Development of an RFID dependant multimodal wayfinding system based on procedural generation of 2D and 3D route visualizations and fitted wayfinding information

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ABSTRACT

Navigating in complex indoor environments such as hospitals, can be a complicated task. In addition to losing one's way, lack of sufficient wayfinding information is also known to cause both psychological and physiological strain. All of these issues can cause delays and extra work for hospital staff, consequently leading to financial losses for the institution. Over the course of three experiments of limited sample sizes (6, 15, 10), we have developed an RFID enabled multimodal wayfinding system based on procedural generation of 2D and 3D route visualizations and fitted wayfinding information. In a comparative study conducted in situ at Aalborg University Hospital South, we determine that the egocentric 3D route visualization and dynamic allocentric map activated through RFID detection leads to improved wayfinding performance in metrics such as completion time, hesitations, and route length compared to the in-place navigation system (signs, colored floor lines, etc.). We see the potential in a more comprehensive implementation, due to the clear indications of wayfinding improvements, and the benefits that these afford for both institutions and wayfinders.

1. INTRODUCTION

As hospitals grow larger both in size and/or patient count, guiding patients efficiently to their intended destination within the complex architectures, carries increasingly more importance. Ineffective navigation of hospital-space can result in disorientation [1] which may foster negative physical or psychological consequences such as physical strain (stress symptoms [2], tiredness from wasted walking [1]), or anger (e.g frustration from insufficient wayfinding information)[1]. People who have experienced being lost, characterise their efforts of finding their destination as time wasting, stressful and frustrating[1].

Furthermore, insufficient navigation can lead to financial losses for hospitals [2, 3] in terms of coalescing delays and cancellations, when patients become lost while looking for their destination. Consequently, improvements to making sufficient wayfinding information available with a low technological barrier for ease of use is essential. However, "sufficient wayfinding information" is an elusive paradigm, considering the variation in demographics with age, mobility, ethnicity, language and literacy levels differences between hospital-visitors. Taking these factors into account, the wayfinding information that is provided and usability of the system cannot depend on prior technological, cultural or linguistic knowledge or training, instead it should be universally interpretable and usable. What we propose, is to create such a system, utilising information mediation and seamless human computer interaction (HCI). To accomplish this, we investigate the use of multiple modalities and different information mediation techniques initially in a university building and then in a hospital setting. We also investigate how off-the-shelf passive wireless solutions can reduce the need for direct interaction with a wayfinding system, in turn lowering the technological barrier needed for successful wayfinding, where the solution incorporates technologies.

We hypothesize that the integration of such an HCI interface combined with suitable information mediation techniques will increase wayfinding efficiency. We determine this through a series of iterations to improve the prototype system and subsequently an experiment run at Aalborg university Hospital in where we compare the developed wayfinding system with the in-place wayfinding system.

2. RELATED WORK

Wayfinding is characterized as human behaviour and knowledge of where you are, where to go, which route to go by, recognising your destination and being able to reverse the process [1]. In a complex building such as a hospital, meeting these demands can become a complicated task.

2.1 Wayfinding Information

Technological wayfinding solutions are being increasingly explored as technology has increased in capabilities, and people become more comfortable with technological augmentations or revisions of traditional systems. These augmentations typically utilize multimodal systems such as auditory, visual or audio-visual modalities, in a technological context (e.g visual information is screen based), for mediation of wayfinding information. Screen based solutions generally mediate their navigational information through map-based allocentric representations [4, 5], 3D route-visualizations that approximate the egocentric view of the tour through the route [6, 7, 8] or 3D maps, which allow users to freely roam in a 3D representation [9]. Allocentric representations are defined by localisation through exterior points independent of the holders position [10]. In contrast, an egocentric view represents locations with respect to the perspective of the perceiver[10].

In a recent study, van Schaik et al. [11] found that their 3D egocentric system had a higher acceptance, faster completion time, and lower perceived disorientation over a traditional map and signage system in a hospital. The 3D egocentric system mediated wayfinding information through a 3D route visualization at a pace of 9.36 km/h. They attribute part of the better scores to how this egocentric "preview" of the environment facilitates the development of one's cognitive-map. These findings are corroborated by Oulasvirta et al. [9], who explain how 3D maps, through realistic visualizations, support representation of real world objects in a more comprehensive manner, how 3D maps allows users to view spatial information from multiple perspectives, and support egocentric alignment. In comparison, 2D maps typically rely on cues and symbols for representation of environmental features, which in turn requires decoding before a correlation between 2D map and real world can be established. Because this correlation is essential for the navigational process, their suggestion is to adopt a realistic approach when developing a 3D map, and allowing the user to determine how to best utilize the available information.They investigated this in a field study, through creation of a semi photo-realistic 3D map, containing important environmental features such as landmarks and correct building geometry. The 3D map was viewable on a mobile device and the user was able to navigate in the 3D map using buttons on the handheld device. Their conclusion is that in comparison with a handheld 2D map with similar controls, their 3D map yields significantly worse wayfinding performance, when navigating to points of interest in outdoor environments. Oulasvirta et al. [9] state that, what one would assume to be benefits of 3D maps, for example rapid landmark recognition and egocentric alignment, works poorly as tools for navigating using their system. Egocentric alignment proved difficult because of issues relating to alignment of an appropriate egocentric perspective while maintaining a point of interest in line of sight. Similarly landmark recognition also proved more difficult than expected, primarily due to localization difficulties in the 3D map and in some cases landmarks would be difficult to distinguish from each other due to the small screen size of the handheld device. We propose that, to avoid issues relating to egocentric alignment and distinguishability of landmarks in our system, the screen size should be significantly larger and self-control (button navigation) should be excluded. Next, the user should, from initiation of the system, be aligned with the egocentric perspective and upon activation be moved to their destination along a procedurally generated path e.g a 3D route visualization, similarly to the approach utilized by [11].

