Real-time Process Data Acquisition with Bluetooth

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ABSTRACT
Healthcare workflow processes are extremely complicated. Surveys and interviews are a common but a rather expensive way of conducting process research. This paper elaborates a new approach based on wireless technologies for data gathering of healthcare processes. We have developed an automatic process measurement system for collecting real-time process data. The system consists of mobile devices that detect Bluetooth sensors. The identifiers of the detected sensors are stored in log files. We apply the system to three Linux-based platforms. Empirical tests are conducted to evaluate the performance of the system. The Radio Signal Strength Indicator (RSSI) is used to improve the accuracy of the data collected by the system.

Keywords
Healthcare process; process mining; real-time data acquisition; Bluetooth; Android

1. INTRODUCTION
Research on measuring the processes of elderly healthcare are conducted in the Value Creation in Smart Living Environment for Senior Citizen (VESC) project and 'ICT, Service Innovations, and Productivity' project in the Research Institute of Finnish Economy (ETLA). As the population aging has brought up severe challenges to the whole world, there is a pressure to improve the productivity of healthcare services and to develop smart services that support elderly people to live an independent life. There are needs to study elderly people's daily behavior and measure the nursing personnel's behavior in healthcare processes. Therefore, precise models of healthcare processes are necessary.

Healthcare processes are very complex because of two main reasons. First, the processes require a large amount of real time data, which must be timely available. Second, the processes rely on multi-professional personnel in multi-skilled teams. In one case example we had 12 professions working in 21 different teams. Traditional modeling techniques collect data by conducting interviews, and then process charts are drawn manually. It is time-consuming and in complex cases requires modelers with professional knowledge and skills. Therefore, this paper adopts the idea of mining process information from workflow logs [5]. The process mining technique extracts data from event logs and then generates process models automatically. Those event logs are usually recorded by various information systems. As the main contribution in this paper, we propose a novel method called automatic process measurement to collect more accurate logs. We develop a measurement system that is capable of collecting real-time process data by using Bluetooth wireless communication technology. The collected data can be used in further process mining, automatic process modeling and process analysis.

1.1 Bluetooth Overview
Based on ETLA's previous research, the Wireless Local Area Network (WLAN) network coverage ability cannot be guaranteed in hospitals, and the GPS will not work indoors, so we choose Bluetooth technology. Bluetooth is a short-range wireless communication technology standard, using a worldwide and license free radio band – Industrial, Scientific, and Medical band (ISM) at 2.4 GHz. Bluetooth has high anti-interference capability: it uses Adaptive Frequency-hopping spread spectrum (AFH) as its solution to avoid interference from other technologies also operating the 2.4 GHz ISM band, such as cordless telephone, microwave oven, WLAN, wireless USB, and Zigbee. The usage of Bluetooth is not limited in computer peripheral equipments, it can be integrated into almost any digital equipment. It has the advantage of low power consumption, which is especially important for small size devices. In addition, Bluetooth enables temporary ad hoc connection, a Piconet is established dynamically and automatically when one Bluetooth device enters the radio proximity of another Bluetooth device [1].

The core part of Bluetooth technology is the protocol stack, which is protocols that are organized in a hierarchical structure. Remote devices use this protocol stack to inter-operate. In our research, we use BlueZ, the official Bluetooth protocol stack in Linux. It has been included in Linux kernel since version 2.4.6. BlueZ supports Bluetooth core layers and protocols, currently, it consists of many separate modules, such as Bluetooth kernel subsystem core, Logical Link Control and Adaptation Protocol (L2CAP) kernel layers, Radio Frequency Communication (RFCOMM), Host Controller Interface (HCI) protocol general Bluetooth and Service Discovery Protocol (SDP) libraries [3]. Besides, it provides a set of Application Programming Interfaces (API) to facilitate developers to communicate with Kernel level protocols.

