to be addressed before its application can be extended from a prototype to a large scale project and before it can be used to make any judgment on productivity or work quality levels. Nevertheless, our primary motivation has been fulfilled –

highlighting potential uses of RTLS technology and innovative use of spatial-temporal data for workflow analysis.

ACKNOWLEDGEMENT

Authors of the study would like to acknowledge all technical and research personnel of W21C and University of Calgary Faculty of Medicine researchers and practitioners, who took part in the development, installation and testing of the prototype system at W21C. We also would like to acknowledge the support of industry partners and Alberta Health Services.

BIBLIOGRAPHY

[1] CAVALLERI M., MORSTABILINI R., RENI G., A wearable device for a fully automated in–hospital staff and patient identification. Proceedings of Engineering in Medicine and Biology Society (IEMBS'04), 26th Annual International Conference of the IEEE, 2004, pp. 3278–3281.
[2] GUERRA A., Location, location, location. Denver Health decided to get a better handle on its clinical equipment with location tracking software. Healthcare Informatics, Vol. 23, 2006, pp. 95.
[3] BAUER J. C., Statistical Analysis for decision makers in Healthcare. Published by CRC Press, 2009.
[4] CORBIN J., STRAUSS A. C., Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory (3rd edition). Published by Sage Publications, 2007.
[5] KROHN R., RFID: It's about more than asset tracking. Journal of Healthcare Information Management, Vol. 19, No. 3, 2005, pp. 20–23.
[6] LENERT L., CHAN T., GRISWOLD W., KILLEEN J., PALMER D., KIRSH D., MISHRA R., RAO R., Wireless Internet Information System for Medical Response in Disasters (WIISARD). AMIA Annual Symposium Proceedings, 2006, pp. 1192.
[7] MEYER M., FAIRBROTHER P., EGAN M., CHUEH H., SANDBERG W., Using location tracking data to assess efficiency in established clinical workflows. AMIA Annual Symposium Proceedings, 2006, pp. 1031.
[8] GAVRILOVA M., NAYYAR S., GILGEN J., JOHNSTON O., GHALI B., Ergonomic design of interface for conceptual floor plan model and spatial event handling in RFID application, Journal of Medical Informatics and Technologies, Vol. 13, 2009, pp. 169–174.
[9] DUBOIS P., MySql (Chapter 1–5). Published by Addition–Wesley, 2009.
[10] SCHUERENBERG B. K., RFID and Wi–Fi square off. Health Data Management Magazine, Vol. 15, 2007, pp. 45–52.
[11] TANG C., CARPENDALE S., Mobile voice communication system in medical setting: love it or hate it? Proceedings of 27th International Conference on Human Factors in Computing Systems, 2009, pp. 2041–2050.
[12] BARLOW R. D., Healthcare Purchasing News: What's the radio frequency of real time? Northfields, Vol. 33, 2009, pp. 50–57.
[13] ELNAHRAWY E., MARTIN R. P., Studying the Utility of Tracking System in Improving Healthcare Workflow. Proceedings of Pervasive Computing and Communications Workshops (PERCOM Workshops), 8th IEEE International Conference, 2010, pp. 310–315.
[14] www.rfidupdate.com/articles/index.php?id=1231.
[15] www.pencomputing.com/news/news_rtls.html.
[16] www.radarfind.com.