Alternatives to map-based pedestrian navigation

with location-aware mobile devices

OPINNÄYTTEEN TIIVISTELMÄ

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Vaihtoehtoja karttapohjaiselle jalankulkijoiden navigointiopastukselle paikkatietoisilla mobiililaitteilla

Abstrakti:

Tämä opinnäytetyö käsittelee eri tapoja, kuinka jalankulkijoille voidaan välittää navigoimisen apuna käytettävää informaatiota mobiililaitteilla. Näkökulmana toimii se, kuinka informaatiota voi välittää muilla keinoin kuin perinteisen kartan avulla. Uuden sukupolven älypuhelimien suosion kasvaessa, tarve ja kiinnostus erityisesti jalankulkijoille tarkoitettuihin navigointisovelluksiin on viime aikoina kasvanut.

Tämä opinnäytetyö määrittelee navigointiin liittyviä kognitiivisia toimintoja, tarkastelee jalankulkijan erityispiirteitä ja rajoitteita, sekä pohtii navigaatioinformaation esittämistä paikkatietoisilla mobiililaitteilla. Kartta on toiminut perinteisenä navigoinnin apuvälineenä jo vuosisatoja, mutta mobiililaitteiden ominaispiirteet, kuten pieni näyttö, vaikeuttavat informaation välittämistä tässä muodossa. Tekstissä esitellään neljä vaihtoehtoista keinoa informaation välittämiseen: augmented reality (lisätty todellisuus), audiopohjainen käyttöliittymä, taktiili käyttöliittymä ja tutkakäyttöliittymä. Lisäksi pohditaan näiden vaihtoehtoisien keinojen sopivuutta jalankulkijakäyttöön.

THESIS SUMMARY

Abstract:

This thesis discusses different methods of presenting navigation information to pedestrians on mobile devices. The focus is on presenting information by other means than a traditional map. The recent rising popularity of the next generation mobile phones has created a need and an interest in navigation applications aimed at pedestrians.

This thesis defines the basic terms involving the cognitive processes of navigation, examines the attributes and constraints of a pedestrian, and discusses the presenting of navigation information with location-aware mobile devices. Maps have functioned as traditional aids in navigation for centuries but some inherent constraints of mobile devices, such as a small screen, make it difficult to present information this way. Four different alternative methods of presenting navigation information to users are presented in the text. These methods are: augmented reality, auditory display, tactile display and radar display. In addition the compatibility of these alternatives for pedestrian use is examined.

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1 Introduction

In recent years car navigators that employ the global positioning system (later GPS) have become common and popular. Most of the different models use a standard map-based user interface with spoken route guiding to present navigation information to the user. As access to GPS has also become quite common in personal digital assistants (later PDAs) and next generation mobile phones, there has been a lot of interest in creating navigators for pedestrian use. Most of these applications either simply bring the interface used in car navigators or web-based map application, such as Google maps, to the mobile device. However, the pedestrian setting is very different from the car driver or the home computer user setting, and a standard map-based interface might not be the optimal one in all situations.

The premise for this thesis is the assumption that some pedestrians, such as tourists, could use an alternative that would require less visual attention and cognitive processing to comprehend than a regular top-down perspective map. In this thesis I am presenting four different methods to present navigation information to pedestrians. I am also presenting commercial and prototype examples, which employ these methods. I am focusing on the output of these user interfaces rather than examining them as a whole. With output I mean the information that the user interface gives to the user and not how the user interacts with the user interface.

I got the idea to this thesis from one of the Demola's Innosummer '09 project, where I was a part of the team that created the concept and the prototype for *Local Buddy*, presented later in this thesis. Our goal was to create a virtual mobile guide for tourists and we ended up deciding to move away from maps and implement an alternative way to guide the user. As the team's concept designer I ended up looking for information about the subject and got interested in it. At first it was very hard to find research done on this subject but after meeting Matt Jones, one of the researchers behind the ONTRACK prototype, which is also presented in this thesis, I got some advice on the subject and started moving to the right direction

Some of these alternative methods presented here, such as auditory and tactile display, have been researched extensively in the context of presenting information to people

with disabilities, such as visually impaired people. In this thesis the focus lies on how well these types of interfaces suit a sighted pedestrian.

The first chapter of this thesis, entitled *Spatial perception*, focuses on articulating some basic terms that define how humans process and acquire spatial information. In the next chapter *The definition of a map*, I define what I mean by map, as it is a broad term that can include a lot of different things. In *The pedestrian setting* chapter, the different pedestrian types are discussed and the attributes and constraints, which are unique to pedestrians, are examined. In the chapter *Location aware mobile devices* I define the term. The constraints of presenting information on mobile devices and the Gestalt laws that can be employed to counter them, are also examined. The chapter *Presenting navigation information to the user* is used to present the four alternative methods for presenting navigation information to the user: Augmented reality, auditory display, tactile display and radar display. I am also evaluating them in the pedestrian context. *Summary and conclusions* wraps up the content of this thesis and presents the conclusions.

2 Spatial perception

People rarely give much thought to navigation unless they are disoriented or lost in an unfamiliar environment. When people are situated in a familiar environment e.g. their home town, they tend to navigate intuitively from place to place and choose the shortest way or the preferred route without the help of any source of spatial representation such as a map. In contrast, when visiting a foreign city, people often want to use a map or other external aid to help them in navigating from one location to another.

2.1 Elements of navigation

The cognitive processes that are involved in pedestrian navigation have been studied quite extensively and some basic concepts can be defined:

Wayfinding is the cognitive element of navigation. It is the process inside the brain that does not involve movement itself, but produces the strategy and the tactic of guiding the movement. Wayfinding occurs, not only before the movement, but also during it. [Darken & Peterson 2001]

Cognitive map is an essential part of the wayfinding process. It is the spatial representation of the environment that the person is navigating in. The cognitive map is an individual representation that varies from person to person. It is not just an image in person's head, since it also has symbolic quality. [Darken & Peterson 2001]

Motion is the motoric task of navigation. It's the physical process of taking steps, walking, moving from point A to point B. [Darken & Peterson 2001]

Navigation is the task that combines wayfinding and motion. It involves both the cognitive element (wayfinding), and the motoric element (motion). A person always performs the navigation task when he is controlling his movement through geographical environments. [Darken & Peterson 2001] In this thesis the term *navigation information* is used in describing spatial information that is aimed to assist a person's navigation task.