A study conducted by Münzer and Stahl [7, 8] found that mediating visual wayfinding information from allocentric and egocentric perspectives both create grounds for efficient wayfinding. Their experiment compared completion time, hesitations, misapprehensions and questions asked, amongst participants wayfinding using either static allocentric information (2D maps), static egocentric information (pictures) or dynamic egocentric information (3D route visualization). They conclude that the egocentric representations benefit from being dynamic, but did not investigate the effects of dynamic allocentric information. Considering the benefits of dynamic egocentric 3D information, one would also assume that introducing dynamic elements into the allocentric information domain would be beneficial. Harrower [12] explains how this integration should take into account simplicity and segmentation of the information, to not overwhelm the user. Harrower also describes how users are easily frustrated if they have no control over the animations or movement in a digital map. Something as simple as pause/resume/restart buttons are important, even if they might not be used. Furthermore, Harrower discusses the importance of grabbing the attention of the user for critical moments (such as landmarks), with auditive and visual cues. Based on this, dynamic allocentric visual information should be integrated along side the route visualization (Dynamic egocentric information), when mediating wayfinding information.

However, the perspective of the visual information is not the only important factor. The content of the visual representation is essential. Landmarks in the environment help us build our internal representation of environments. May et al. [13] found that approximately 72% of the required information for successful wayfinding was directly related to environmental landmarks. van Schaik et al. [11] utilized this for in-door wayfinding where their 3D route visualization system emphasized certain landmarks present both virtually and physically on the route. Along a wayfinding route, decision points arise. These are locations at which a user has to make a decision about the next step in the wayfinding process. According to May et al. [13], these points can elicit disorientation and uncertainty for the user, if not provided with sufficient wayfinding information. They conclude that 68% of successful wayfinding instructions is given at main navigational decision points (cross-roads). However, they also emphasize the importance of the last 32%, which is presented between decision points, and plays an important role in maintaining credibility of the information received at the decision points. In a hospital setting, tools such as landmarks, colour highlighted line-directions, and the in-place signage system, can potentially help to maintain wayfinding credibility between decision points when integrated with our system.

Landmarks might not always have to be conveyed through visual means. Audio can also be used in a more traditional sense for spoken directions and auditory landmarks. Stahl [14] has used short duration auditory landmarks as indication of directionality and distance to points of interest with some success. The same methods could be utilized to provide distance and directionality measures to our proposed wayfinding system. The integration of the auditory landmarks could be achieved through use of individualized abstract sound, for example each user is familiarized with a sound at the first wayfinding point, and subsequently the same sound should be used to attract their attention and provide directions to the next wayfinding point, when in their proximity.

Streeter et al. [15] has used spoken directions in a study, with 57 participants, divided among four wayfinding conditions (1. Spoken directions, 2. Map, 3. Spoken directions and map, and 4. Control). The participants were asked to navigate by car to a predetermined destination. Both map and spoken direction conditions integrated landmarks as an essential frame of reference for directions. Wayfinding performance was measured based on miles traveled, amount of turns, travel time and errors made. Streeter et al. [15] concluded that spoken directions yielded better wayfinding performance, compared to both allocentric maps and allocentric maps with spoken directions.

Wright et al. [4] also integrated spoken directions in their wayfinding system. They designed and implemented a wayfinding information kiosk that utilized allocentric visualizations, spoken directions and written directions. Out of their total 1517 way-finders, audio directions were disabled in 28% of use attempts indicating that a substantial segment of users who do not appreciate auditive instructions in some way. Since the audio was opt-out, there might be even more who might not be fully comfortable with the audio directions, but not aware of their ability to turn it off. While reception staff reported that the audio from the terminal was not a problem, complex wayfinding information through spoken audio requires that a high amount of the directions are correctly comprehended, which can be hard in areas of high background noise levels, especially for older adults [16]. In some situations, the volume level needed to convey long sets of instructions, might potentially be annoying or embarrassing for the user.

2.2 System interactivity

Considering the potential cultural and age diversity of out-patients, the interaction with the wayfinding terminals needs to be as seamless and intuitive (walk up and use) as possible. Ideally, any out-patient arriving at the hospital would be automatically registered as arrived in the hospital system, and shown the necessary wayfinding information needed to find their way to their prearranged destination. With multiple terminals, the registration and updated wayfinding information can occur multiple times while traveling through the hospital. Such a process could also allow administrative personal in the hospital access to information about patient arrival and their last registered position, so as to anticipate potential delays, reschedule other patient meetings or assist the patient. Such a system should already be theoretically achievable with passive long-range wireless technology such as UHF RFID. RFID or radio frequency identification, is an emerging technology used worldwide for registration purposes [17]. An RFID system is comprised of two elements, tags and readers. The tags come in two variates passive and active: Active RFID tags need to supply their own power, but supports very long ranges. Passive RFID tags on the other hand needs no additional power, but that which is supplied by the magnetic field generated by the RFID reader. With a sufficiently powered UHF RFID reader, cheap passive UHF tags can be reliably read over distances of 1-10 meters[18, 19].

