MODELING AND ANALYSIS OF HEALTHCARE FACILITIES USING RFID DATA

YANG, W., TAN, Y., HU, S., GAKU, R. & TAKAKUWA, S.

Abstract: Radio frequency identification (RFID) technologies have been used for inventory management in supply chains and in tracking the movement of people in healthcare facilities. A large number of daily logs that are automatically collected and stored in the database requires effective methods for further analysis and use. In this study, we propose a procedure for obtaining important measures, such as daily walking (movement) distance and residence time spending per room for a particular medical staff in a hospital. Furthermore, we proposed a modeling approach for building system simulations using RFID-tracking data. The performance of our proposed model can be verified by comparing the simulation results with historical data analysis.

Key words: RFID, Simulation, Healthcare system, 3D visualization, IoT

Authors' data: Yang, W[enhe]*; Asso. Prof. Tan, Y[ifei]**; Hu, S[ike]***; Prof. Gaku, R[ie]****; Prof. Takakuwa, S[oemon]***, * Kyoto Tachibana University, 34 Yamada-cho, Oyake, Yamashina-ku, Kyoto, 607-8175, Japan, ** Chuo Gakuin University, 451 Kujike, Abiko, Chiba, 270-1196, Japan, *** Chuo University, 1-13-27 Kasuga, Bunkyo-ku, Tokyo, 112-8551, Japan, **** St. Andrew's University, 1-1 Manabino, Izumi, Osaka, 594-1198, Japan, yo-f@tachibana-u.ac.jp, yftan@mc.cgu.ac.jp, a16.tef6@g.chuo-u.ac.jp, r-gaku@andrew.ac.jp, takakuwa@kc.chuo-u.ac.jp

This Publication has to be referred as: Yang, W[enhe]; Tan, Y[ifei]; Hu, S[ike]; Gaku, R[ie] & Takakuwa, S[oemon] (2021). Modeling and Analysis of Healthcare Facilities Using RFID Data, Chapter 07 in DAAAM International Scientific Book 2021, pp.085-094, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-31-0, ISSN 1726-9687, Vienna, Austria
DOI: 10.2507/daaam.scibook.2021.07

1. Introduction

The recent and rapid development of information and communication technology (ICT), sensing technologies, the internet of things (IoT), and artificial intelligence (AI) is widespread and available in various enterprise activities. Among them, for tracking and monitoring commercial items, RFID technology is widely implemented and used in many industries, including libraries, airports, banks, manufacturing, and retails and warehousing. However, the research and development processes of this technology in the healthcare sector are relatively slow (Abugabaha et al., 2020). RFID technology is expected to bring disruptive innovation in the field of healthcare (Wicks et al., 2006; Deryahanoglu & Kocaoglu, 2019). Also, the strategic use of data collected automatically and continuously through IoT systems is an important issue for process improvement and strengthening the competitiveness in healthcare.

As a flexible method that handles the variability, uncertainty, and complexity of dynamic systems, simulation modeling is an effective tool for analyzing the current performance of a particular healthcare unit (e.g. hospital, outpatient departments, diagnostic centers, et al.) or forecast future behaviors of the system (Mielczarek, 2016). Wijewickrama and Takakuwa (2006) proposed a simulation model of an outpatients department of a hospital to shorten the wait time by identifying an optimum schedule with respect to patients and doctors. Takakuwa and Katagiri (2007) developed a simulation model of a planned outpatient ward of a university hospital to examine patient waiting time and congestion.

This study proposes an approach that uses the time-series positional data from the RFID-aided indoor location information system and builds a simulation model using tracking data for visualization, further system analysis, and improvement.

2. RFID Technology and Digitalization in Healthcare Sector

RFID is generic for technologies that use radio waves for data collection and transfer; it captures data efficiently and automatically without human intervention (Yao et al., 2010). After the world's first active RFID tag was patented in 1973, research in commercial applications of this technology started around 1985 in Japan and these developments have been widely applied in various contactless and electronic access cards, such as transportation IC cards, ETC, car immobilizers, etc. RFID tags are considered the next-generation authentication information media to replace barcodes.

RFID transfers information wirelessly, and if the signal transmission/reception system is properly designed, the tag is automatically authenticated from several meters away. Moreover, multiple RFID tags can be read and written simultaneously. If in healthcare, automated authentication is achieved without human intervention, medical errors are significantly reduced during operational processes (Yao et al., 2010; Barbora & Hromada, 2020).

