An Agent-based Indoor Wayfinding Based on Digital Sign System

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ABSTRACT: Developing effective urban planning approaches is a major challenge for outdoor and indoor environments. Wayfinding in unfamiliar indoor environments is a prime task which everyone would be encountered. The development of assistive technologies to aid wayfinding is hampered by the lack of reliable and cost-efficient methods providing location information in the environment. We have applied RFID technology as a low-cost and operative approach. Our contribution is the suitable design and placement of digital sign system that can be readily detected by a handheld device. We have simulated the task with an agent-based modeling. The hypothesis of the research is that the wayfinder has a handheld device such as a PDA or a mobile system which receives and responses the signals from digital signs through passive tags. Performance of the simulation showed that the appropriate design of digital signs in an unfamiliar environment would result in a more efficient wayfinding process.

1 INTRODUCTION

This paper outlines the idea of an agent-based simulation for indoor wayfinding using a digital sign system. The ease of movement and navigation in indoor spaces such as hospitals, airports, metro stations, and promenade has significant impact on urban development. As these sites may be unfamiliar with visitors, so creation and appropriate placement of efficient aids make more feasibility for citizens as well as foreign people. Such aids (signs, maps, guides, timetables) are crucial to help people make seamless navigation (Boag Association 2004).

The advances in portable devices and wireless networks are stimulating demand for mobile services to assist wayfinding. In a scenario of using mobile system for wayfinding, individuals gain information about the environment from its distinctive physical features and ongoing activities. When individuals are on the move, the information delivered via mobile devices can be updated depending on their specific locations (Casakin et al. 2000). By means of Radio Frequency Identification (RFID) technology, it could be possible to represent sequences of wayfinding instructions via handheld devices such as personal digital assistants (PDAs) and mobile devices (Boag Association 2004). Each single instruction guides the wayfinder from one decision point to the next. The instructions are based on geometric data from the street network, which is typically the only dataset available. RFID is a promising solution for ubiquitous positioning. Using RFID, compared to the other tools such as talking signs, talking lights, dead reckoning and systems using Wi-Fi signals, makes reliable and cost-efficient method for providing location information in an indoor environment (Tjan et al. 2005).

This paper addresses the question of best placement and design of digital sign system for solving wayfinding problem in an indoor area using RFID technology for mobile users. So we utilize the advantages of agent-based simulation for optimum designing of signage in order to simplify the task of wayfinding in an unknown complex building. Our study area is Atie hospital in Tehran, one of the private hospitals in Iran which is being visited by many users every day.

Section 2 gives an overview of current wayfinding system and presents the related works that carried out using RFID in urban activities. Section 3 describes the wayfinding process and the importance of signage and guidance instructions for efficient navigation. The concept of RFID technology and its application to creating instructions at decision points is explained. At the rest of this section, the challenges of best placement of digital signs with agent-based simulation are evaluated. Section 4 explains the methodology of research. A case study in section 5 is presented to demonstrate the proposed method. Finally, section 6 gives conclusions and directions for future work.

2 RELATED WORKS ON MOBILE WAYFINDING APPROACHES

Wayfinding process in indoor and outdoor spaces has been investigated in a number of research and different wayfinding solutions are established. Previous work on sensor-based information systems was predominantly conducted for mobile guiding systems.

The CYBERGUIDE system was one of the first that used location aware information to help tourists. The indoor component relied on infrared beacons broadcasting a unique ID that was used to display an arrow on a map whenever the user entered a new room. Additionally, the user's orientation was estimated from her/his actual walking, direction and the topology of the building. In outdoor system, GPS is used to determine the user's position and to display it on a map (Baus Kruger and Stahl 2003; Neisany Samany 2006)

GUIDE is a location-aware multimedia tourist guide developed for the City of Lancaster. The system provides location based information using on a radio cell infrastructure (Baus Kruger and Stahl 2003).