1.2 Android Platform
The Android mobile operating system is based on Linux kernel and it runs Google's own Java virtual machine Dalvik, which is optimized for mobile devices. Android has a variety of tools to support development, such as the Android Development Tools (ADT) plug-in for Eclipse Integrated Development Environment (IDE), the device emulator, and the Java Debugging Wire Protocol (JDWP) debugger.

Eclipse with ADT plug-in are highly recommended for Android application development. The biggest advantage of ADT is that it provides very simple ways to export signed/unsigned Android Packages (APK) compared to packaging regular Linux applications. The Bluetooth capacity of Android platform is also based on BlueZ, but the difference is the Bluetooth APIs: in Linux operating system, the Host Controller Interface (HCI) provides a set of unified APIs to access low-level Bluetooth functionality while Android operating system provides several higher level classes to manage this.

2. RELATED WORK

Many studies on healthcare processes have been conducted, and most of them are using the traditional process modeling approaches that are applied in industry: Van der Bij, J.D. [4] studied the quality and production control of the healthcare processes. They collect process-flow data by individual, semi-structured interviews and they found out the healthcare processes generally go beyond the boundaries of departments or units, and in some cases these even go beyond the boundaries of the organization; in Pradhan, M.'s study of healthcare processes [7], they presented a proactive approach of workflow process modeling that uses sequence diagrams and they aimed to understand the risks associated with each step of the delivery of patient healthcare. The traditional process modeling techniques are time-consuming and require modelers have professional knowledge and skills Models are defined by modelers manually, based on the analysis of process documents and consultations with process participators. This leads to problems, such as the individual experience of modelers and participators will greatly affect the objectivity of process models, large numbers of redundant data will influence the efficiency of traditional modeling methods [12] and in many domains processes are evolving and people typically have oversimplified and incorrect views of actual processes [11].

Based on existing research conducted by ETLA, the health care processes are extremely complicated because some of the treatment processes are ambiguous, and unambiguous processes, the treatment practices can still vary between areas and units. This finding indicates that increasing productivity in health care is a challenging mission. Furthermore, Rebuge, Á. [2] identified that analyses of the processes in healthcare organizations are particularly difficult due to the highly dynamic, complex, ad hoc and multi-disciplinary nature of healthcare processes. Lenz, R. [9] studied the potential of using IT technologies in the analysis of healthcare processes. The result of their study shows that the potential of process-oriented IT technology to improve healthcare quality is attractive.

A new process modeling method called process mining became popular in recent years, the idea was advanced by Cook, J.E. [5] as early as in 1995, and was applied in process modeling field by Agrawal, R. [8] since 1998. Although this technique solves mentioned problems in traditional process modeling approaches, it fails to achieve the accuracy of process data. It extracts information from event logs that are usually recorded by various information systems, so the data are not as accurate as real-time data. So our goal is to develop a measurement system that collects accurate real-time process data with Bluetooth technology. We identify activities by detecting the Bluetooth signal in specific places where the activity taking place. This way, we use Bluetooth for indoors positioning. Many previous studies also use Bluetooth for positioning. For example, the indoor Bluetooth-based positioning system developed by Feldmann, S. [10]. The system estimates the range by approximating the relation between the Radio Signal Strength Indicator (RSSI) and the associated distance between sender and receiver. Hallberg, J. [6] has developed a Bluetooth positioning system that implements two different ways of positioning with Bluetooth (including register positioning service, or use the Bluetooth unique address for looking up respective position in a database). Another study conducted by Zhou, S. [13] uses RSSI measurements in their positioning system too. In this paper, we also consider using RSSI to filter the noise data in the event logs that are recorded by the measurement system.

3. IMPLEMENTATION

In the implementation phase, we use an iterative software development process combined with software prototyping approach. Firstly, we develop a prototype in C++ for Ubuntu Linux platform with Qt Creator, then customize it and port it to the Maemo mobile platform. Since most Android applications are written in Java and it is not possible to port Linux applications to Android platform directly, we use a third iteration to rewrite the measurement system in Java for the targeted Android platform.

