Defining Virtualization Based System Abstractions for an Indoor Assistive Living for Elderly Care

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Abstract:
We consider an indoor assistive living center for elderly care which requires constant monitoring facility in an unobtrusive fashion. We present a middleware solution GuardianAngel that takes into account the unique challenges of providing a system that is able to guide the users at the same time monitor the users in a coarse grain manner that is controlled and initiated by users. We use virtualization technique to provide assistance to individuals and monitor them as virtual units of location. We use a distributed server as information provider and handheld computational devices for local assistance for users using RFID technology for sensing. We have designed, implemented and evaluated GuardianAngel using a small scale RFID testbed as well as large scale distributed scalability study using emulated devices.

1. Introduction

Consider the following scenarios in an indoor assisted living center for elderly residents: Grandma Ayesha is not able to find her medicine bottle. She has forgotten where she kept it last and she is not able to locate it now. Uncle Joe, on the other hand, has been in the restroom for over an hour. He is not responding from inside. These are imaginary scenarios but very common in an *Assisted Living Center* for *elderly people*. In both scenarios, it is evident that there should be guidance and monitoring system to assist the residents. This problem becomes more challenging when Grandma Ayesha and Uncle Joe are not interested in a monitoring facility that is obtrusive (e.g., video based monitoring or wearing a badge for monitoring purposes).

Figure 1. (a) Spatial displacement (b) Temporal displacement (c) Virtual position over space and time (d) fine grain information sensed by user

We have looked at *system* solution approach to enhance guidance and monitoring capabilities that are inspired by requirements in assisted living centers for elderly care. From the monitoring perspective, there is a requirement to find out information regarding the user's *spatial displacement* and *temporal displacement* in real time in a scalable fashion. A simple example of spatial displacement is a person falling down from his/her bed at night; and a person staying in the restroom for an extended amunt of time is an example of temporal displacement which is very common in assisted system environment as shown in Figure 1. The state of the art indoor sensing techniques are capable to capture these displacements but fail to meet the user's requirements. The user's perspective is different in this regard. The users are interested in getting support from technology for guidance and assistance purposes but in a way that is unobtrusive, the users are not interested in being tracked continuously. Instead, the users are interested in sharing information in a coarse grain level that may be enough for certain level of monitoring. The two sets of requirements provide a unique system level challenge. A very detailed level knowledge of the environment is required to guide the user which is not acceptable to share for monitoring purposes. On the other hand, coarse grain information that is reasonable to monitoring purposes may not be the best option to provide a detailed view of the environment. There is a requirement for a strong system solution that is scalable, efficient in delivering real time data in case of any emergency situation and provides the information to the user and caregivers in a form that is acceptable to all level of application users.

We have found that there are very interesting research effort that take into account user requirements from the interface perspective and there are very strong set of work that deal with various sensing techniques. However, there is a gap among the indoor sensing systems and the user centric interfaces. The user centric interfaces have a very good idea on the user's need but in many cases do not address the system challenges (e.g., scalable, real time performance) while many of the sensing systems focus on performance (e.g., how accurately the environment is sensed) but fails to address user needs (e.g., "does the user feel comfortable everyone else knowing about how precise that position is?"). We looked our effort in bridging this gap from the systems perspective by providing a middleware solution that supports monitoring and guidance allowing system abstractions that provide user initiated and user controlled data dissemination through the entire system. Our system is named ***GuardianAngel*** that considers an RFID tagged environment that is sensed by users carrying mobile computational devices for guidance and monitoring applications. It works in two layers to address the challenges of monitoring and guidance by allowing coarse grain and fine grain information processing for two different purposes. We consider a virtualization based technique that provides user monitoring information over space and time called virtual location as can be seen in Figure 1 –(c) and Figure 1-(d). It provides several system components such as:

- Virtual station (VS): these are distributed monitoring servers that are able to provide a scalable system
- Mobile objects (MO): these are mobile computational devices (e.g., cell phone or PDA) along with RFID reader
- Pervasive environment (PE): the indoor building, office or home that is equipped with RFID tags

The system uses a communication mechanism among the virtual stations called *virtual path* that enables efficient communication among the devices that is consistent over time and space. We discuss the entire system in later sections.