The MOBIS system is an electronic guide based on a PDA that provides information on the exhibits to a visitor of a museum. The PDA receives its position from infrared beacons distributed in the environment and uses this position as a pointer to a specific content that is stored in a database on the PDA. The HIPS system uses sub-notebooks, which supports a broader range of media content than the PDA used for MOBIS. HIPS takes into account the absolute position, as well as the distance to objects in the exhibition and uses a radio back-channel for downloading information (Baus Kruger and Stahl 2003). In this context, RFID technology has been successfully applied in various cases. RFID Technology enabled smart cards poised to revolutionize life in the 21st Century, fundamentally altering the relationship between consumer and retailer, citizen and the State, as well as employer and employee. RFID smart cards enable companies and State enterprises to automatically identify, track and capture information electronically. The commercial and social applications of RFID smart cards are limitless (Reid 2006).

For example, RFID chips are used during the Soccer World Cup 2006 in Germany for entrance controls. Such technology makes it also possible to track visitors and support them in their wayfinding tasks, e.g., from the parking lot to theirs seats in the stadium. RFID was also used to improve the position of mobile robots and persons in their environment. Much work has already been done on location detection, including systems that use RFID. Malek and Aliabadi (2005), used RFID-based technology in wireless network for identifying rescue operations in their location-based mobile information system called MODDARES (Malek & Aliabadi 2005).

Literature reported detailed user evaluations of context-aware PDA hosted systems, however it is more important to design suitable signs to guide user and this paper seeks in part to address this gap. There is a real challenge for information designers to demonstrate that where the best placement of user-led design is.

3 A RFID AUTOMATED WAYFINDING SYSTEM

RFID is a relatively new, growing technology that allows more detailed tracking and monitoring of peoples' movements and decision making. It proposes a new location detection mechanism with a lower large scale deployment cost and more accuracy than other systems we are aware of. We use long-range, passive, standard-based RFID tags, which allow easy and inexpensive deployment over multiple large areas with minimal coordination.

3.1 Wayfinding

Wayfinding, getting from some origin to a destination, is one of the everyday problems that humans encounter (Raubal and Winter 2002).It is a purposive, directed and motivated activity (Golledge, 1999). Human wayfinding researchers investigate how people find their ways in the physical world, what they need to find it, how they communicate directional information and how people's verbal and visual abilities influence wayfinding (Raubal et al. 1997). According to Lynch (1960) wayfinding is based on "a consistent use and organization of definite sensory cues from the external environment". Wayfinding is a complex human activity involving moving along while evaluating alternatives and making decisions. It is defined as a spatial problem solving process with the three sub-processes including decision-making, decision execution and information processing (Timpf 2005).

Wayfinding typically requires planning and the ability to stay oriented while moving. Navigation is a coordinated and goal-directed travel through space. It consists of two components, locomotion and wayfinding. Locomotion refers to the guidance of oneself through space in response to local sensor motor information in the immediate surrounding and includes such tasks as identifying surfaces of support, avoiding obstacles and moving toward visible landmarks. Locomotion generally occurs without the need for an internal model or cognitive map of the environment. Wayfinding refers to the planning and decision-making that allows one to reach a destination that is not in the immediate sensory field and includes such tasks as choosing efficient routes, scheduling destination sequences orientating to non-local features and interpreting verbal route directions (Hajibabai et al. 2006).

People use various spatial, cognitive, and behavioral abilities to find their ways. These abilities are necessary prerequisites to use environmental information or representations of spatial knowledge about the environment. The spatial abilities are task-dependent and seem to involve mainly four interactive resources: perceptual capabilities, information-processing capabilities, previously acquired knowledge, and motor capabilities (Allen 1999). As for the spatial abilities, the cognitive abilities also depend on the task at hand. Finding one's way in a city uses a different set of cognitive abilities than navigating in a building.