Orientation is our awareness of the space around us, including the location of important objects in the surrounding environment. Orientation in space is crucial for finding one's

way (or wayfinding) from one location to another. A person is oriented when he knows his own location in relation to the surrounding environment. [Hunt & Waller 1999]

2.2   Spatial knowledge

To be able to navigate successfully, the wayfinding process has to consult the cognitive map that represents a person's spatial knowledge. The cognitive map is a dynamic representation, in which information is being constantly updated and supplemented [Golledge 1999, 7]. There are many ways to acquire spatial knowledge of any environment, but they can be divided into two fundamental distinctions: Information that is received directly from the environment (primary) or from some other source (secondary) such as a map, a photo or verbal directions [Darken & Peterson 2001].

In this thesis, I am focusing on the secondary source of spatial knowledge. Acquisition of this knowledge can also be divided into two distinctions in whether or not the source is to be used preceding navigation or concurrent with navigation. This is important because, if e.g. a map is being used concurrently it requires orientation, as in placing oneself on the map. If a person is using a traditional paper map, he needs to perform a perspective transformation from egocentric perspective to a geocentric perspective, which means mentally rotating the cognitive map so it is in align with the paper map. This is a big part of the mental load when using a map concurrent with navigation. [Darken & Peterson 2001]

The longest standing model to represent spatial knowledge is the *Landmark, Route, Survey* (later *LRS*) model [Darken & Peterson 2001]. The spatial knowledge of an environment is divided into three hierarchical levels.

Landmark knowledge is the first level of spatial knowledge and is the most easily acquired [Darken & Peterson 2001]. A person gains spatial knowledge of *landmarks* that are prominent visual objects in fixed locations [Werner et al. 1997]. In urban environments these are usually large recognizable buildings or areas, which can be seen afar. When travelling in an urban environment a person can navigate to a landmark without knowing the exact route which to use, if he is able to keep track of the landmark.

Route knowledge is the next level of spatial knowledge, in which *routes* are formed to connect the landmarks. A route can be described as a sequence of *nodes* that are locations where the user selects a new bearing [Hunt & Waller 1999]. In an urban environment a node can be e.g. a turn at a crossing of streets. Another element of route knowledge is *edges* that prevent or deter travel. These can be e.g. a river flowing through the city or railroad track, which cannot be crossed by pedestrian. With route knowledge a person not only knows an exact route to his destination, but can also find the way from an arbitrary point on a route to another point further away on the route. [Werner et al. 1997]

As a person picks up more and more routes to his cognitive map, he starts to understand the environment as a graph of nodes and edges. This is the third and final level of spatial knowledge and it is referred to as *survey knowledge*. As it develops, the graph becomes complete and a person can generate routes between any two points as he is able to estimate their relative distances and directions. [Darken & Peterson 2001]

3   The definition of a map

As described in the title of this thesis, the focus is to discuss alternatives to maps. First, however, it is important to define a map.

Definition of a map by Board [1990] is quoted:

> *"...a representation or abstraction of geographic reality. A tool for presenting geographic information in a way that is visual, digital or tactile"* [Kraak & Ormeling 2003, 35]

In other words a map places geospatial data e.g. data about objects or phenomena of which one knows their geographic location, in their correct relationship to one another [Kraak & Ormeling 2003, 33]. In the context of the LRS model of acquiring spatial knowledge, maps allow a person to proceed directly to survey knowledge since they are able to show the completed graph of nodes and edges all at one time. [Darken & Peterson 2001]

The main division of maps of urban environments has traditionally been between *topographic* and *thematic* maps. Topographic maps convey the general image of the surface of the area by showing streets, rivers, houses and the names of the various mapped objects. Thematic maps represent the distribution of one or several particular phenomena such as population density or the occurrence of traffic accidents. Maps of urban environments are often a bit of both such as a map that illustrates tram lines inside a city. The map shows topographic information of the city but highlights the tram lines, so that the rest of the information is perceived as ground. [Kraak & Ormeling 2003, 36]

Picture 1 - The map of the Helsinki tram lines

In addition to the main division between maps, a third genre can also be defined. *Schematic* maps display the basic functional essence of a network of routes by abstracting them into a cartographic caricature. The aim is to present information in a simplified manner to help a person to trace his movement through a complex network of routes easily. With a schematic map connections can be quickly compared and destinations located at a quick glance. [Elroi 1988]