Introducing and implementing RFID technology will affect all participants involved in the healthcare industry, including patients, healthcare staff, technicians, hospital managers, insurance companies, and government regulators. By introducing RFID tracking and automatic authentication technology, medical malpractices and the

workload of medical service providers can be reduced, thus efficiently improving healthcare operations (Abugabaha et al., 2020). RFID technology can eliminate most manual entries while providing a large and valuable dataset (Miller et al., 2006).

In an RFID-aided indoor real-time location system (RTLS), RFID receivers installed on the ceiling of the facility receive radio waves from RFID tags attached to patients, medical staff, and medical equipment, and grasp these locations in real-time. Active RFID tags send radio signals to antennas automatically and continuously. Then, the antennas and receivers transfer and store these positioning data to the server via a network in chronological order, as shown in Fig. 1. Large datasets of daily logs that are automatically collected and stored in the database require effective methods for further analysis and use. Therefore, data cleansing, analysis, and use of RFID-generated data are challenging issues (Wicks et al., 2006).

Miller et al. (2006) used RFID to capture simulation data (processing time) in a hospital emergency department. Asamoah et al. (2018) presented a simulation experiment showing that RFID technology significantly improves patient scheduling. Furthermore, Nakagawa et al. (2019) proposed a method for using behavioral data obtained from a location information system to predict the behavior of medical staff and optimize the allocation of workforces through machine learning. Most studies only gathered or used partial data in RTLS. However, in this study, we develop a data processing process that helps process vast data obtained from the system and apply it to simulation modeling.

Fig. 1. Image of an RFID-aided indoor RTLS.

3. Facility Descriptions and RFID Data Acquisition

Here, we consider a health facility system in charge of acute medical care located at Sapporo, Hokkaido, Japan. Many patients are accepted from nearby medical treatment hospitals and elderly welfare facilities, and 60%–70% of these patients need long-term care. Ricoh Company, Ltd. (2017) proposed and introduced an indoor RTLS for acquiring location data from RFID systems.

Over 580 active RFID tags were attached to patients, medical staff, and medical equipment. Antennas were installed on the ceiling of the entire hospital. Upon receiving signals from RFID tags, the antenna transfers these signals to the information system server via the network. Next, the information system identifies the location of the RFID tags according to the location of the antenna and gateways by which the signals were received.

Then, the system plots the location on the map in real-time and displays it on the monitor, making it possible to visualize people and equipment locations in a hospital in real-time, reducing patient search time, allowing easy calling and support requests from other nurses, and swift searching of medical equipment (Nakagawa et al., 2019). Selected associated pictures are shown in Fig. 2. Although this RTLS views the current location of targets, such as medical staff, patients, etc., grasping previous and back positions and behaviors in the context of the timeline remains a challenge.

In this hospital's RTLS, RFID tags automatically send radio signals to antennas every 6 s. We obtained over 600 million records of positioning data in 25 days. Applying a large amount of raw data exported from RTLS directly to a simulation model is difficult. Consequently, we employed Excel spreadsheet software to preprocess the data before introducing them into a simulation model.

4. Procedure for Analyzing RFID Data

4.1 Overview of an analytic procedure

Preparing the basic data on the position of a receiver or an antenna and RFID subject's displacement beforehand is necessary. First, the moving route of a medical staff and a major medical device is drawn in floor drawings at the hospital using the longitude and latitude of the antenna positional information file used to receive the signal from the RFID subject. An antenna position and relation of a migration route are shown in Fig. 3. Then, the “[3] from-to chart” (distance matrix between two positions) reflecting the walking line of the associated route is completed,

RFID data are composed of subject ID, measured time, antenna ID, and so on. An analytic procedure is as follows, and the associated overview is shown in Fig. 4.

- [Step 1] First, designating the subject ID, a series of data of ID number, time, floor ID, and antenna number is extracted from RFID data.
- [Step 2] From the “[3] from-to chart,” “[4] fixing the current position of the designated subject” is extracted for the corresponding floor ID and antenna number.
- [Step 3] From the “[3] from-to chart,” [5] the moving distance from the current to next destination positions is computed. Then, [6] a time interval for the object to move positions is computed.
- [Step 4] Based on “[6] A time interval for the object to move positions,” “[7] Route time to the destination position for the subject” and “[8] the time length of the subject’s stay at the position” are obtained and integrated.