RFID systems have already been integrated in wayfinding systems on multiple occasions. Chumkamon et al. [20] created a system in which low frequency passive RFID tags were integrated into footpaths and used as location indicators in wayfinding system for visually impaired individuals. The users of the system were equipped with an RFID reader able to detect the embedded RFID tags when near them. Based on the location information provided by the RFID tags, appropriate spoken wayfinding information was mediated to the visually impaired individual. Similarly, Chang et al. [21] investigated the integration of passive RFID tags for use as location indicators in a wayfinding system for individuals with cognitive impairments. The passive RFID tags were embedded at decision points and would display egocentric visual wayfinding information, on a handheld device, when registered by their RFID reader. Their system also incorporated a tracking mechanism based on expected and elapsed travel-time between registration points. In case of prolonged travel time or failure to arrive, the correct authority could be notified.

Equipping every wayfinder with an RFID reader and embedding passive RFID tags in the environment allows for very precise location tracking, but scales very badly with the amount of potential users of a system. On the other hand, it could potentially be both cost effective and more practical to supply every user with a unique passive RFID tag, with RFID reader terminals placed at strategic locations and decision-points in the environment. Out-patients could be equipped with a passive UHF RFID tag directly embedded in the call-letter that summons them to the hospital.

2.3 Summary

Navigating complex hospitals can be a tiresome task and out-patients experience frustration, when trying to navigate with insufficient wayfinding information. The importance of sufficient wayfinding information is also underlined by the potential financial losses hospitals might incur due to delays and cancellations caused by out-patients being lost.

Wayfinding information can be mediated using different modalities but considering the findings from this section, we see potential in utilising 3D visual information in combination with auditory landmarks and spoken directions. The following modalities are integrated in an initial wayfinding system prototype:

- **Dynamic Egocentric Visual information** - A 3D route visualization of the respective wayfinding path
- **Dynamic Allocentric Visual information** - A Simple map incorporating a dynamic representation of the wayfinders position, and simplified representations of visual landmarks in the environment.
- **Spoken Directions** - Spoken directions provided in designated sound zones, ideally utilising directional sound source
- **Auditory Landmarks** - Sound-beacons attached to wayfinding terminals, emitting individualized sound cues to provide information about direction and distance when near wayfinding terminals.

Furthermore, dynamic allo- and egocentric information and spoken directions should emphasize static environmental landmarks and the information should be available, through wayfinding terminals, at appropriate decision points, dependent on route complexity. With these requirements, the physical design of the prototype wayfinding terminal needs both visual and auditory capabilities, and with the high volume of potential users in a hospital setting, the prototype should be one or more statically located wayfinding terminals that patients can utilize at their own volition. Providing information between decision points is also important in order to maintain credibility of the wayfinding information received at the wayfinding terminals. This is achieved by integrating the already existing wayfinding means in Aalborg Hospital in combination with referencing and highlighting static landmarks (signs, elevators etc.), between decision points, in the 3D route visualisation and allocentric map.

In addition, out-patients should be registered and provided with suitable wayfinding information upon entering the range of a wayfinding terminal. This proposes a challenge, as each user of the system needs an identification tag uniquely linked with their respective destination. Ideally each call letter should be equipped with a passive RFID tag, readable by RFID readers located at each wayfinding terminal. Beyond registration upon arrival at the hospital, the RFID technology should also facilitate registration of the user at any wayfinding terminal that the user happens upon during their transit. This can help to inform hospital staff of the approximate position of a user to anticipate delays or help the patient if lost.

3. PRELIMINARY EXPERIMENTS

Based on the knowledge synthesized in Section 2, two preliminary experiments were carried out on respectively 6 and 15 participants. Each experiment employed a further iteration of the prototype wayfinding system.

3.1 Preliminary Experiment 1

The preliminary experiment 1 was purposed with defining the benefits of different modality combinations for mediating wayfinding information in context of our system. The initially developed prototype 1 had the following functionality:

Upon simulated (at the time no actual RFID was implemented) registration of a test participant at the wayfinding terminal, an audio landmark would try to get the participant's attention by calling out the participant's name. Subsequently, the wayfinding information would start, either in the form of a 3D route visualization, spoken directions, or both. The 3D route visualization consisted of an animated walk from the starting point to the destination, recorded from the egocentric perspective, along with a small circular allocentric "mini-map" with an indicator of the current position in the walk-through. The spoken directions consisted of five sets of directions with emphasis on specific static visual landmarks e.g "turn right after the elevator". The spoken directions were played in chronological order at a normal talking pace. After the play-through of the respective modalities, depending on which condition the test participant had been submitted to, the system interface would turn black, and the participant should start the navigational task.

Early on in experiment 1 it became evident that the prototype 1 interface was insufficient, and obscured the initial purpose of the experiment. Based on observations and analysis of video footage it was apparent that the automatic activation of the 3D route visualization upon simulated registration was not ideal, as participants generally missed out on information due to not being ready or prepared for what was to come. Also apparent was that participants lacked an overview, despite having the allocentric mini-map available during the 3D route visualization. Participants explained that, as they did not know were their destination was in the allocentric map, it was not very useful and at times confusing. Furthermore, all participants were unsure on when the wayfinding information had concluded and when they where supposed to start their navigational task. Finally, the auditory landmark seemed promising in aiding participants in discovering the wayfinding terminals. However, without the integration of a functional long-range RFID reader, the simulation of the registration and audio cue playback process relied on remote activation, and was difficult to facilitate.