One of the most famous examples of a schematic map is *the tube map*, which represents the lines and stations of London's rapid transit rail system. In contrast to more traditional types of maps that provide survey knowledge of an environment, schematic maps provide lower level route knowledge, as they depict the nodes of routes, but not necessarily their geographic location in relation to each other.
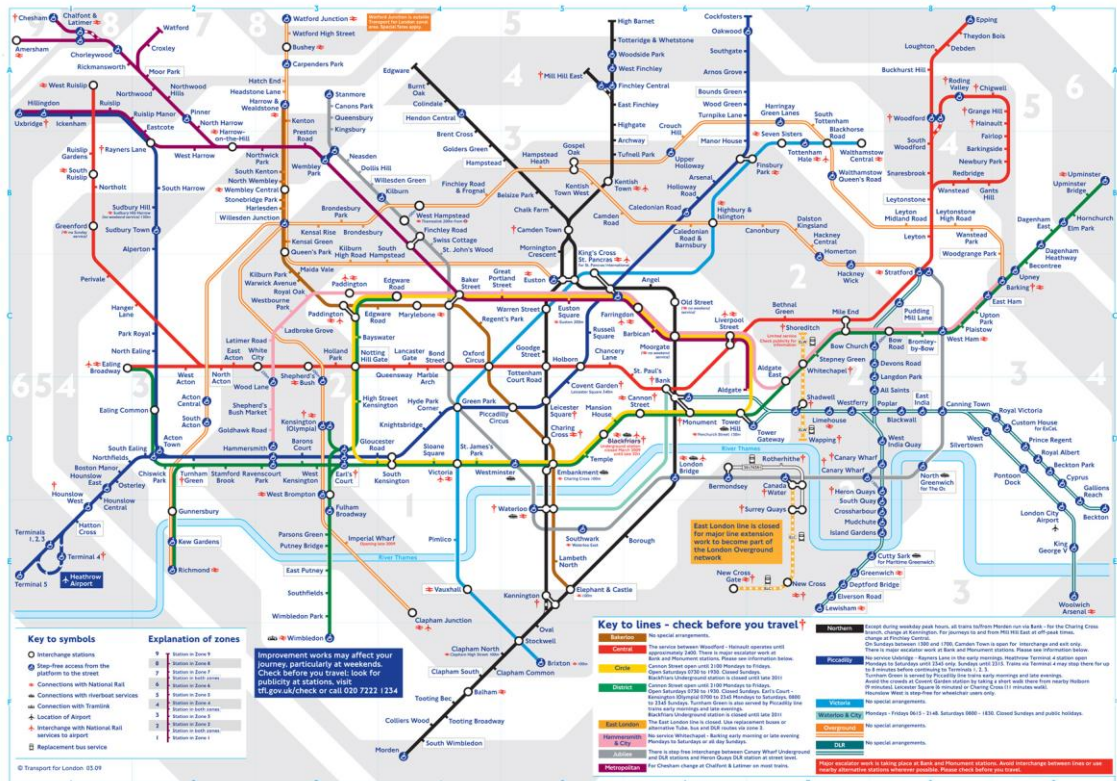
Picture 2 - London Tube Map (taken from: http://www.tfl.gov.uk/gettingaround/1106.aspx)

4 The pedestrian setting

To be able to assess different ways to provide navigation information for pedestrians in an urban environment, it is essential to examine the specific characteristics of a pedestrian. Before looking at different constraints and attributes of pedestrians, three different pedestrian types are presented via short scenarios.

4.1 Pedestrian types

A tourist is usually travelling in fairly unfamiliar surroundings and is interested in a wide range of different places around him, such as museums, restaurants and shops. A tourist is interested in enjoying his surroundings and taking in the sights of the city so he does not want to be guided by means that are intrusive and take a lot of his visual attention. Time is not usually an issue for a tourist, so a fast guidance from point A to point B is not as important as the freedom to wander about without getting lost. [Walther-Franks 2007, 20]

A travelling businessman doesn't usually have a lot of time to squander. Short-term changes of appointments and their locations can always occur, so it is essential to get fast and effective route guiding that can be plotted and revised on-the-go. The target destinations might not always be commercial in nature, so they might not have any easily noticeable store signs. This means that the guiding must be as precise as possible for locating the destination. [Walther-Franks 2007, 20]

A local is familiar to his surroundings and does not necessary need specific route information. For a local it might be useful to get an overview of *points of interest* (later POIs) around him, such as restaurants or specialized stores. Information about public transportation might also be relevant for a local.

4.2 Pedestrian constraints and attributes

The pedestrian context has a different set of attributes and constraints that differ greatly from those of driving a vehicle. The following is a list of some of the most important ones by Walther-Franks [2007]:

- **Wide access:** Pedestrians are not restricted to city streets and roads so they can move freely in open places. In other words their movement is less restricted than the movement of vehicles by the road network.

- **Free orientation:** Pedestrians can rotate and change direction almost wherever and whenever. This results in less predictable movement in terms of speed and heading compared to vehicles.

- **Traffic safety:** Pedestrians are very vulnerable to getting seriously hurt in traffic accidents. This means that they should use caution when approaching paths designed for other modes of traffic, such as cars or trains, and only use the designated crossing places. Within pedestrian areas this matter is less critical.

- **Attention:** Use of any additional device takes up a certain amount of the pedestrian's attention and available cognitive resources. As described earlier, different types of pedestrians have different requirement when concerning attention.

- **Handling:** Additional navigation devices can be attached and integrated into a vehicle, but for pedestrians they usually have to be carried. The device can be either stowed away in a bag or a pocket to be used on demand, or to be constantly available and carried in the hand or strapped in the wrist. This can be constraining to the pedestrian. Hands-free devices that give information in audio format may restrict the pedestrian's hearing.

- **Environment:** In contrast to the confined space of a car, pedestrians are exposed to the elements of an outdoor setting. Weather conditions, such as rain, drizzle or fog, and lighting conditions, such as direct sunshine or darkness, has to be taken into consideration.

[Walther-Franks 2007, 21]

5 Location-aware mobile devices

In this thesis location-aware mobile devices are defined as portable electronic devices that can at minimum sense their approximate geographical location in outdoor environments.

Usually these are understood as PDAs, mobile phones or laptop computers that have access to GPS data to define their geographic coordinates on Earth. These devices may also have other sensors such as an *accelerometer* to detect magnitude and direction of the acceleration as a vector quantity [http://en.wikipedia.org/wiki/Accelerometer], or *a magnetometer* (compass) for determining direction relative to the Earth's magnetic poles [http://en.wikipedia.org/wiki/Magnetometer] to provide additional information about the current inertial state of the mobile device.