(a) RFID tag worn by patients

(b) RFID tag worn by staff

(c) RFID tag for medical devices

(d) RFID receiver on the ceiling

(e) Monitor for conforming position

Fig. 2. RTLS in the healthcare facility

- [Step 5] “[9] Velocity required to rout to the next destination position” is computed, using “[5] Moving distance from the current position to the next destination position” and “[7] Route time to the destination position for the subject.” (This is used separately in a simulation model.)
- [Step 6] Every moving distance is examined in detail, and if the figure is improper, the associated one is corrected.

Fig. 3. Route connection two positions

Fig. 4. Overview of an analytic procedure

- [Step 7] “[10] Total moving distance,” “[11] Total moving time,” and “[12] Total time length of staying at each position or room” for the designated subject are summed up, using the “[5] Moving distance from the current position to the next destination position,” “[7] Route time to the destination position for the subject,” and “[8] time length of the subject’s stay at the position.”

If the displacement in [step 6] is canvased and the improper numerical value detected, the correction is done. Step 6 is a necessary action to correct improper values caused by overcrowding possibly because of RFID-data acquisition among the neighboring RFID receivers on the same or different floor.

4.2 Results of a sample example

The total distance, moving time, and time length of staying at each selected position or room for a designated subject, say, medical staff with ID number 3011, are summarized in Tab. 1. Some important measures for the daily activities are summed for each medical staff by applying the proposed procedure of analyzing a mass of RFID data. Notwithstanding, the medical staff walked a distance of 7,236.7 m on average in the hospital for one day. Additionally, associated measures can be used to verify the result obtained by simulation experiments that use the same RFID data.

Total moving distance (m)	Total moving time (sec.)
7236.7	6571.0

Position (Room)	Total time length of staying (sec.)
Room No.306	1521
Room No.307	1018
Room No.310	932
Room No.311	845
Room No.312	353
Room No.313	0
ICU (3 F)	337
Nurses' station (3FA-1)	13
Nurses' station (3FA-2)	28
Nurses' station (3FB-1)	1190
Nurses' station (3FB-2)	10828

Tab. 1. Selected results for a subject in a day

5. Simulation Model

Simio, a simulation-modeling framework based on graphical object-oriented programming (Smith et al., 2018), was used to build the model in this study. Furthermore, Excel VBA programs were developed and applied to batch data processing. The proposed procedure for RFID data processing and model construction is shown in Fig. 5. The main steps of the procedure are iterated below:

- [Step 1] Extract and generate the entity list (a list of medical staff, patients, equipment, etc.) from the position data using VBA macros.
- [Step 2] Generate a routing sequence for each entity from the position data using VBA macros.
- [Step 3] Import the routing sequences file into the Simio data table.
- [Step 4] Construct and implement the model using Simio.

In this study, we constructed a 24-hour prototype simulation model of the inpatient floor. Fig. 6 shows the complete simulation scene of the model.

The simulation model can be switched to 2D and 3D display modes while running. The figure captures an overview of the whole floor and the movement of people using the realistic 3D animation for model validation. Since the simulation model uses historical data from RTLS, it is possible to repeatedly check previous events at a specific time through animation. Also, the execution results of the simulation can be obtained quantitatively, such as the entire distance traveled during implementation, which can be used for further verification. Thus, the results of the simulation experiment are verified by comparing them with the results obtained from the proposed procedure of data analysis.

Fig. 5. RFID Data Processing Procedure and Simulation Modeling.

6. Conclusions

Two procedures on data and simulation analyses were proposed using a mass of RFID data to examine important measures for medical staff in a hospital. First, by taking advantage of a mass of RFID data, we proposed a procedure to obtain important measures, such as daily walking (movement) distance and time spent per room for the particular medical staff in a hospital. During the data analysis, it is found that careful inspection of the RFID data and appropriate corrections was required, because of possible RFID data congestion between RFID receivers installed above and below the floor and neighboring RFID receivers. Additionally, we proposed building a simulation model using the same RFID data. The results obtained by performing a simulation experiment can be verified by comparing them with those obtained from the proposed procedure of data analysis for the common mass of RFID data.

Finally, any ID symbol/name shown in this article is fictitious and simply for explanations.