3.1 Architecture

The main objective of the system is to collect accurate process data that can be used for automatic process modeling. We determine following data is necessary: what is the activity, who performs the activity, which team performs the activity, and the begin and end time. The system uses Bluetooth and the BlueZ Bluetooth protocol stack. It records timestamps of activities by detecting real-time Bluetooth signals and distinguishing the global unique address of different Bluetooth devices. Fig. 1 shows the structure of the system, which includes fixed stations, movable clients, and the measurement system.

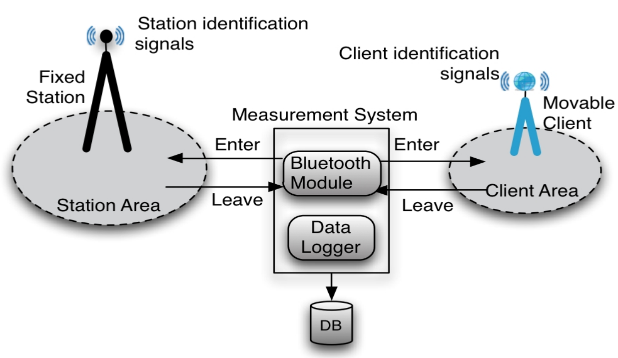

Figure 1. The structure of the measurement system

A fixed station is a Bluetooth sensor located at a specific place to represent a specific activity. It periodically sends the station identification signal that can be received within the station area. A movable client is a Bluetooth sensor carried by elderly people that periodically sends out the client's identification signal that can be received in the client proximity. The Bluetooth module of the measurement system will periodically detect nearby Bluetooth sensors.

Once the system enters the radio proximity of a remote Bluetooth device, a wireless ad hoc connection will be established between them [1]. Next, the system sends out a discovery request and remote Bluetooth devices will respond by sending back relevant information (e.g. Bluetooth address, user-friendly name, device type, connection signal strength). The data logger records required information defined above and uploads those records to the database for later process data analysis. Fig. 2 shows the boundary of the system and its use cases in more detail. The user interacts with the system, which will record his/her activities.

The system has three states that distinguish the different sets of system tasks. Open state is the initial state at startup of the application: it detects all nearby Bluetooth devices. Secondly, in training state we train the system to recognize allowed Bluetooth devices and save corresponding information into a text file, which can be used later while measurement. Finally, in run state, the system collects real-time process data, determines activity's timestamps and creates accurate event logs according to the needs of automatic process measurement. The main task of our implementation, recoding event logs, is depicted in Fig. 3 as activity diagram.

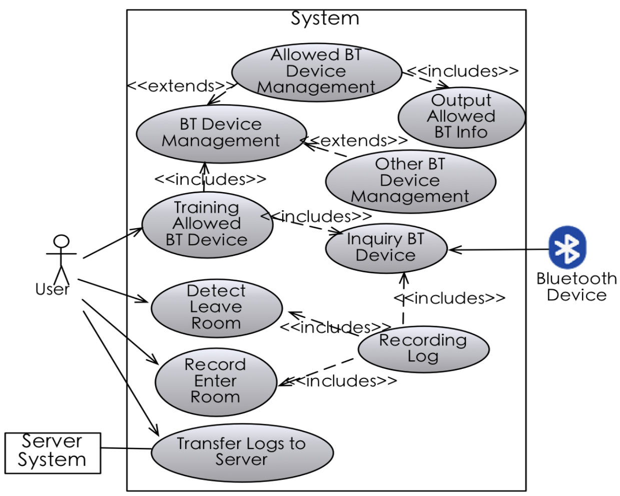

Figure 2. Measurement system boundary and use cases

3.2 Graphical User Interfaces

Based on the testing and analysis of the two prototypes built for Ubuntu Netbook Remix and the Maemo 5 platform, we decided to target at Android, currently the most popular smartphone platform. This platform enables us to design interfaces in a declarative fashion – using Extensible Markup Language (XML) layout files, which nicely separates graphical user interface and business logic code. Using this way, the user interface can be easily interchanged with another one. Fig. 4 shows the structure of the user interface: LinearLayout is a ViewGroup, TextView and Buttons are Android's predefined widgets, and BTDeviceCanvas is a self-defined ImageView, which is used to present the detected results dynamically.