3.2 Preliminary Experiment 2

Another preliminary experiment was conducted purposed the same as experiment 1, utilising a second iteration of the prototype. We hypothesized that *"combining spoken directions and dynamic allo- and egocentric visual information (spoken-visual) would yield a better wayfinding performance, compared with only spoken directions or dynamic allo- and egocentric visual information respectively"*. See Appendix A for more details about this experiment. The new prototype 2, contained the following additions and changes compared with the first prototype:

- Allocentric map route indicator was implemented - line leading from start to finish, establishing an overview and indicating destination.
- Automatic activation of wayfinding information was disregarded, instead deliberate user action, starts the wayfinding information
- Explicit information about arrival was implemented - Text and speech based affirmation was implemented when the wayfinding information has concluded.

The second prototype still did not have a functional long-range RFID reader, and to optimize the facilitation process, the auditory landmarks were disabled for experiment 2, with the focus of the experiment being the comparison of the other wayfinding mediation modalities.

The experiment took place at Aalborg University, Create Building located in Aalborg. 15 Participants participated, all were recruited in situ. Three modality conditions were possible: Visual (3D route visualization and allocentric mini map), spoken directions, and a combination of visual and spoken directions. The experiment used a between-subjects experiment design and measured wayfinding performance based on completion time, hesitations at decision points and errors made. In addition, participants were also asked to rate the system in relation to overall usefulness, visual directions, spoken directions, usage of in-place signage, and credibility of the presented wayfinding information.

The participants in the experiment showed greater reliance and more trust in the wayfinding system when submitted to the visual and spoken-visual conditions. However, the spoken directions were rated significantly lower compared to the visual directions in the spoken-visual condition. From the significantly lower credibility rating of the spoken directions in general, we concluded that the wayfinding prototype would not benefit from the addition of spoken directions when the combination of allo- and egocentric visual information is both easier to implement with regard to procedural generation in a complex environment and shows a higher acceptance without significantly influencing the wayfinding performance. Furthermore, based on observations of the participants, it was apparent that there was a problem with not affording the participants an initial overview of the route or their destination, in turn disorienting some participants at the the very beginning of the 3D route visualization.

4. METHODS

Based on the knowledge synthesized in Section 2 and the data from two preliminary experiments in Section 3, we iterated the system and developed a third wayfinding system prototype ready to be evaluated in situ in a comparative field study conducted at the Aalborg University Hospital South. We hypothesize that test participants that utilize this prototype will fare significantly better when measured on their wayfinding performance, compared with those that use only the in-place navigation systems. The prototype would ideally allow participants to navigate faster, cover less distance, make fewer errors, feel need to ask less questions and feel more security in their navigation.

4.1 Wayfinding system prototype 3

The third prototype (See Figure 1) encapsulates two main functionalities: User registration and wayfinding information mediation. The prototype terminal consists of an 8 inch. *NVIDIA Shield* tablet [22] and a *U Grok It* UHF Gen 2 RFID reader [23].

Figure 1: The prototype terminal setup at a central location in the entry hall of Aalborg University Hospital

User-registration is managed through the RFID reader, which is consistently able to register a user's RFID tag within a 2-3 m proximity of the wayfinding prototype. Prior to testing, each participant is outfitted with a call letter containing a passive UHF RFID tag. Based on the unique identification code contained in the tag, the prototype would read who is using the prototype, and access information on which destination they need to navigate to. In practice, the test participant's information is added into a database and linked with a specific tag by a test facilitator prior to the beginning of the test.

As a valid tag is registered near the wayfinding prototype the RFID reader emits a sound to acknowledge a successful registration and to direct attention to the prototype. In addition, the prototype calls out the participant's name in their native language using the Google Translate API [24]. This is also done to direct attention and provide information about the location of the prototype. On the tablet screen, used in portrait mode, the participant's name is illustrated along with their destination and the time they are expected at their destination. A large finger icon blinking near the bottom of the screen prompts the user to click the screen to proceed. Clicking the screen initiates a transition to an allocentric map of the hospital area, with a starting point, a destination and a procedurally generated optimal route drawn between the two points. At the top of the screen is written *"Click to proceed to route visualisation"* and the touch icon is once again shown in the bottom.

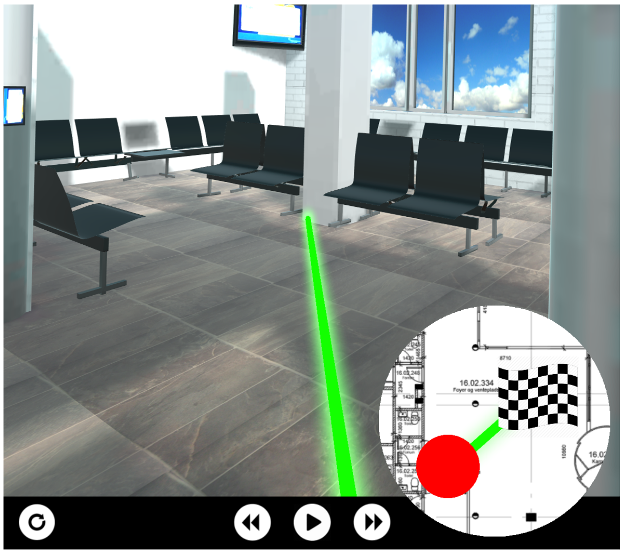

Figure 2: A screenshot of the 3D route visualization

Touching the screen again initiates a transition to the egocentric route visualisation. The route visualisation is purposed with mediating wayfinding information through a procedurally generated virtual walk-through based on an accurately dimensioned 3D model of the intended environment. Allocentric information is also present in the form of a small "mini-map" in the lower right corner, showing the current position and route of the virtual camera.