5.1 Presenting information to the user on location-aware mobile devices

A location-aware mobile device can present information to the user in multiple different ways. Most commercial mobile devices that have access to GPS data rely heavily on presenting information visually through a graphical user interface (GUI). The obvious challenge when designing a GUI for mobile devices is the relatively small screen size that comes with portability. Therefore, design principles and techniques should be used in a clear and logical manner to enable the user to quickly grasp the underlying functionality of the GUI. Visualizing information, structuring the content and the interaction possibilities are a priority before decorative aspects. [Zwick, Schmitz and Kuehl 2005, 140]

5.2 The Gestalt laws

The Gestalt laws are a series of rules that explain the psychological perception characteristics of human beings. The origins of the Gestalt theory that these laws are based on can be found in some orientations of Johann Wolfgang von Goethe, Ernst Mach, and particularly of Christian von Ehrenfels and the research work of Max Wertheimer, Wolfgang Köhler, Kurt Koffka, and Kurt Lewin, who opposed the elementistic approach to psychological events, associationism, behaviorism, and to psychoanalysis [http://gestalttheory.net/gtax1.html]. The use of the Gestalt laws is

especially effective on small screens where the visual information has to be very organized, because they help the user to understand content quickly and clearly. The following seven laws summarize the most important principles of visual perception, and how humans tend to group individual stimuli into larger wholes.

The law of proximity states that humans tend to perceive elements as a group or unit, if they are arranged closely together. In GUIs this principle is effective when organizing content and creating units that the user should understand to have a common meaning. The law of proximity can be used only to a limited extent on small screens as there is not much space to allow large gaps between different units in order to separate them visually. [Zwick et al. 2005, 140]

The law of similarity states that elements with similar visual properties are perceived as a group or unit. An example of employing similarity is the color coding of elements to separate them (different color) or to indicate that they are related to each other (same color). This principle is not affected by scale, and can be said to be the most important organizational resource for mobile devices with small screens. [Zwick et al. 2005, 140]

The law of closure states that humans tend supplement incomplete elements to perceive them as a part of familiar form. In mobile devices this unconscious process has sometimes been used to create a link between buttons on the hardware and the functions that are displayed on the screen above the buttons. Of all geometrical figures, the circle has been found to be visually most robust. Humans will automatically complete the figure and perceive it as a circle, even if only fractions of the circle are present. [Zwick et al. 2005, 141]

The law of good form states that humans tend to look for the greatest degree of simplicity, clarity and regularity when perceiving things visually. This principle is often something that has to be taken into consideration to avoid accidentally confusing the user by giving an impression of a connection that does not exist. [Zwick et al. 2005, 141]

The law of symmetry states that humans tend to understand symmetrical and regular forms to have a common meaning. This symmetry can be created by applying equal gaps for grouped elements or connecting them by mirrored axes. The law of symmetry can be effectively applied also by breaking it to achieve the opposite effect. The user's

attention can be focused to an element that is breaking the symmetry. [Zwick et al. 2005, 142]

The law of figure/ground states that a salient element will be perceived as the relevant form and the surrounding space is perceived as the background. If this relationship is not clear, the user might be left confused and functionality of the element may not be understood properly. A good example of this is an element that is intended as a button but does not stand out from the background well enough for the user to perceive it as a separate element that performs a function when pressed or clicked. A way to separate figure and ground can be achieved e.g. by using brightness and contrast levels to set the foreground clearly apart from the background. [Zwick et al. 2005, 142]

The law of continuity states that the human perception system does not analyze each new component afresh, but instead draws conclusions based on past experiences. [Zwick et al. 2005, 142] This principle can be seen in effect by e.g. when reading a text that includes a misspelled word. We can still probably decipher the content because we can understand from the context what the writer was intending. In the same way we can perceive motion if we are looking at a comic book, where there are three images of the same person, in the first of which the person is on the left side of pool of water, in the second of which he is flying above the pool and in the third of which he is standing on the right side of the pool. This principle can be exploited and used to save space or to give feedback on a mobile device's small screen.

6   Presenting navigation information to the user

Presenting navigation information for pedestrians visually is usually very effective because most of the users are accustomed to consume navigation information this way by consulting a map. However, the nature of location-aware mobile devices makes this challenging.

The visualization of spatial information to assist the user's wayfinding process is particularly difficult on small screens because context and reference points are always necessary if the user is to get their bearings and achieve orientation. The screen must show not only enough detailed information, but also enough contextual information. The presentation form, perspective and degree of abstraction are essential elements to balance when presenting spatial information to the user on a mobile device.[Zwick et al. 2005, 90]

The aforementioned Gestalt laws can be applied to presenting maps to the user on a small screen. As mentioned before, a combination topographic and thematic map uses the figure/ground principle to highlight the relevant information, such as the route to the user's destination, but the topographic information that is perceived as background is still needed for context to navigate successfully. Therefore, highlighting the most relevant information and reducing the less relevant, but still essential, information to background may even make the map interpretation more difficult.

Schematic maps employ the law of symmetry and good form to make the network of routes more easily understandable by abstracting them to more regular shapes. Schematic maps are easier to interpret on a small screen, but they do not offer that much detail outside of the routes. If the user accidentally strays away from the route, he could have difficulties to find his way back. [Gartner & Radoczky 2005]

Even with the use of the Gestalt principles, maps shown on mobile devices suffer from the small screen size and low resolution. It is often difficult to identify locations and landmarks on these maps. If the user is a tourist visiting an unfamiliar city, the map must also present the user with POIs, that are relevant to the user's needs, such as locations of ATMs, pubs, shops, and restaurants. The visualization of the POIs in addition to the topographical information of a city may result in visual clutter and make

the map interpretation difficult - if not impossible - for the average user. [Rohs et al. 2007]

6.1 Augmented reality

A visual augmented reality (AR) interface has been emerging as the next hip thing in navigation interfaces as the popularity of smart phones equipped with a large display, video camera, GPS and a compass, has increased. A number of commercial programs have been published for iPhone OS X and Google's Android operating systems, such as *Layars* and Acrossair's *NY Subway.* AR interfaces in pedestrian navigation context have two main elements that define the nature of the interfaces: How the interface blends virtual elements to actual reality and what is the form of the navigation information it presents to the user.