Fig. 5 (a), (b), (c) shows the system user interfaces corresponding to three states of the system mentioned earlier. Different icons represent different types of Bluetooth devices: a mouse, a PC/laptop, a phone, other Bluetooth devices. In training state, the system numbers all allowed Bluetooth devices and in run state, a green icon signals that the device is in the system's proximity, while, red icon means it is out of range.

3.3 Testing

Practical testing was conducted in Department 101, the Helsinki University Central Hospital (HUS). We used ten Bluetooth mice to simulate Bluetooth sensors, which were located at different locations in Department 101, as shown in Fig. 6 (e.g. Mouse No. 7 is in Room 3).

The test was performed by a nurse from HUS, carrying the smartphone that runs the measurement system. The test run took about 3 hours and resulted to the recording of about 200 activity records, each record contains relevant information such as the Bluetooth sensor address and the enter and leave time from the radio proximity of the Bluetooth sensor.

In order to assess whether the workflow logs can be used in further automatic process mining, we first mapped Department 101, shown in Fig. 6, into a two-dimensional coordinate system (X-axis and Y-axis). Furthermore we plotted these 200 logged records in a line graph to represent the nurse's movements between activities, shown in Fig. 7. The T-axis contains a timeline while the P-axis shows the activity's position in the coordinate system in Fig. 6. The blue and red lines represent the values on the X- and Y-axis respectively.