Located at the bottom of the screen are playback control buttons with functions and designs made to mimic common conventional VCR controls(see Figure 2). Five functions are possible: Replay, slower speed, pause, faster speed. As the virtual walk-through concludes at the destination, a prompt pops up on screen informing the user that this is their destination both visually and verbally.

4.1.1 *Experimental Design*

A blocked within-subjects experiment design is used to evaluate the third prototype. A within-subjects experiments allow us to optimize the amount of samples gathered in testing. By selecting routes with minimum overlap we ensure that any potential bias related to already becoming familiarized with outlay and way of the routes is avoided.

Each run of the experiment required the participant to navigate both routes, one with the prototype and one without (as a control condition) using in-place navigation. The order in which participants are submitted to conditions is blocked, meaning the equal numbers of participants start navigating using the prototype, as do those who start without the prototype. The two comparative settings we test are:

- **Condition 1**

- Route 1 **(With prototype 3)**
- Route 2 **(Without prototype 3)**

- **Condition 2**
  - Route 1 **(Without prototype 3)**
  - Route 2 **(With prototype 3)**

When submitted to **condition 1** the participant would navigate through *route 1* with the help of the prototype and through *route 2* without the prototype, aided only by the in-place navigation system (Colored lines, static allocentric maps and signage). In **condition 2** participants would navigate through *route 1* without the prototype and through *route 2* with the prototype.

Two routes were, as illustrated in Figure 3, used in both control and test condition to avoid any bias related to specific routes. Objective dependent variables measured during the experiment are: Completion time (Only travel time, time spent interacting with the prototype is not be counted), route length, hesitations (a hesitation is counted if a participant stops, or slows down significantly, due to insecurity of where to go), errors (participant turns down a path which cannot lead to the destination). In the case of a participant making such an error, they are informed within 10 seconds that they are lost, and lead back to the point where the initial error occurred. In addition a spatial ability questionnaire[25], and questionnaires based on Davis [26] and Davis [27] for measuring usefulness and ease of use of the prototype (See Appendix B), are also included.

4.1.2 Participants

Participants were primarily recruited from Aalborg University locations, as a request for permission to recruit participants in situ was denied by the hospital administration, based on ethical considerations. 10 participants, aged between 20 and 30, were recruited. All participants were currently enrolled in an education at Aalborg University. In the initial recruitment process we ensured that the test participant were unfamiliar with the selected areas of the hospital where the experiment took place.

4.1.3 Wayfinding routes, Materials and equipment

The experiment takes place in situ at Aalborg University Hospital South. The hospital employees circa 6500 people across multiple departments located in northern Jutland. Each year over 500.000 out-patients are handled. 93.000 surgeries are carried out and around 80.000 people are discharged. Cumulatively this means that more than half a million people frequent or visits the hospital departments each year [28]. With its 43 separate departments and over 400 admission beds, Aalborg University Hospital accounts for the majority of the patient traffic. Due to its size, and restriction from administration, we used only a small section of the Hospital area for testing. The area includes the main entrance and numerous departments including the Eye out-patient department and the emergency room, both of which are used as target destinations. The in-place wayfinding system in the selected area is serviced by text signs and arrows pointing to locations. The signage in the main entrance area serve as a starting point when navigating to different departments in the hospital and does therefore also contain a comprehensive signage overview. Besides the signage overview at the main entrance, less comprehensive signage is located at decision points where relevant. Two routes with varying difficulty was selected for test purposes:

- Route 1. **Main Entrance(ME) → Emergency Room(ER)** - This route begins in front of the main entrance. The optimal route is approximately 85 m long and includes four decision points. At each decision point in-place signage is available with directions to the destination location.
- Route 2. **ER → Eye Out-patient area(EA)** - This route starts in the Emergency Room waiting area and the optimal route is approximately 111 m long and includes five decision points. In-place signage with directions to the destination is available at two of these decision points.

The difficulty variation is based on the amount of decision points and in-place wayfinding information available during the wayfinding process. In this case route 2 (**ER →EA**) is the more difficult one. The optimal routes can be seen in Figure 3.

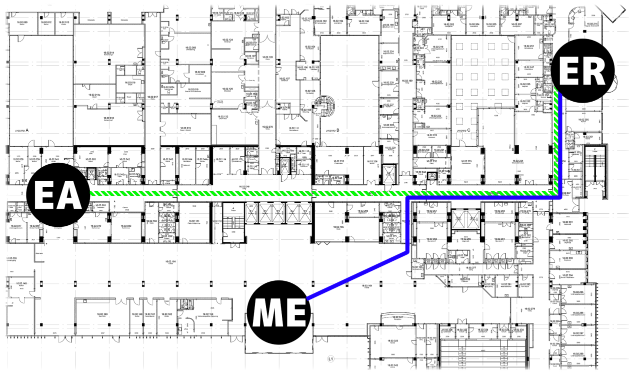

Figure 3: Optimal routes of the experiment. The solid blue line represents the optimal route from ME to ER, and the dashed green line represents the optimal route from ER to EA.

4.1.4 Procedure

On arrival to the hospital, participants were seated at a location away from the actual testing area to avoid any potential bias related to exposure to the testing environment. At this location the participants were informed about the purpose of the prototype and asked to fill out a consent form, a demographics questionnaire and a spatial ability test.