Allen (1999) distinguishes between three categories of wayfinding tasks: travel with the goal of reaching a familiar destination, exploratory travel with the goal of returning to a familiar point of origin, and travel with the goal of reaching a novel destination. A task within the last category, which is also the focus in this paper, is most often performed through the use of symbolic information. Without wayfinding aids, people would not be able to negotiate their way efficiently through an unfamiliar environment.

There are four classes of environmental variables that influence wayfinding performance within built environments: visual access, architectural differentiation, signs and instruction guidance to provide identification or directional information and plan configuration (Weisman 1981). However, the original concept of delivering the instructions has not changed very much. Still, spoken language instructions use a relatively small set of commands (like 'turn right now'), which only refer to properties of the street network (Brenner and Elias 2003). There are two different kinds of route directions to convey the navigational information to the user: either in terms of a description (verbal instructions) or by means of a depiction (route map), (Hajibabai et al. 2006).

3.2 RFID advantages and applications in wayfinding

There is interest in several technologies for indoor wayfinding systems. A partial list of these technologies include: Talking Signs, Talking Lights, RFID tags, dead reckoning (gyroscopic systems, computer-readable pedometers, etc), and systems using Wi-Fi signals. Among these tools, a more flexible system which would couple an inexpensive method for determining a pedestrian's location and heading with readily accessible information about the building environment, capable of guiding pedestrians along routes, supporting free exploration, and describing points of interest to the pedestrian is RFID technology (Lu et al. 2006).

RFID is a technology which allows remote interrogation of objects using radio waves to read data from RFID tags which are at some distance from an RFID reader. RFID refers to a branch of automatic identification technologies in which radio frequencies are used to capture and transmit data. A RIFD system consists of tags and a reader (Lu et. al. 2006).

Each tag contains a small integrated circuit chip and an antenna that are encapsulated in a protective shell. The reader contains, at a minimum, an antenna and a scanner in order to communicate with the tags (Lu et al. 2006). RFID tags can be classified into active tags (battery powered) and passive tags, which are powered by the reader through radio waves. They can also be grouped by working ranges: near-field RFID systems (limited to a few feet) operate on lower band RF (for example, 13.56 MHz) and use an inductive power mechanism; the far-field systems run on higher band RF (about 915 MHz) and use an electromagnetic powering mechanism to achieve interrogation distances greater than 10 ft (Richter and Klippel 2004). In addition, RFID tags can be read-only or read-and-write, and the volume capacity of their built-in memories varies from a few bits to thousands of bits (Lu et al. 2006).

With RFID tags it is possible to create maps using mobile platforms that are equipped with RFID antennas which assist localization (Boag Association 2004). RFID technology can be used to collect environmental data and build up a Bayesian network for positioning (Arthur and Passini 1992). RFID Tags, in typical usage, a powered stationary reader decodes “passive” tags on inventory, ID cards, etc. in its vicinity using radio frequency. In principle, inexpensive passive tags could be used to label salient points in the environment and a navigator could carry an RFID reader to capture information from the tags. Although RFID technology is rapidly developing for commercial applications, an appropriate configuration for wayfinding application is not yet available due to a lack of portable readers capable of decoding tags at a range of Meters (rather than Centimeters – this is because a relatively strong RF signal from the reader is needed to power tags) and with directional (as opposed to omni-directional) sensitivity profile (Reid 2006).

The structure and technologies used for An RFID automated wayfinding system is illustrated in Figure 1.