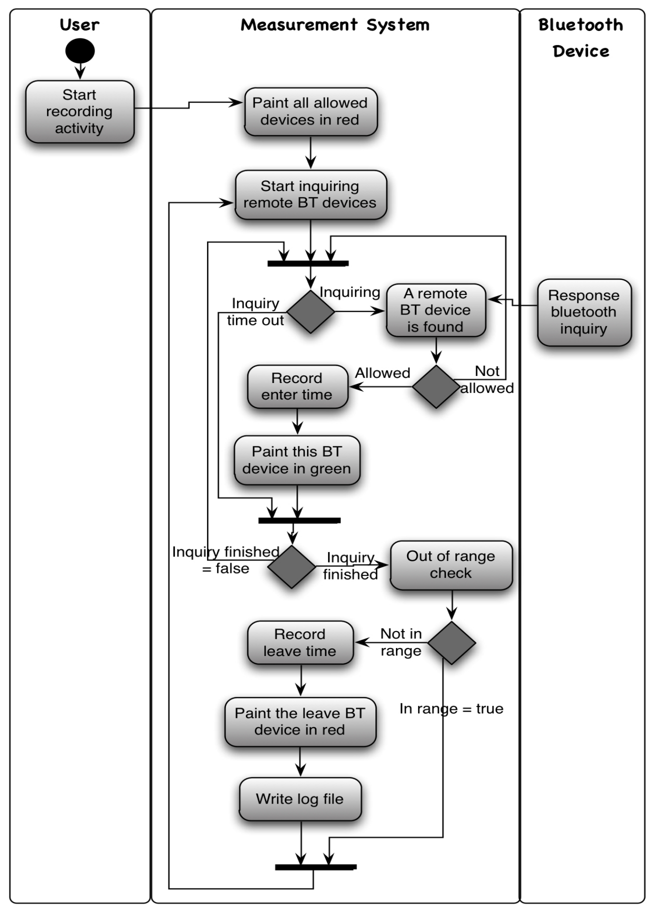

Figure 3. The process of recording logs

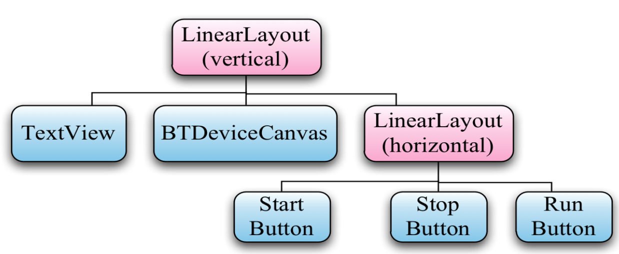

Figure 4. Structure of user interface

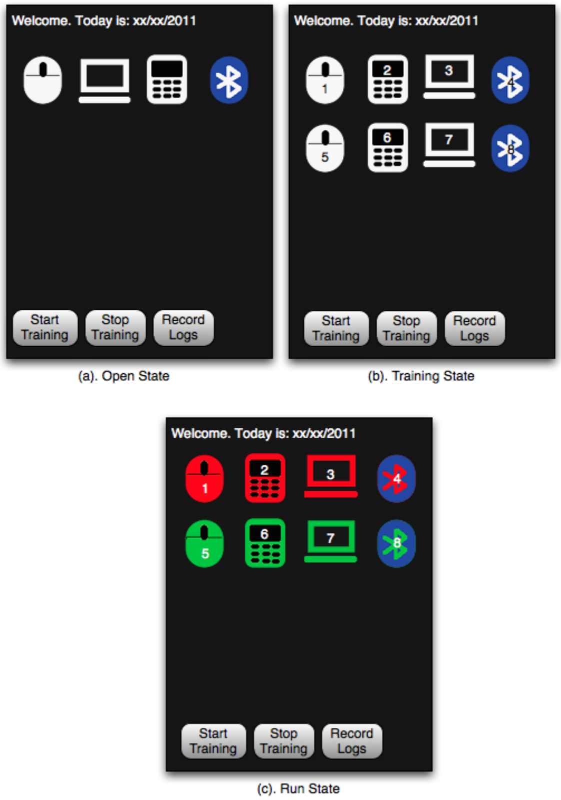

Figure 5. User interfaces of the measurement system

3.4 Performance Evaluation

Three prototypes for different platforms have been developed (see Table 1). The detection of the enter time has been greatly improved in prototype three – the Android platform. The average response time for detecting the enter time is 2 seconds, where the average response time for detecting the leave time is much longer, about 18.86 seconds. The reason is the Bluetooth API that defines a Bluetooth inquiry as an asynchronous call, which lasts 12 seconds. This explains the substantial delay since the leave time can only be checked after this API call is executed.

According to the analysis shown in Fig. 7, activities that constitute a process can be clearly extracted from the logs. Therefore, the process data collected in logs fulfill the needs of further automatic process modeling. In order to improve the accuracy of process data, there are needs to solve Bluetooth signal overlapping problems. We are planning to use a method that approximate the distances between measurement system and Bluetooth sensors based on the Bluetooth RSSI. We measured the mean RSSI of the Bluetooth mice in increments of 0.1 m. The result shown in Fig. 8 indicates that the relationship of Bluetooth RSSI and distance fits the polynomial function as shown in (1). This can be used later to help filter noise data in the activity logs:

$$y = 0.0033x^2 + 0.189x + 2.835 \qquad (1)$$

4. CONLUSION

In this paper we proposed a new approach of using wireless technologies in process and productivity research. We presented an automatic process measurement system for collecting real-time process data. The idea of process mining that extracts processes from event logs was adopted. The Bluetooth technology has been successfully applied in the developed system to record the activity data from a real work process. We have evaluated the system in practical environment in Department 101 in HUS, and the testing results can be used in later process analyses, such as automatic process modeling. But, to extract process models from event logs is out of the scope of our research in this paper.

Besides, we have found out a feasible solution to solve the signal overlapping problem. We use RSSI to approximate the distances between the measurement device and Bluetooth sensors. This improves the accuracy of the recored logs by filtering noise data. We have upgraded the system to be able to run as background service, so that the measurement device, the smartphone, can have other usages simultaneously. This is a critical issue for the later application of the system in the hospital working environment. For nurses, one device for only single use is impractical.

In real processes there are usually many activities that are conducted by a group of people. In our future research we plan to study the behavior of teams of people in the processes: How can we analyze the team activities from the logs recorded by the measurement system. Then we shall use the mobile phones carried by the personnel also as Bluetooth sensors.