1. Background and Related Work

It is interesting to find out how our work is related to other research efforts in various aspects.

2.1 Indoor Positioning

There has been research works intended for indoor *positioning systems* such as the active badge location system [1], the Radar system [2], the Cricket system [3], LotTrack [4] and Landmarc [5]. The goals of these systems are to figure out the precise location information. Our system is complimentary to these systems as any of the sensing techniques can be used as the underlying positioning systems. We consider a framework that enables users to control the positioning information and send it to a system rather than the system tracking a user's location information. There have been research efforts in *wayfinding* systems in various outdoor scenarios while we focus on an indoor environment.

2.2 User Centric Systems

There are very strong set of research effort that consider the user's requirement in finding out context sensitive information. Chang et. al [6] provides a tag enabled environment as we do, and it focuses on the interface which can be paired with our system that considers the underlying system. Abascal et. al [7] focuses on a context aware system that considers a system sensing the users where we want the user to sense the system.

2.1 RFID Middleware and Path

There are middleware solutions for RFID enabled environments such as Savant [8], RFIDStack [9], WinRFID[10] and RF^2ID[11] but most of these systems focus on item tracking solutions. Our concept of path is inspired by the abstraction shown in ScoutOS [12] and RF^2ID [11].

2. The GuardianAngel System

We have designed and developed a monitoring and guidance system GuardianAngel. We propose a monitoring system that works in two layers as can be seen in Figure 2. The lower layer named as the *Guidance Layer* provides the locality information to the user to make guidance decisions in a fine grain manner. The upper layer known as the *Monitoring Layer* has the global knowledge of the environment. The environment named as pervasive environment, is equipped with low cost RFID tags. The guidance layer is supported by a handheld device that has an RFID reader attached to it. The guidance layer is thus able to provide information regarding the resident's current location and immediate objects by sensing the environment. The monitoring layer has the information about the entire environment. The guidance layer periodically updates coarse grain information defined as the *virtual location* about the resident to the monitoring layer. The guidance layer with its limited capability only keeps partial map information that is acquired on demand from the monitoring layer. If we go back to our previous example: Grandma Ayesha can use her handheld device through the guidance layer to figure out where she is and where her medicine is. Uncle Joe is periodically sending information about his coarse grain location information to the monitoring layer. It detects an unusual amount of time spent in the restroom and sends out an alert signal to the application layer. Our specific contributions are the following:

- Design and development of GuardianAngel system that allows fine grain information processing for mobile devices (held by users) and coarse grain information processing for monitoring devices
- Evaluation of GuardianAngel using small scale RFID testbed and large scale scalability study using emulated environment

Figure 2. System Architecture of GuardianAngel

3.1 System Components

The GuardianAngel system comprises of three major system components – the virtual server, the mobile object and the pervasive environment. We describe each of these components in detail to get a clear understanding of the system.

3.1.1 Pervasive Environment

The pervasive environment represents the entire indoor environment under consideration It is logically subdivided among regions which can be matched with physical entities (e.g., each room in a house or each floor in a building). The regions are again subdivided into zones to have smaller logical mapping of the environment such as family region may have TV zone, sitting zone etc. The pervasive environment requires a setup phase for initialization followed by location phase that provides location information.

- Setup Phase: In this phase the environment is installed by RFID tags. We have used an (a x b) grid spacing for tag placement that enables us to get better accuracy of the tag information considering the inherent unreliability of RFID devices. We use a semi-dynamic method for zone setup within the tag grid which allows us to define root nodes of zones and the system automatically uses a breadth first variant search to cluster tags into specific zones.
- Location Phase: The location phase enables a sensing device to make a decision about its current location within the pervasive environment. The accuracy of the current location is heavily dependent on the sensor readings and given the unreliability of RFID devices, the system is required to measure multiple samples to make sure the location information do not cross the error bound. The observation accuracy can be increased by the number of samples where observation accuracy is defined as $Pr(O) \equiv 1-(1-Pr(r))^{S}$ where s is the number of samples and o is the probability over the number of samples. The system also needs to take into account the history information to determine the direction information of the mobile user within a window of time to make sure the user gets real time inputs. We describe the details in the literature presented by Nova et. al. [13].