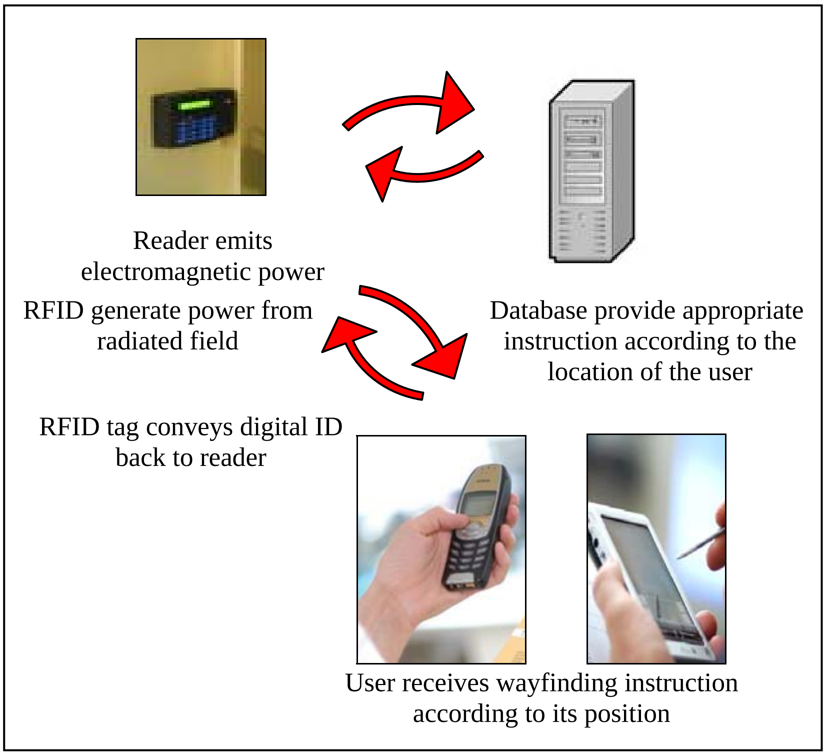

Figure 1. RFID automated wayfinding system architecture

In an innovative RFID-based automated wayfinding system, disabled travelers, for example, could collect a card for their route (probably standardized to start with, but eventually customized), and when in doubt at complex interchanges, consult a display terminal. The terminal would have been programmed with directions for each route, and as the person came within the range, it would display appropriate directions (for example ‘go your right and follow the signs’). People would not have to make direct contact with the terminal or interact directly with it, reducing queuing times and allowing the wayfinding system to serve the maximum number of travelers. The presentation of the information would be tailored to the needs of the individual (Brenner and Elias 2003).

Because the wayfinding terminal would know exactly where it is, and therefore where the traveler is, it would be able to offer precise and informative directions, and respond to get people who had drifted off the best route back to the optimal path, or provide them with alternatives. They would be able to input a change of mind at any wayfinding terminal and be issued with a new token (Kritzler et al. 2006).

Wayfinding instructions should present the following items through this system (Neisany Samany 2006):

- Create a tourist/visitor friendly environment.
- Facilitate ease of movement.
- Provide distinct and recognizable signs.
- Send clear and direct messages.
- Display graphically consistent design.
- Compliant with applicable regulations.

3.3 Effective signing

A signing system could well be made up of localization (Boag Association 2004):

- Recognition panels or ‘information points’ at key decision areas in main interchange areas (e.g. station concourses) indicating direction.
- Individual signs at decision points along routes
- Digital signs that can be varied according to unexpected circumstances allowing the system to be flexible and adaptable as the system changes.

People who face with the wayfinding process would solve these problems localization (Boag Association 2004):

- Where are the key decision points for navigator?
- How the placement of signs is affected by location and routes?
- Where are the traveler's directional signs and/or routing signs, appropriate colors, symbols, and graphic presentations available?
- Quantities of signs that people can easily cope with without feeling overloaded.

In this paper we have considered the digital signs which could be provided for travelers at decision points. Therefore, we have attempted to establish the appropriate design and placement of these elements. To achieve this goal we applied the agent-based simulation.

3.4 Agent-based simulation

Agent-based simulation has been implemented in the field of artificial intelligence and brings a new solution to the concept of modeling by offering the possibility of representing individuals, their behavior and interactions. An agent system provides more flexibility by dynamically modeling agents with different abilities, faster problem solving, decreased communication by transmitting only high-level partial solutions to other agents rather than raw material to a central site, and increased reliability by allowing agents to take on responsibilities of other agents that failed.