One at a time, each participant would be handed an RFID equipped call letter while a facilitator would set up a scenario for the participant in which the participant had just arrived at the hospital with an appointment to one of the destinations within a five minute time frame (from the onset of the task). Upon expressing their understanding of the scenario the participant was lead to the main outer entrance of the hospital, at which they were outfitted with a pedometer and asked to start the navigational task. In case the participant was submitted to **condition 1** they would be registered by the prototype upon entering the hospital at *ME*, and had to interact with the prototype to find their way to *ER*. Upon reaching *ER*, the pedometer data would be logged and the participant re-informed about the next scenario of locating the destination in *EA* without the use of the wayfinding prototype. For **condition 2** the same routes are traversed, but the usage order of the wayfinding prototype is reversed.

Upon conclusion of the tasks, a test facilitator would asked the participant a few exploratory questions in relation to specific decision they made along the way e.g "Why did you hesitate at X location?", "Why were you so sure on where do go at Z location?". Through out the entire navigational process the test participant is video recorded from a frontal-profile angle. For each test run approximately 30 minutes was allocated, and included 10 minutes for instruction and initial questionnaires, 10 minutes for actual navigation and 10 minutes for post experiment interview and prototype evaluation questionnaire.

5. RESULTS

Ten people participated in the experiment taking place at the Aalborg University Hospital. We acknowledge the limitations of general applicability in working with such a small sample. The analysis of wayfinding performance metrics and system evaluation questionnaire is accounted for below. The performance metrics are segmented by route. Two sample T-tests with an alpha value of 0.05, have been used to statistically analyze the compiled results.

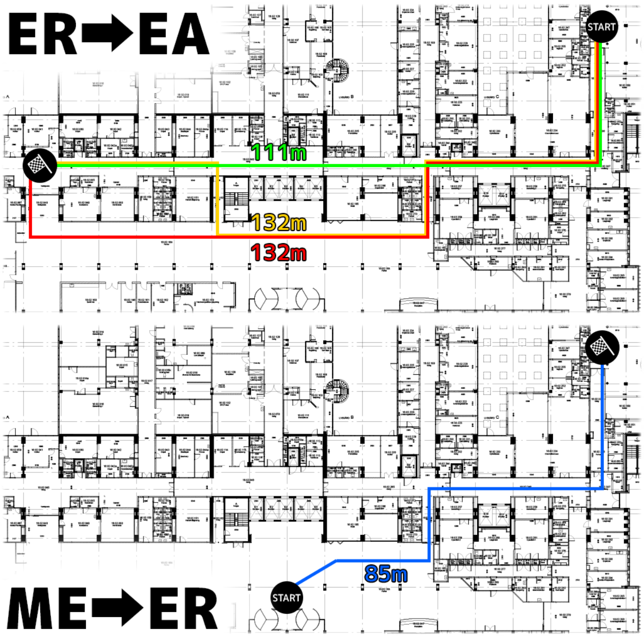

Figure 4: Routes taken by participants during the experiment. Participants took several different routes from ER → EA, whereas ME → ER sees everyone taking the optimal route.

Considering first the shortest route, ME → ER, all participants navigated to the destination along the optimal route, yielding no significant difference. The optimal route can be seen in Figure 3.

ME → ER	+ Prototype	- Prototype	P-Value
Errors	0.4	0.2	>0.05
Hesitations	0.8	1.8	<0.05
Route Length /m	85	85	>0.05
Questions	0	0.2	>0.05
Completion Time /s	72.8	102	<0.05

Table 1: Dependent-variable-result-comparison between wayfinding from Main entrance to Emergency Room with and without the use of the wayfinding prototype

In relation to number of hesitations occurring while navigating the ME → ER route, a two sample T-test yields that participants using the system [M=0.8, SD=0.44] are significantly less hesitant (t(8)= -2.3, p=0.04), compared with participants navigating without the system [M=1.8, SD=0.83]. This indicates that participants are more secure in their navigational process when utilizing the functionality of the wayfinding prototype.

Also apparent is that participants navigating this route using the prototype [M= 72.8 SD=15.7] are significantly faster (t(8)=-2.7, p=0.02) compared with people navigating without the use of the prototype [M=102, SD=17.6]. Completion time is accounted for as travel time only, meaning that time spent interacting with the prototype interface is excluded (Participants spent on average 56 seconds interacting with the wayfinding interface when navigating ME → ER). Furthermore, there is no significant difference (t(8)=0.63,p = 0.54) between error rates amongst users of the prototype [M=0.4, SD=0.54] and without [M=0.2, SD=0.44]. Similarly, no significant difference (t(8)=-1, p = 0.3) was found in relation to questions asked. All results in relation to the ME → ER route is accounted for in Table 1.

Considering the route leading from ER → EA area, only participants navigating using the wayfinding prototype followed the optimal route. Participants navigating using only the in-place navigational system walked two alternate longer routes. Every participant navigating using the prototype travelled approximately 111m while participants navigating without the use of the prototype travelled a significantly longer route of approximately 135m. The routes are illustrated in Figure 4.