3.1.2 Virtual Station

The virtual station (VS) is the distributed computational element that provides a scalable infrastructure to the system. Every region in the pervasive environment is supported by a VS entity. It is the heart of the system as many of the core functionalities are incorporated in this component defined as communication management, status management and information management.

- Communication Management: The VS provides different level of communication among the components. There is a VS to VS communication using the concept of path. A path is created among the VSs to support the mobile users in the environment to transparently support through the environment. The mobile objects (the user's device) communicate to the VS periodically to exchange information regarding status or current map. There is another communication mechanism managed by the VS to support communication among the users using a message board interface. It also allows the dissemination of an alert message in case of an emergency situation.
- Status Management: The VS keeps the status of the MO in the form of state change diagrams as can be seen in Figure 2 (System View). The MO periodically updates VS with its current virtual location. The status management allows the application to define various rules that can be checked against the user status and alert signal can be sent to the application as well as users if any of the rules are violated. Currently, we support global rules for all the users in the system.
- Information Management: The VS also acts as information repository of the entire system. It supports physical and logical map of the entire region and shares area specific information to the MO as demanded. It eases the overhead to store large map information of memory constraint mobile devices. The relationship of MO and VS for map information sharing can be described similar to the main memory and cache relationship.

3.1.3 Mobile Object and other components

The MO comprises of the physical computational element equipped with sensing device which is the RFID reader here and a small software component that is in charge of making local decisions as well as communicating to the VS.

The caregiver or other users that do not reside in the pervasive environment may be interested in sharing the monitoring information and it must make sure that this level of communication follows some level of secured communication prior to being acknowledged and accepted by the user.

We have designed and implemented the GuardianAngel system – the details of the implementations are presented in the following section.

3. Implementation and Results

In this section we describe the implementation of the system followed by the evaluation of it and how the development has opened up various interesting research questions and directions for future work.

Figure 3. (a) Reading of RFID tag based on attenuation and reader to tag angular position in RFID testbed (b) RFID reading performance based on inter tag distance in RFID testbed (c) Reader performance in large scale environment using emulated RFID environment (d) RFID testbed setup (e) RFID testbed GUI that shows zones, root tags

3.1 Implementation

We have implemented the GuardianAngel system as presented in the system architecture section. We have conducted validity study of such a system using a small prototype environment using RFID tags and readers (as shown in Figure 3 (d)) along with scalability study in a distributed system using emulated RFID readers due to the limitation of resources. The code is developed in C and we have used MPI library for communication among system components.

- RFID Testbed: We have used a setup that uses a single VS that interacts with a mobile RFID reader (M220 reader from RFCode) using blue tooth connection. The assistive environment is the laboratory setup with 25 active RFID tags (M100-i IR Asset Tags). The RFID reader sensitivity ranges from -58 dB to 108 dB and has eight factory programmable ranges each with a 5 dB increment in power level.
- Distributed System using Emulated RFID Devices: The system runs over a 53 node, 106 core DellPowerEdge 1850 Linux Cluster with dual Pentium4 Xeon EMT 64 processors using Infiniband interconnects and Gigabit Ethernet.

3.2 Evaluation

We have first studied the RFID testbed using RFID tags and readers. The reading performance under various reader to tag distances and relative angular positions are observed in this study. Figure 3 (a) indicates how the reader power level various in various reader to tad distances and angular positions. There are angular positions that have lower reader signal strength compared to other angular positions. We have studied RFID tag placement for coarse grain guidance information. For this particular experiment, the system has been equipped with pre-installed information of the tag placement and a well defined source to destination route. The user equipped with the RFID reader, provides the system its current observed tags. The system has been able to successfully guide the user when the reader is placed at power level 2 as opposed to lower power level (power level =1) as shown in Figure 3 (b). This experiment is a proof of concept study that shows how the system is able to guide the mobile user if the reader power level is matched to the inter tag distance in the environment.

The scalability study using emulated RFID devices show how the system performs in a larger environmental setup. We have considered a 3900 sq foot indoor space that approximately corresponds to 1100 x 1100 tag placement in a grid setup with inter tag distance of 50 cm with emulated tags and readers. It is evident that the inaccuracy to define regions and direction increases with the larger region size but it never exceeds 7%. This shows the promises of the system in a large scale deployment.