The realistic representation of human behavior in crowd simulations requires rich models or architecture that is able to represent partly, the complex human behavior in fire emergencies. Modeling complicated human behavior for a general situation is extremely difficult and involves a certain degree of abstraction backed up by a rich architecture. One of the commonly used ways has been designing an intelligent agent that will mimic the overall characteristics of a human.

Neglecting the focus on particular methods and applications, the core element of agent theory is the agent concept (Arthur and Passini 1992). According to the heterogeneity of the field, there is no common agreement about a definition of the term ‘agent’. Anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors can be an agent (Russell and Norvig 1995). An agent is an entity that is capable of acting and perceiving its environment (Figure 2).

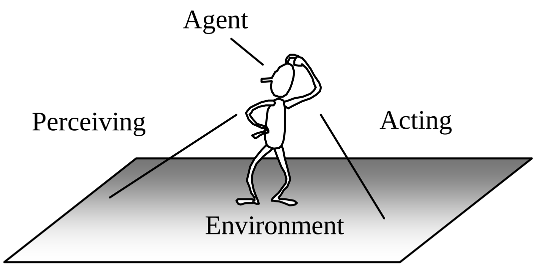

Figure 2. An agent embedded into the environment.

Intelligent agents are autonomous, cooperative, learnable and adaptable and equipped with social ability, reactivity and pro-activeness. Agents, in general, differ in the way they interact with the environment, to what extent they know the environment and whether they can predict the changes in the environment or not. A perception system enables an agent to classify and distinguish the states of the environment and other agents. The agent links the observation of the reality with its internal cognitive system and learns about the environment. By learning the wayfinding environment, the agent updates its beliefs (Krek 2002).

4 METHODOLOGY

Our work has focused on the suitable design and placement of digital sign system that can be readily detected and identified by a handheld device and guide the wayfinder. So we have simulated the task with an agent-based modeling. The reason we have used the agent-based simulation instead of custom computational geometry approaches is that we wanted to find the optimum placement of the signs not the coverage of them in the environment. Also the cognitive relationship of the wayfinder with the cues was an important factor to be considered in this issue, so we used the agent-based modeling in the research.

The hypothesis of the research is that the wayfinder has a handheld device such as PDA or mobile system which receives and responses the signals from digital signs through passive tags. The digital sign system sends informational signals that would be converted to text or speech format in the wayfinder's PDA system.

Being the sign or some other informational devices at appropriate positions in order to best introduce the environment for reliable decision-making is very important. Placement of digital sign system and the suitable quantity of them in the environment are effective factors for optimum guidance of a wayfinder who is unfamiliar with the environment and needs to have the information in his/ her PDA system. In this research we have simulated the scenario with an agent-based model in various situations of placement and quantity of the digital sign system. The model has been successfully analyzed in this research in order to gain the most optimum design and placement of the building cues (Hajibabai 2006). By comparing the different situations, we can find the best results for designing the positions of digital sign system that would affect the wayfinding efficiency and simplify the task in an unfamiliar building.

The simulation has been done with an agent who performs actions such as perceiving information from the alarms in the PDA device and moving through the environment. Given a sequence of digital sign system between the current position and a desired destination, the controlled object is programmed to execute the appropriate steps necessary for an agent to reach the destination point. Formalizing the conceptual model for the cognizing agent allows describing it more precisely than by using a verbal description and to create a practical tool for simulating the test case (Figure 3).