Picture 3 - : Left: Acrossair's NY Subway (taken from: www.acrossair.com) Right: Layar (taken from www.layar.com)

6.1.1 Blending

Blending virtual elements to actual reality has long been seen in science fiction movies with futuristic heads-up displays (HUDs) giving information to the user about actual reality objects and conditions. The emergence of the new generation mobile phones, that are equipped with compasses have finally brought augmented reality interfaces to real life. Devices equipped with GPS, an accelerometer and a magnetometer (compass) can sense in which direction in 3d space the device is pointed, which enables virtual objects

to be embedded inside a video image shown on the device's screen. This makes it possible for the user to view his surroundings through a sort of magic lens which lays virtual objects and information in actual spatial environment, thus augmenting it.

In general there are two basic ways to blend virtual objects to actual reality and create augmented reality: *highlighting existing objects* and *visualizing non-existent objects* [Walther-Franks 2007, 25]. In navigation context these ways are usually employed by highlighting real objects, such as buildings, to indicate the location of a POI, and visualizing route instructions. Although it might seem that AR interfaces aim to fit virtual information seamlessly into the actual reality to create an augmentation that is indistinguishable from it, for pedestrian navigation purposes this is not necessarily advantageous.

> *"For navigation scenarios, it is apparent why easily distinguishable augmentations are necessary, as augmentations are primarily used as a means to navigate the world, not to improve or change the perception of it. Thus, the focus here is on easily recognizable, clearly visible and distinguishable route instructions."* [Walther-Franks 2007, 24]

To make the augmentation easily distinguishable it is good to use bright colors, that are not dominantly present in the actual reality, such as bright red and yellow, or to get the user's attention by movement or blinking.

6.1.2 Form of navigation information

AR interfaces are well suited to give the user route knowledge by visualizing the route in the augmentation. The route visualization can be divided into two categories: *implicit* and *explicit* instructions [Walther-Franks 2007, 25-26].

Implicit instructions ("follow me") visualize or highlight an object in the augmentation for the user to follow. The object can be the target destination or the route path itself. The purpose for the user is to move towards the object to progress to the target destination. These objects can be visualized in several different ways. If the object is marking the destination it can be visualized by showing a distinguishable marker, such as a crosshair, a circle or a square in front of the destination. If the object is visualizing

the route itself, it can be shown to the user in the augmentation by projecting the path on the ground or in the air. [Walther-Franks 2007, 25]

Explicit instructions ("go there") give the user instructions about where to go next. They provide the user incremental guidance to his destination by visualizing instruction notices along the route. These notices can be visualized by projecting arrows or written instructions in the augmentation. [Walther-Franks 2007, 26]

These two categories are also easily combinable into solutions that provide both implicit and explicit instructions, such as showing the route plus immediate turning instructions.
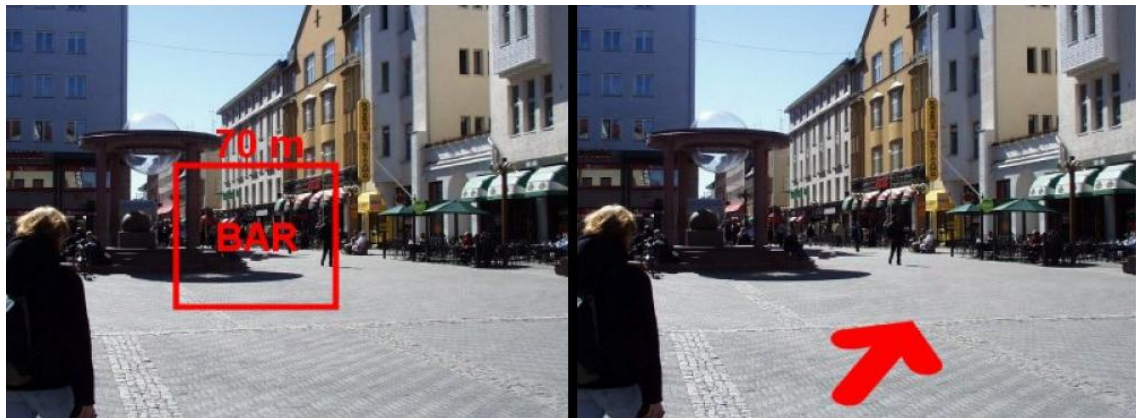
Picture 4 - Left: Implicit instructions / Right: Explicit instructions (taken from Pyssysalo et al. [2000])

6.1.3 AR navigation interface examples

There are already several commercial AR pedestrian navigation applications for mobile phones in the market.

Acrossair's *NY Subway* is an application for iPhone 3Gs that shows the user where he is and where the nearest subway stations are. It employs GPS, accelerometer and compass to give an effective AR interface for the user. The use of the application is very simple and straightforward. When the user is looking at the ground through the iPhones display, the application projects colored arrows on the ground that display all 33 lines of the New York Subway. The arrows show in what direction each of the lines takes the user. By tilting the phone upwards, the user will see the nearest stations: what direction

they are in relation to the user's location, how many miles away they are and what lines they are on. If the user continues to tilt the phone upwards, he will see stations further away, as stacked icons. [http://www.fastcompany.com/blog/kit-eaton/technomix/augmented-reality-round-navigation-apps]

Layar is an application also for iPhone 3Gs that employs the same features as the NY Subway. Layar adds content layers on top of the iPhones video function that displays actual reality. These layers display different sets of geo-spatial information, such as location and relevant information about nearby restaurants, real-estate value of nearby houses or the nearby hospitals, and they can be switched on-the-go. At the moment there are 172 layers available, some of them location specific and some of them global. [http://layar.com/]

Boulder, Colorado based mobile application developer Occipital has released a still unnamed research demo that provides route instructions with an AR interface. The interesting thing about the demo is that it goes beyond using the basic features of an iPhone. After the application has established an approximate GPS position of the user, video frames are transmitted to a server, where they are compared with a vast database of street-level imagery. Using this information, the application is able to estimate the user's position within a meter and provide very accurate augmentation. [http://www.fastcompany.com/blog/kit-eaton/technomix/augmented-reality-round-navigation-apps]

6.1.4 Evaluating AR interfaces in the pedestrian navigation context

AR interfaces seem to be a very attractive option for mobile pedestrian navigation application nowadays, as most of the newer high-end mobile phone models include a compass, which is an essential feature for AR interfaces.