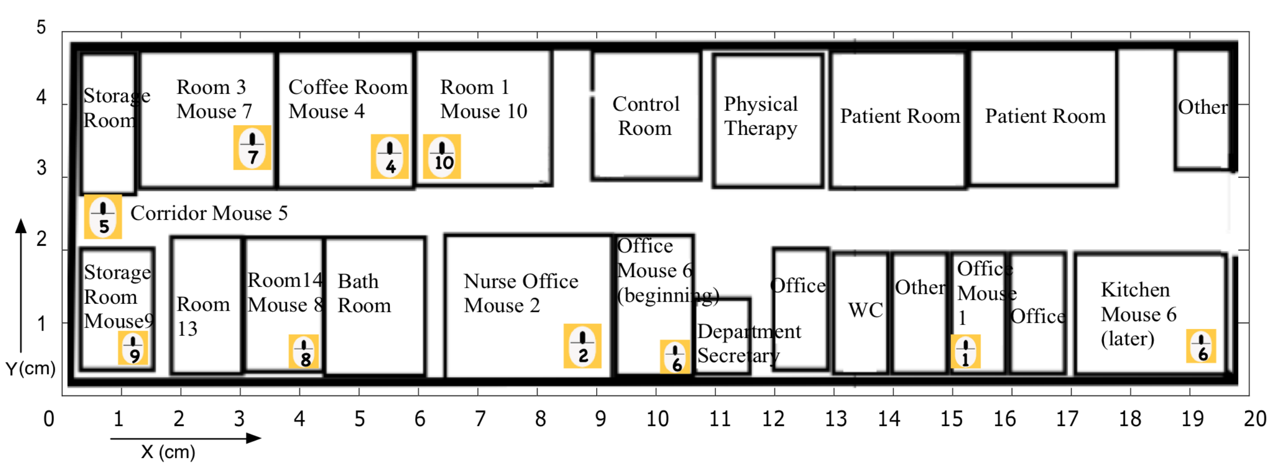

Figure 6. The map of Department 101 in HUS

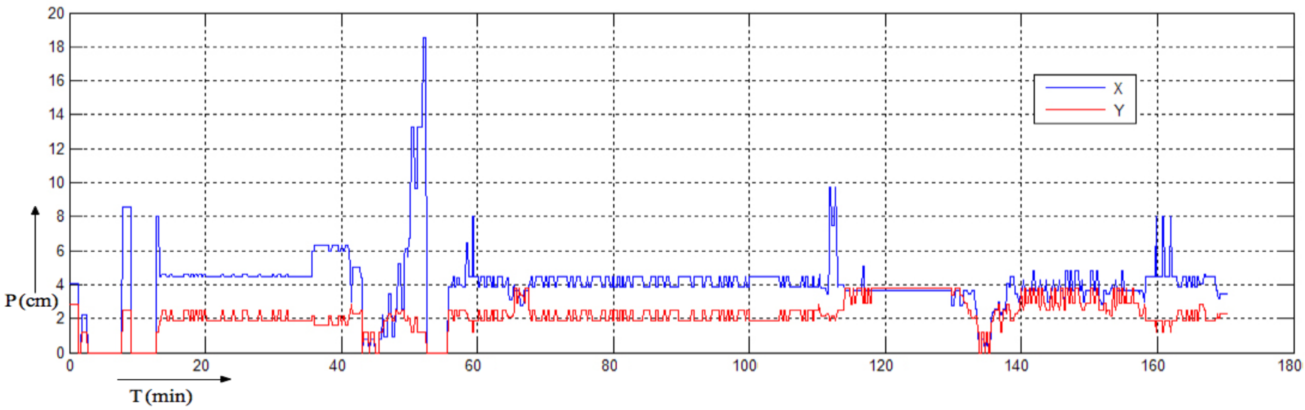

Figure 7. Testing result – movement of a nurse

Table 1. Developed measurement systems

	Prototype 1	Prototype 2	Prototype 3
Running Device	Mini-laptop	Mobile Phone	Mobile Phone
Running Platform	Ubuntu	Maemo 5	Android 2.1
Development Tool	Qt Creator	Qt Creator; Nokia Qt SDK	Eclipse; ADT plug-in
Programming Language	C++	C++	Java
Number of Modules	4	4	3
Average Response Time (Enter)	6s	7.64s	2s
Average Response Time (Leave)	17.3s	20.7s	18.86s