ER → EA	+ Prototype	- Prototype	P-Value
Errors	0.4	0.6	>0.05
Hesitations	0.4	3.2	<0.05
Route Length /m	111	132	<0.05
Questions	0.2	0	>0.05
Completion Time /s	113	135	>0.05

Table 2: Table illustrating dependent-variable-result-comparison between wayfinding from the Emergency Room to the Eye out-patient area with and without the use of the prototype

Similarly, a significant difference was established (t(8) = -5.11, p= <0.01) in amount of hesitations when navigating using the prototype [M=0.4, SD=0.89] compared to without use of the prototype [M=3.2, SD=0.83]. In relation to completion time no significant difference was established (t(8) = -0.96, p=0.36), though a tendency indicate a faster completion time using the prototype [M=112.6, SD=43.9], compared to without [N=135.2, SD=28.5] (Participants spent on average 90 seconds interacting with the wayfinding system interface, when navigating the ER→ EA route). No significant difference was established (t(8)= -0.42, p = 0.68) in relation to error rates and questions asked between wayfinding using the prototype [M=0.4, SD=0.89] compared to wayfinding without the use of prototype [M=0.6, SD=0.54].

Prototype Evaluation	Condition 1	Condition 2
Ease of Use	4.86	4.74
Usefulness	4.56	5.28

Table 3: Illustration of mean usefulness and ease of use scores for condition 1 and 2

Participants where asked to evaluate the prototype system's "usefulness" and "ease of use" based on a 7 point Likert scale, with 7 being the highest score. This questionnaire included questions like *"The Audio cue helped me find the wayfinding terminal"* and *"Interacting with the wayfinding system is frustrating"* for the ease of use segment and *"Using the wayfinding system improves my wayfinding performance"* and *"Using the wayfinding system makes it easier to navigate"* for the usefulness segment.

As illustrated in Section 5 the prototype scores an average of 4.8 out of a maximum 7 in ease of use across conditions. Incorporated into the ease of use related segment of the evaluation questionnaire, were specific questions related to the contribution of the audio landmarks used to direct attention to the wayfinding prototype. The audio landmarks scored an average of 4 out of a maximum of 7 in relation to ease of use. Facilitators observed that the ambient sounds levels, especially in the main entrance area, would at times, reduce the usefulness of the auditory landmark due to noise, making it harder to accurately gauge the influence of the audio components on the ease of use of the prototype. In addition, it became apparent, through analysis of video footage, that many participants had trouble understanding the transition from the allocentric map to the egocentric route visualization to various degrees, consequently impacting the overall ease of use score. Despite being written on the screen, and pointed at with a large icon, six participants did not expect the prototype to provide any further wayfinding information after seeing the map. Subsequently, two of the participants were confused about when to start the navigational process after the virtual walk-through had finished, which lead to brief hesitations before they would initiate the navigational process.

The prototype yields an accumulated average score of 4.9 across conditions in relation to usefulness. During the post-experiment interview, participants expressed that they in some cases felt an inconsistency in relation to distances in the 3D route visualization compared to the actual distances in the hospital e.g, one participant said *"It was strange, I felt that the distance was longer in the route animation"*. When asked one participant also said *"[Map only] is fine by me"* and expressed that he felt able to navigate the route after only viewing the allocentric map. This was supported by another participant who expressed similar thoughts, and in addition he also explained that he felt slightly confused after viewing the 3D route visualization. One participant also mentioned that *"I don't think this feels insanely close to what I just saw earlier"* while travelling through the busy corridors of the ER → EA path. Lastly it was also apparent through analysis of the video footage that participants showed less reliance on the in-place wayfinding system when using the wayfinding prototype. This was especially apparent at decision points where participants were less hesitant.

6. DISCUSSION AND FUTURE PERSPECTIVES

As accounted for in Section 1, insufficient wayfinding information induces disorientation which in turn, may foster both psychological and physiological strain. Consequently, wayfinding problems also lead to financial losses for hospitals due to delays and cancellations. In an effort to explore a more efficient wayfinding system, both for hospitals and patients, we have iterated and tested a wayfinding terminal prototype aimed at increasing user wayfinding performance over the course of three experiments with a total of 31 test participants. Our findings indicate that such an RFID enabled wayfinding system does allow for better performance in several key metrics of those employed by Münzer and Stahl [8] for measuring wayfinding performance: Hesitations, completion time, and route length.

The decrease in hesitations accounted for when navigating with the wayfinding prototype indicate a higher sense of security and information credibility established in comparison with the in-place navigation system. It is possible that the decrease in hesitations is due to a larger total amount of wayfinding information being available, but considering the participants' decreased reliance on in-place navigation, it does not seem likely. The high performance in regards to hesitations when navigating with dynamic egocentric (3D route visualization) wayfinding information is also in agreement with the findings from Münzer and Stahl [8], who also found lesser hesitations with this type of visualization, though in comparison with allocentric and static egocentric wayfinding information.

The increased wayfinding performance is also manifested in the completion time, with a statistically significant difference established in relation to the more difficult ME → ER route and a strong tendency apparent in context of the ER → EA route. Completion time is of course dependent on the walking pace of participants, but more so on distance traveled and hesitations. This is also why a prolonged completion time when navigating without the system is corroborated by an increase in hesitations and distance traveled.