The advantage of an AR interface in the pedestrian navigation context is that it is completely aligned with actual reality, which removes the cognitive load of aligning the navigation information with the user's mental map. Unfortunately this can also serve as a disadvantage as the accuracy of GPS in mobile devices is usually not very precise. In contrast to a map, where the user's actual precise location can be pinpointed by comparing the map with actual reality, an AR interface does not usually give any other reference to reality than the actual reality itself. A location given by a mobile device's

GPS can easily have an error of 20 meters and for a pedestrian that can make a big difference. For example if the AR interface is marking the destination building and the GPS location is non-accurate, the marking might be projected not only on the wrong building but in some situations even on the wrong city block. Without any other reference than the augmentation, the user has no way of verifying the error. The research demo by the mobile developer Occipital described earlier counters this problem by comparing the video frames captured by the device with a database of street-level imagery to increase the accuracy. Although the solution is very innovative and effective it relies on the coverage and the scale of the image database.

Other problems may also occur when evaluating AR interfaces in the pedestrian context (see chapter 4). As the AR interface only can display a part of a route that is limited to user's current viewpoint, following a route requires a lot of attention from the user, who has to check the mobile device for more navigation information quite often. Even if the AR interface only marks the destination in the augmentation, it is challenging to indicate the distance to the destination in an effective way, as numerical distance has been shown to be hard to comprehend in pedestrian navigation [May et al. 2003].

The high attention requirement may also affect the traffic safety aspect in the pedestrian setting. It is possible for the user to move at same time while receiving navigation information, as AR interfaces make it possible for the user to also see the actual reality. By concentrating the viewing of his surroundings through a relatively small screen, the user's range of vision may suffer and this can make him exposed to traffic accidents.

6.2   Auditory display

Presenting navigation information to the user visually is not the only solution. In the recent years there has been some research done on auditory display, which means the use of sound to communicate information from a computer to the user. [http://en.wikipedia.org/wiki/Auditory_display]

Auditory display usually aims to improve accessibility in representing information to users who are blind or partially sighted, but can be very useful for the normally sighted users also, especially in situations where the user has to direct his visual attention elsewhere. Being a pedestrian in an urban environment is a good example of this kind of situation.

Sonification is a way of creating an auditory display system. Sonification means the representation of data into the sound domain using non-speech audio [Nasir & Roberts 2007]. A familiar example of sonification is the Geiger counter that measures ionizing radiation levels by presenting the user with repeated clicking sounds, and using the frequency of the clicks to indicate the relative radiation level. Sonification is very suitable for presenting spatial data as sound itself is also spatial and humans are good at locating the source of a sound especially on the horizontal plane [Moore 2003, 266]. Sonification also has the ability to present a large number of variables in one display and can be seen as especially useful in conveying rapidly changing information to the user [Nasir & Roberts 2007].
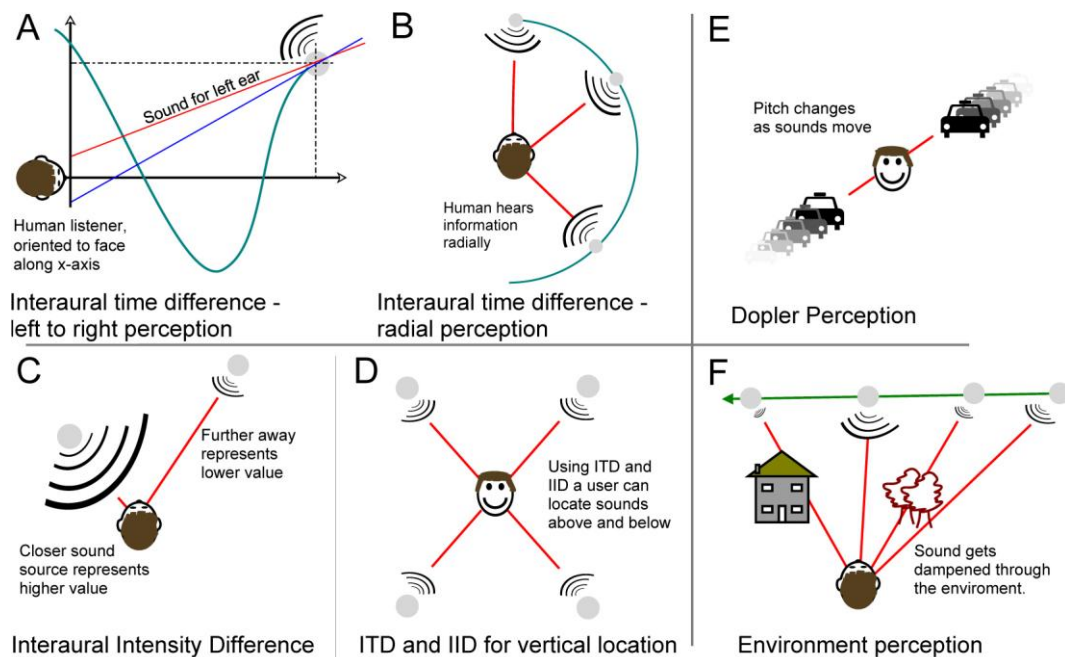
6.2.1 The components of sonification

Nasir & Roberts [2007] have collected and presented six different categories of components to present data to the user. Two of the categories are non-spatial and four are spatial.

- **Non-spatial audible variables:** These variables are the basic building blocks for sonification. They include *pitch, loudness, attack* and *decay rates, timbre tempo* and *brightness*. These variables are especially efficient in presenting relative quantity of a data dimension, as in whether something is larger or smaller than something else.

- **Non-spatial motifs:** These are higher order components that communicate information at a higher-level and may require the user to learn their meaning. These include for example earcons (auditory icons), that can communicate different objects through sound motifs. The similarity in the data is represented by similar motifs. Earcons are often employed in e.g video games to notify the player of an in-game event, such as the player scoring a point, without distracting attention from playing. Other familiar example of Non-spatial non-speech auditory motif is the Morse-code.