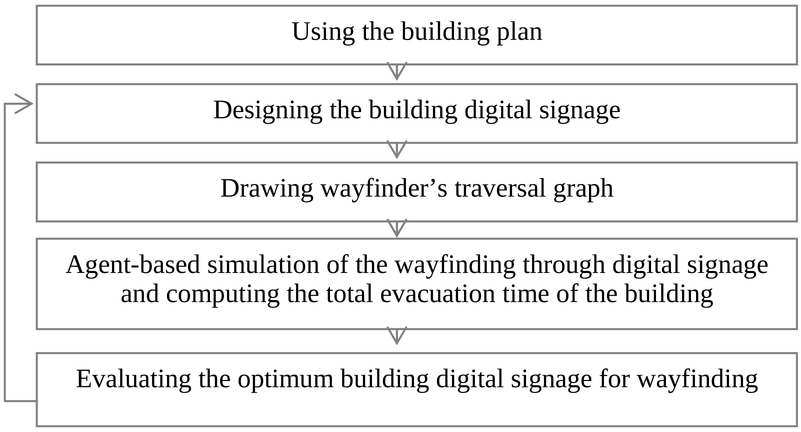

Figure 3. Conceptual model for the cognizing agent

As shown in Figure 3, in order to represent and simulate knowledge and action in such a wayfinding situation, we have designed the building digital sign system’s placement and a wayfinding traversal graph in the building plan. The agent moves in the building environment and changes its position. The wayfinding agent observes the information about the situation in the PDA and learns about the building environment. Planning happens at every decision point where the agent has to select the next way to continue wayfinding via the optimal path to the destination. The agent’s decision is based on the plan; it takes the path suggested by the planning program as the first on the planned path to the destination (Figure 4).

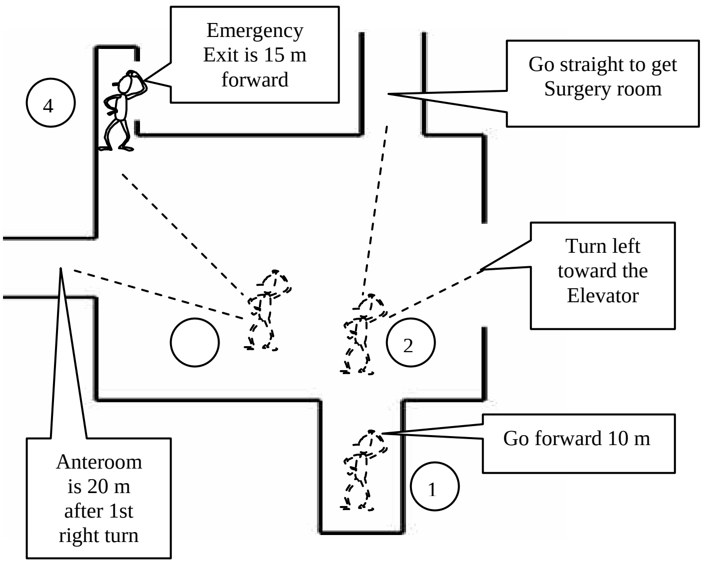

Figure 4. Sent messages to the agent

The agent would gain information from the building’s digital sign system. At position 1 the agent gets the text "Go forward 10 m" from the digital sign system in the way to the decision point 2. It goes and receives some other texts about "Turn left toward the Elevator" and " Go straight to get Surgery room" in its PDA system at position 2, which is not its destination. It goes in another direction (position 3) to receive some other textual information from the signs, so it receives "Anteroom is 20 m after 1st right turn" and also "Emergency Exit is 15 m forward" information and it selects the information guiding it to the emergency exit that is its destination. It takes an action and goes to the emergency exit, which is the position 4.

There are cases in which the signal including the information about the goal, may not be received in the PDA. In such cases the wayfinder needs to move in order to get the suitable signals (Figure 4).

Based on the knowledge in the world, the information from digital signs, the wayfinder takes a sequence of actions until the wayfinding task is completed. Starting with imperfect observations of the space, the wayfinder derives incomplete and imprecise knowledge and based on such knowledge takes an action. Actions lead to further observations and knowledge, recursively to further actions until the goal is reached. In this paper the total time consumed to reach the emergency exit of the building is computed in order to evaluate the signs planning and achieve the optimum placement of the signage.

5 SIMULATION OF AGENT-BASED WAYFINDING USING DIGITAL SIGN SYSTEM

This research takes the agent-based simulation and determines an optimal plan to find a special way in the building in the shortest time possible (Hajibabai et al. 2006). Agent simulation of the optimum building signage placement has an effective role in urban management and improves upon other simulation models that are concerned with numerical analyses of inputs or number of people and structures.