In the context of route length, participants traveled significantly longer when navigating using only in-place navigation in context of the more difficult route (ER → EA). This might have been caused by the decrease in available in-place navigation when not originating from the main entrance area, which serves as the "official" starting point for the waste majority of navigational tasks at Aalborg University Hospital. That being said, sufficient in-place navigation is present along the optimal ER → EA route, but participants instead choose to walk back to the main entrance area to re-orient themselves. When the navigational process originates from the main entrance area (ME → ER), the participants wayfinding without the system follows the optimal route, which we assume to be a product of more available and easily accessible in-place navigation cues. However, when starting a navigational task from a department within the hospital (as with the ER $\rightarrow$ EA route), the amount and accessibility of in-place navigation cues are reduced, consequently increasing the difficulty of the wayfinding task. The wayfinding prototype, ensures access and availability of sufficient wayfinding information from and too any location. Besides the reduction in travel distance, this could also help prevent congestion of central locations in times of high patient traffic. With a sufficiently aware system, patients could even be provided with routes around currently problematic areas. With the current prototype system already procedurally generating the route to the destination, few modifications are needed to change the route generation parameters in ways to accommodate such additions.

Another aspect positively effecting wayfinding performance is how the user is able to preview their entire journey while using the wayfinding system. In comparison, the in-place navigation only provides wayfinding information one step at a time. This means that participants navigating using only in-place navigation needs to continuously look for new signs, likely placing a higher cognitive load on the participants. As routes grow increasingly more complex the routes mediated through the wayfinding prototype would likely also need to be split up (e.g., directing users towards another terminal along their route, while also showing a comprehensive overview), but we already see signs that the continuous length of one such wayfinding segment can be much longer than the distance between regular signage. Multiple segments would likely work just as well.

In the context of egocentric visualization, the benefits of procedural route generation are only achievable when the 3D building and the content within, is recognisable enough to facilitate wayfinding. Participants generally had no trouble recognising specific areas, though one participant did comment that in certain areas the (Hallway, route ER $\rightarrow$ EA) the 3D representation were not representative of the actual area. This induced doubt, likely because a correlation between real and virtual world was hard to establish. In this specific area empty hospital beds were frequently placed along the walls, which alternated the environment dynamically. To account for dynamically changing environments it would be beneficial to include additional easily recognisable static landmarks in areas where large objects are moved around frequently, as also suggested by van Schaik et al. [11].

Participants also reported that they felt inconsistencies between distances in the 3D route visualization and actual hospital. This is not ideal, considering that distance measurements play an important role in the navigational process. Resolving this issue would likely entail simple adjustments to the virtual camera settings and the default virtual movement speed. Depending on how much patient data could be accessed by the system, variables such as these could be automatically adjusted to better fit each patient.

During the experiment different issues in relation to system interface also arose. Specifically, some participants had trouble understanding that an egocentric route visualisation could be initiated proceeding the allocentric map, despite being indicated with text and an icon on screen. Participants appeared so focused on their navigational task and the allocentric map that they, to some extent, ignored the information prompts on screen. The participants would likely have benefited from knowing beforehand what information could be expected during their interaction with the system. This could for example be achieved by the inclusion of a pictorial progress bar, indicating the current state in navigational information. This progress bar could also be used during the actual route visualisation as an indication of when the journey has ended. Participants generally had no trouble understanding the initial interaction with the system, that being the registration process and transition from greeting screen to the allocentric map.

During the experiment no issues were encountered in relation to the RFID registration process. The RFID reader identified tags when participants were within 2-3 m from the prototype with a success rate of 100%. This is of course partly due to participants being asked to walk through a specific entrance or past a specific point to ensure that they would be in range of the scanner, as part of the experimental planing and procedure. We needed to implement registration in this way as only one RFID scanner was available at the time. Of course on a larger scale, we would need to add several RFID readers to facilitate the use of multiple terminals and to ensure that participants are registered in larger transition areas, such as entrance halls.

7. CONCLUSION

Two initial experiments were purposed with defining the appropriate modalities for mediating wayfinding information in the context of our prototype. We hypothesized that *"combining spoken directions and dynamic allo- and egocentric visual information (spoken-visual) would yield a better wayfinding performance, compared with only spoken directions or dynamic allo- and egocentric visual information respectively"*. The first experiment failed in answering this hypothesis as, at the time, the prototype interface was insufficient and faulted the initial goals of the experiment, instead valuable information was collected in relation to better the system interface, and lead to a second iteration of the prototype. The second preliminary experiment, was as its predecessor, purposed with establishing an ideal modality combination, with the same hypothesis as in the first experiment. While spoken directions showed significantly less performance in some metrics (hesitations, questions asked), there were no significant differences between spoken-visual and visual conditions. In both conditions containing spoken directions, the information was given a significantly lower credibility rating compared with the visual information, which ultimately lead us to exclude spoken directions in the third iteration of the prototype.

This prototype was evaluated in an in situ experiment at Aalborg university Hospital, purposed with comparing wayfinding performance of participants using our wayfinding prototype and participants navigating using the in-place navigation system. We hypothesized that *"test participants that utilize the wayfinding prototype will fare significantly better when measured on their wayfinding performance, based on completion time, route length, hesitations, questions asked and errors made, compared with the utilization of only in-place navigation systems"*.

In conclusion, navigating using the third wayfinding prototype shows, depending on route, either statistically significant or strong tendencies for improved wayfinding performance in relation to completion time, route length and distance traveled. In relation to questions asked and errors made, no significant differences were established. Based on the analysis of the data gathered and presented in this paper, we conclude that, despite a limited sample size, we can see the potential in an implementation of a more complete and extensive system to assist with wayfinding, time-saving and the reduction of disorientation and frustration for people finding their way. . This information and type of adaptive system can be applied not only in hospitals but also in large institutional buildings generally, where people unfamiliar with the surroundings and layout have difficulty finding their way. Based on this, we contribute an adaptive wayfinding system with procedurally generated route-visualizations, automatic user registration, and user fitted wayfinding information.

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