- **Interaural Time Difference (ITD):** The principle of ITD states that there is a phase difference between the sound arriving to the ears. ITD can be used to place sound sources on the horizontal plane using binaural sound [http://www.fp3d.com/papers/WhyHeadphones.pdf].

- **Interaural Intensity Difference (IID):** The principle of IID states that objects, which are closer sound louder. IID can be used with ITD to locate sounds both on the horizontal and the vertical plane.

- **Doppler and time-based effects:** The Doppler effect or frequency changes give the listener perception of sound source's distance and movement in regards to the listener's perspective. A practical example is an ambulance coming towards a person and the frequency of the siren changing as the ambulance first moves closer to the person and then passes him and moves further

- **Environment perception:** This effect can be used in locating objects in a spatial area. The listener can perceive object's location as a sound coming from behind the object gets dampened when it passes it.

[Nasir & Roberts 2007]

Picture 5 - Spatial components of sonification (taken from Nasir & Roberts [2007])

6.2.2 Audio-based interface examples

Location-aware auditory display user interfaces have typically been designed to meet the needs of visually impaired users, and as of yet, there hasn't been that many commercial pedestrian navigation applications for mobile devices aimed at sighted people, that use sound as a primary means of communication with the user. However, there has been research on employing auditory display user interfaces in the context of sighted pedestrian navigation to free the visual attention and the hands of the user. In contrast to visually impaired users, who need much more complex and complete information about their surroundings, the sighted but minimally attentive user can cope with a simpler interface, that doesn't place a large processing and attention burden on the user.

Holland, Morse & Gedenryd [2002] created a prototype of a pedestrian navigation system entitled *AudioGPS* that relies on a virtual acoustic display as the user interface. By taking an audio signal and transforming it into a binaural signal that the user listens to through the headphones, the signal appears to emanate from a given environmental location and can assist the user to navigate towards his destination or an intermediate waypoint. AudioGPS provides the user with two essential pieces of navigation information in non-speech audio: the distance and direction to the destination or an intermediate waypoint. [Holland et al. 2002]

The direction is provided by the simple means of panning a sound source representing the destination across the sound stage. The direction is relative to the direction of the user's movement, which is calculated from GPS data. With panning it is easy to distinguish between sound sources coming from left and right, and at some intermediate points in between them. However, simple panning does not help to distinguish between sound sources placed in front of the user and one placed behind the user. AudioGPS provides a pragmatic solution to this problem by using a sharp tone when the destination is in the front half of the horizontal plane, and a more muffled tone when the destination is in the half of the horizontal plane that's located behind the user. To support and increase the accuracy of the spatial sound source in providing the direction to the destination, AudioGPS employs a 'chase tone' which works as follows. A repeated tone at a fixed pitch that is appropriately panned in space indicates the destination. A second tone (chase tone) coincides exactly in pitch with the first front the

destination is straight ahead, but then chromatically changes in pitch as the destination moves more to the left or right in relation to the direction of the user's movement. [Holland et al. 2002]

The distance to the destination is provided by a Geiger counter-style method. An audible click is used to map the distance to destination. The more rapid the clicks the closer the user is to the target destination. [Holland et al. 2002]

Two newer prototypes, *gpsTunes* by Strachan et al. [2005] And *ONTRACK* by Jones et al. [2008], take the idea of an audio-based pedestrian navigation system for sighted people to a more useable direction. Instead guiding the user by non-speech audio pulses, gpsTunes and ONTRACK both guide users by adapting the spatial qualities of the music they are listening to. The approach is perhaps more suitable to everyday situations, as people probably prefer listening to music while navigating instead of abstract sound pulses. The direction is presented basically with the same method as in AudioGPS. The music is panned between a pair of stereo headphones to create an auditory image that it is emanating from the destination. gpsTunes pans the sound in a fine-grained way but ONTRACK uses thresholds of 30 degrees because research has shown the users can cope better with macro rather than micro guidance [Strachan et al. 2005; Jones et al. 2008]

The two prototypes take diverging approaches to presenting the user the distance to his destination. gpsTunes sets a threshold distance to the destination and switches the music to the lowest audible volume when the user is farther from the destination than the edge of the threshold. After the threshold, as the distance to the destination is decreased, the volume increases back towards the user's preferred level. ONTRACK on the other hand discards presenting distance to the destination completely and rely solely on directional guiding with spatial audio. The route is divided into intermediate beacons, to which the adapted music seems to emanate from. As soon as the user walks into the boundary of a beacon, the audio music cues are modified to indicate the next beacon on the route. [Strachan et al. 2005; Jones et al. 2008]

6.2.3 Evaluating audio-based interfaces in the pedestrian navigation context

Audio-based user interfaces are not yet in common use in pedestrian navigation application for mobile devices, but new commercial applications might emerge in the

future. Using music to convey navigation information is especially interesting, because it provides the user with route knowledge, while he is doing something enjoyable (listening to music). Non-speech audio is also easy to generate on-the-go, which enables the user to select his destination spontaneously.

The problem with these kind of auditory display compared to visual alternative is that it is very challenging to present information about multiple targets in the same time. It is not that difficult to perceive where a continuous sound source is emanating on the horizontal plane, especially when employing binaural sound on headphones, which enables 360 degree sound lateralization [http://www.fp3d.com/papers/WhyHeadphones.pdf]. Trying to perceive where multiple different sound sources are emanating might be more difficult for the average user.

On the other hand, audio-based user interfaces free the user's visual attention, which improves the traffic safety aspect. With non-speech audio the user is even able to communicate with speech same time as receiving navigation information in the background [Jones et al. 2008]. This makes it take up less cognitive resources from the user. Using music to present data is very suitable as studies have shown that user's prefer continuous rather than pulsed beacons and non-speech over speech audio [Jones et al. 2008].