The system is also able to provide real time location information that achieves above 90% location accuracy within 50 cm radius and 100% accuracy over a zone of more than 5 tags with 50 cm tag spacing which requires a 5 samples taking an average of 3 seconds of time. This indicates the systems stability for a slow moving person or a person on a wheel chair. The system accuracy decreases as the user increases his or her speed.

4. Conclusion and Future Directions

We have presented a middleware solution GuardianAngel based on RFID technology that enables guidance and monitoring applications that can be ideal for an assisted living environment. We have presented several system abstractions to enhance user controlled information dissemination rather than sensing a user through and environment. By virtualizing the positions, obfuscating precise timing information and giving user control on when and what to report for monitoring performances, we made the system more user friendly for such environments. Our system does not conflict with existing research efforts, it compliments many of the missing pieces to make a concrete system.

Our current research effort has opened up interesting research collaborations among systems researchers with human centered computing researchers and health systems researchers. We are currently working on deploying our system in a small scale real testbed (e.g., hospital or assisted living centers) and study the system for users experiences and comfort along with the domain experts. We are hoping to complete this research effort that may enable a safer place of many of our dear ones.

5. References

[1] R. Want, A. Hopper, V. Falcão and J. Gibbons, “The active badge location system," ACM Trans. Inf. Syst. 10, 1, 91-102, 1992.

[2] P. Bahl and V. N. Padmanabhan, “RADAR:An RF-Based In-Building User Location and Tracking System," Proc. IEEE Infocom, March, 2000.

[3] A. Smith, H. Balakrishnan, M. Goraczko, and N. Priyantha, “Tracking moving devices with the cricket location system," In Proceedings of the 2nd international Conference on Mobile Systems, Applications, and Services MobiSys, 190-202, 2004.

[4] F. Thiesse, M. Dierkes, E. Fleisch, ``LotTrack: RFID-Based Process Control in the Semiconductor Industry," IEEE Pervasive Computing, vol. 5, no. 1, pp. 47-53, Jan-Mar, 2006.

[5] M. Ni, Y. Liu, Y. Lau, and A. Patil ``LANDMARC: indoor location sensing using active RFID," Wirel. Netw. 10, 6, 701-710, 2004.

[6] Y.-J. Chang, S.-K. Tsai, and T.-Y. Wang, "A context aware handheld wayfinding system for individuals with cognitive impairments," in Asset '08: Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility, 2008, pp. 27–34.

[7] J. Abascal, B. Bonail, R. Casas, A. Marco, J. L. Sevillano, and D. Cascado, "Towards an intelligent and supportive environment for people with physical or cognitive restrictions," in PETRA '09: Proceedings of the 2nd International Conference on PErvsive Technologies Related to Assistive Environments, 2009, pp. 1–8.

[8] "Savant technical manual," OAT SYSTEMS & MIT AUTO-ID CENTER, Tech. Rep. Version 0.1 (Alpha), 2002.

[9] C. Floerkemeier and M. Lampe, "RFID middleware design: addressing application requirements and RFID constraints," in sOc-EUSAI '05: Proceedings of the 2005 joint conference on Smart objects and ambient intelligence. ACM, 2005, pp. 219–224.

[10] B. S. Prabhu, X. Su, C. Qiu, H. Ramamurthy, P. Chu, and R. Gadh, "WinRFID middleware for distributed RFID infrastructure," in International Workshop on Radio Frequency Identification (RFID) and Wireless Sensors, Indian Institute of Technology, Kanpur, India, 2005.

[11] N. Ahmed, R. Kumar, R. S. French, and U. Ramachandran, "RF^2ID: A reliable middleware framework for RFID deployment," in International Parallel and Distributed Processing Symposium (IPDPS). IEEE Computer Society, 2007.

[12] D. Mosberger and L. L. Peterson, "Making paths explicit in the scout operating system," in Proceedings of the second USENIX symposium on Operating systems design and implementation (OSDI), 1996.

[13] N. Ahmed and U. Ramachandran, "A path based system for guidance in pervasive environment," Grace Hopper Conference for Women in Computing, 2009.