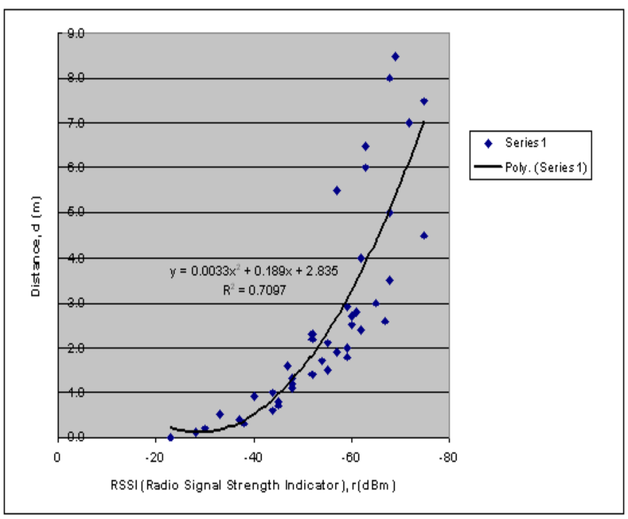

Figure 8. Received Power Indicator vs distance

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] A. Kansal, "Bluetooth primer", Los Angeles: Red-M, 2002.

[2] Á. Rebuge, D.R. Ferreira, "Business process analysis in healthcare environments: a methodology based on process mining", Inf Syst, 2011, Elsevier.

[3] Bluetooth Org, "Bluetooth specification version 4.0, vol.0. Retrieved from: http://www.Bluetooth.com, 2010.

[4] J.D. van der Bij, L. Dijkstra, G. deVries, J. Walburg, "Improvement and renewal of healthcare processes: results of an empirical research project", Health Policy, 1999, pp. 135-152.

[5] J.E. Cook, A.L. Wolf, "Automating process discovery through event-data analysis", Seattle, Washington, USA, Proceeding of the 17th International Conference on Software Engineering, 1995, pp. 73-82.

[6] J. Hallberg, M. Nilsson, K. Synnes, "Positioning with Bluetooth", Telecommunications, ICT 2003, 10th International Conference, 2003, pp. 954-958.

[7] M. Pradhan*, M. Edmonds, W.B. Runciman, "Quality in healthcare: process", Best Practice & Research Clinical Anaesthesiology, 2001, pp. 555-571.

[8] R. Agrawal, D. Gunopuloa, F. Leymann, "Mining process models from workflow logs", Proceeding of the 6th International Conference on Database Technology, 1998, pp. 469-483.

[9] R. Lenz, Manfred. Reichert, "IT support for healthcare processes – premises, challenges, perspectives", Data Knowl.Eng., 2007, pp. 39-58.

[10] S. Feldmann, K. Kyamakya, A. Zapater, Z. Lue, "An indoor Bluetooth-based positioning system: concept, implementation and experimental evaluation", International Conference on Wireless Networks, 2003, pp. 109-113.

[11] W.M.P. van der Aalst, M.H. Schonenberg, M. Song, "Time prediction based on process mining", Information System, Scopus, 2011, vol.36, no.2, pp. 450-475.

[12] Yan Li &Yu-qiang Feng, "An automatic business process modeling meghod based on markov transition matrix in BPM", Mnagement Science and Engineering, ICMSE' 06, 2006 International Conference, pp. 46-51.

[13] Zhou Sheng, J.K. Pollard, "Position measurement using Bluetooth", Consumer Electronics, IEEE Transactions, 2006, pp. 555-558.