Fig. 6. Screenshot of the simulation model

7. Acknowledgments

The authors express sincere gratitude to Mr. M. Itoh of SMART COM. Laboratories Co., Ltd., Ms. M. Arai of Ricoh Company, Ltd., and Dr. F. Hata and Dr. T. Yajima of Sapporo Dohto Hospital Medical Corporation for acknowledging this study. This research was supported partly by JSPS KAKENHI Grant Numbers 20K13595, 17KK0078, and 19K01921.

8. References

- Abugabaha, A.; Nizamuddina, N. & Abuqabbaha, A. (2020). A review of challenges and barriers implementing RFID technology in the Healthcare sector. *Procedia Computer Science*, Vol.170, pp.1003-1010, ISSN 1877-0509
- Asamoah, D. A.; Sharda, R.; Rude, H. N. & Doran, D. (2018). RFID-based information visibility for hospital operations: exploring its positive effects using discrete event simulation. *Health Care Management Science*, Vol.21, No.3, pp.305-316, ISSN 1386-9620
- Barbora, K. & Hromada, M. (2020). The use of RFID technology in hospital, *Proceedings of the 31st DAAAM International Symposium*, pp.638-643, B. Katalinic

- (Ed.), Published by DAAAM International, ISBN 978-3-902734-29-7, ISSN 1726-9679, Vienna, Austria
- Deryahanoglu, O. & Kocaoglu, B. (2019). Applications of RFID systems in healthcare management: a simulation for emergency department. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, Vol.8, No.10, pp.786-792. ISSN 2278-3075
- Mielczarek, B. (2016). Review of modelling approaches for healthcare simulation, *Operations Research and Decisions*, Vol.26, No.1, pp.55-72. ISSN 2391-6060
- Miller, M. J.; Ferrin, D. M.; Flynn, T. & Ashby, M. (2006). Using RFID technologies to capture simulation data in a hospital emergency department, *Proceedings of the 2006 Winter Simulation Conference*, pp.1365-1371, ISBN 978-1-4244-0501-7, Monterey, CA, USA, Dec.2006, Published by IEEE, Piscataway, New Jersey
- Nakagawa, M; Saito, A.; Murakami, K.; Taniguchi, R.; Kuroda, H.; Ito, M.; Yajima, T.; Hata, F. & Nakanishi, T. (2019). Realization of behavior prediction method using behavior log in the hospital and attribute information, Available from: https://www.jstage.jst.go.jp/article/pjsai/JSAI2019/0/JSAI2019_1H3J1301/_pdf/-char/ja Accessed: 2021-08-28 (in Japanese)
- Ricoh Company, Ltd. (2017) Indoor location information service (for hospitals), <https://www.ricoh.co.jp/sensing/hospital/> Accesed on: 2021-08-28 (in Japanese)
- Smith, J. S.; Sturrock, D. T. & Kelton, W. D. (2018). *Simio and Simulation: Modeling, Analysis, Applications: Fifth Edition*, ISBN 978-1727854589, Published by CreateSpace Independent Publishing Platform
- Takakuwa, S. & Katagiri, D. (2007). Modeling of patient flows in a large-scale outpatient hospital ward by making use of electronic medical records, *Proceedings of the 2007 Winter Simulation Conference*, pp.1523-1531, ISBN 978-1-4244-1306-5, Washington, DC, USA, Dec.2007, Published by IEEE, Piscataway, New Jersey
- Wicks, A. M.; Visich, J. K. & Li, S. (2006). Radio frequency identification applications in hospital environments. *Hospital Topics*, Vol.84, No.3, pp.3-8. ISSN 1939-9278
- Wijewickrama, A. K. A. & Takakuwa, S. (2006). Simulation analysis of an outpatient department of internal medicine in a university hospital, *Proceedings of the 2006 Winter Simulation Conference*, pp.425-432, ISBN 1-4244-0501-7, Monterey, CA, USA, Dec.2006, Published by IEEE, Piscataway, New Jersey
- Yao, W.; Chu, C.- H. & Li, Z. (2010). The use of RFID in healthcare: benefits and barriers, *Proceedings of 2010 IEEE International Conference on RFID-Technology and Applications*, pp.128-134, ISBN 978-1-4244-6700-6, Guangzhou, China, Jun.2010, Published by IEEE, Piscataway, New Jersey