In order to clarify the concepts and methods used, we describe a case study that illustrates the situation in which our approach applies. It concerns the problem of wayfinding in a hospital which may be unfamiliar to someone. We have considered a situation in which:

- The agent is a normal person who can read the texts and decide upon various information received in his PDA
- The wayfinding environment is a complex building with various rooms and exit ways.
- His destination is the emergency exit of that floor of the complex building
- He wants to use the digital sign systems to find his way.

This section demonstrates the applicability and usefulness of the presented approach by showing a simulation study. Applying the same wayfinding agent in different situations (e.g. hospital buildings) and comparing the circulation time of them, would determine the most efficient building design from the wayfinding point of view (Figure 5).

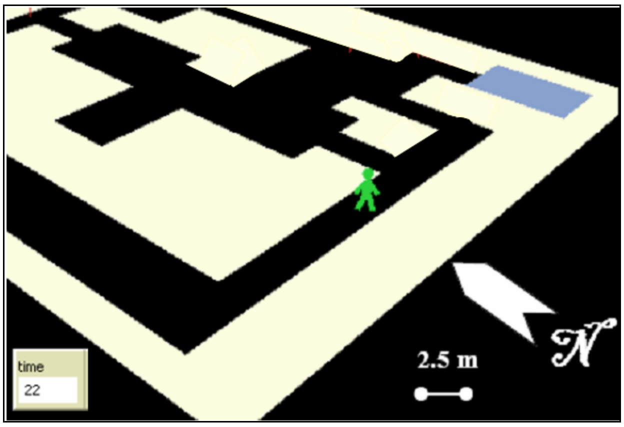

Fig. 5. Designing of the digital sign system in the wayfinding environment.

In order to simulate the wayfinding process in the hospital building, we have programmed the task in a functional programming language, Netlogo, and computed the different evacuation times and found the best placement and design of the digital sign system in the hospital. Wayfinding through the optimum building signage would take the shortest evacuation time. The simulation results have been compared in different designing situations (Table 1).

Table 1. Comparing Total Wayfinding Time due to Signage Design

Different Designing Situations in the Hospital	Total Wayfinding Time (s)
A	126
B	93
C	87
D	45

A is the case with the worst signage design and quantity of the signage. B is the situation with a sufficient quantity but the placement of the signage is not suitable, and C is the case with the optimum placement of the signage, but the quantity of the digital signs is not enough. D is the situation in which both placemen and quality of signage are optimum. It should be considered that the times given in Table 1 are the mean value of the wayfinding times achieved in several calculations at each situation. The difference between the different runs of the time values was not great. It can be observed from the results that in all of the signage design situations, the total time of the wayfinding process from origin to destination have been reduced due to better placement of the cues and optimum determination of the quality and quantity of the digital signage.

6 CONCLUSIONS AND FUTURE TRENDS

In this research, we applied RFID technology as a low-cost and operative approach to assist mobile wayfinder in an indoor area. Our contribution is about the suitable design and placement of digital sign system that can be readily detected and identified by a handheld device and guide the wayfinder. This paper takes the agent-based simulation and determines an optimal plan to find a special way in the building in the shortest time possible. The hypothesis of the research is that the wayfinder have a handheld device such as PDA or mobile system which receive and response the signals from digital signs through passive tags. Performance of the agent-based simulation showed that the appropriate design of digital signs in unfamiliar environment could result in more flexible and efficient wayfinding process.

The results show that the better placement of the cues and optimum planning of the quality and quantity of the digital signage would lead to the shorter wayfinding time. We proposed in this paper formalized strategies which describe how spatial cognizing agent can find the ways in a building by the use of the building digital signage. It can be observed from the results that in all of the digital signage design situations, the total time have been reduced due to better placement of the cues and optimum determining of the quality and quantity of the digital signage.

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