Audio-based user interfaces are also less affected by the environmental conditions such as rain, direct sun light or fog than graphic user interfaces. They can also be hands-free, although if the system utilizes a compass then the user must carry a device to inform the system of the user's bearing. Fitting the compass somewhere, where it always indicates the user's direction such as integration into the headphones or the user's clothes would solve this problem.

6.3   Tactile display

A tactile display means that it is perceptible by touch. One familiar method of conveying information with tactile output is the *Braille system*, which is widely used by blind people to read and write. Braille is read by touching the Braille cells while 6 or 8 pins pop up and down to represent letters [Brewster & Brown 2004]. Braille is a higher-order tactile component which requires the user to learn the meaning of the representations and practice the interpretation of it. For sighted person it is perhaps too

complicated and cognitively heavy task to be suitable for conveying navigation information

6.3.1 Tactons

A tactile user interface for pedestrian navigation on a mobile device might seem as an odd concept, but almost all mobile phones are equipped with a component that can relay information through sense of touch: the vibrating alert. Using *tactons* (tactile icon), which are similar to earcons described earlier, it is possible to represent complex interface concepts, objects and actions and convey this information to the user. [Lin et al] According to Brewster and Brown [2004]:

> *Tactons are similar to Braille in the same way that visual icons are similar to text or earcons are similar to synthetic speech. For example, visual icons can convey complex information in a very small amount of screen space, much smaller than for a textual description. Earcons convey information in a small amount of time as compared to synthetic speech. Tactons can convey information in a smaller amount of space and time than Braille.* [Brewster & Brown 2004]

In contrast to spatial sonification methods, tactile cues are not naturally spatial unless the feedback is given to different places on the human body to represent spatial relation. However, tactile cues can be used for conveying simple navigation information using a mobile phones vibration alert and for example presenting the information through vibrotactile rhythms.

6.3.2 Tactile user interface example

Commercial tactile user interfaces are almost entirely aimed at visually impaired people and require special components to present the information such as the Braille cell. Using a tactile user interface to present navigation information for sighted people is quite a new field of research and I have only managed to find one practical prototype, where the concept is being put to use.

Lin et al. [2008] introduce a pedestrian navigation system that uses tactons to provide navigation information to the sighted user. The prototype of the system presents route

guiding in the form of direction of travel and distance to next turn. The information is relayed by a mobile phones vibrating alert. Three different vibrotactile rhythms represent the direction of travel: seven short pulses for 'turn right', four longer pulses for 'turn left' and one short and one very long pulse for 'stop'. The use of different number of pulses in each rhythm helps to make the rhythms more distinguishable. The distance to next turn was conveyed by playing the rhythms in two distinct tempos: medium tempo (adagio) represented 'take action in the next block' and high tempo (allegro) represented 'take action now'. This encoding resulted in a set of tactons which are:

- Turn right in the next block

- Turn right now

- Turn left in the next block

- Turn left now

- Stop now

With this set of tactons a predefined route can be presented to the user to guide him to the destination at the end of the route. [Lin et al. 2008]

6.3.3 Evaluating tactile user interfaces in the pedestrian navigation context

The definite advantage of a tactile user interface in the pedestrian navigation context is that it frees both the visual and auditory attention to focus on other tasks. A tactile user interface that uses the mobile phones vibrating alert is also very easy to implement and would basically work on a wide scale of different mobile phone models, as it basically only requires access to GPS data, with an accelerometer and a compass being unnecessary.

At the moment the prototype described earlier is quite rudimentary. The set of route instruction it can give the user is very limited. Different cities have different levels of complexity in the way the block structure is designed. In many cases the user might encounter a crossroad where there are more options to move than just left, right or straight forward. Of course it is possible to create more vibrotactile rhythms and expand the set of instruction the system can present to the user. However, this might make it too

complex for the average user to learn and use effectively. In addition, presenting the user with the location of POIs and multiple routes is very challenging with the tactile user interface.

A tactile user interface is also not very sensitive to different environmental conditions, such as direct sunlight. However, a heavy rain might prove to be harmful for a tactile user interface that is carried in the hand and is not designed to withstand extreme moisture. The current tactile user interface prototype is not hands-free, but an improved hands-free model is being devised [Lin et al. 2008]. This would make the user interface require little attention and be minimally intrusive, which is something that can be said to be beneficial in the pedestrian navigation context.

6.4 Radar display

The fourth alternative method to map-based pedestrian navigation interface presented in this thesis is the *radar display*. It is familiar from the displays used in submarines and recently this kind of displays have been used in computer games as 'mini-maps' to represent POIs located in virtual spatial environment around the player. Although the radar display presents information visually similarly as a map, it differs in the nature of the information it provides the user. Maps provide user with survey knowledge, giving an overview of the area. Radar display presents the user with the distance and the direction to different POIs in relation to the location of the user, so it can be said to provide more lower level landmark knowledge.

6.4.1 Radar display example: Local Buddy

This thesis reports on a prototype of a city guide system for mobile devices that uses a radar display entitled *Local Buddy*. The prototype was created as a part of the *Demola Innosummer '09* projects. The team consisted of students from Tampere University of Technology and Tampere University of Applied Sciences. Bertta Häkkinen worked as a producer. The core team consisted of the author of this thesis as a concept designer together with Olli Raivola and Timo Härkönen who worked as programmers and software designers. In addition, Joel Hakulinen provided consulting on usability issues and did some user interface designing and Hanne Zenjuga worked as a graphic designer.

The prototype is designed to utilize the essential features of the *Nokia N97* smart phone, like GPS and the magnetometer. The prototype can also be used in the *Nokia 5800*.

Picture 6 - Local Buddy's radar display

In the project the team wanted to create a mobile city guide that incorporate a minimal attention graphic user interface. The main idea is to give the user spatial information about POIs around the user in a way that makes it easy and quick to perceive and process. That was the reason the team wanted to move away from maps altogether and implement a more minimalistic mechanism than a regular top-down perspective map to present navigational information to the user. We came up with the idea of the radar display, an innovative graphical user interface that gives the user geographical data of a POI by providing the distance from the user's location and the direction of the POI in relation to the direction where the user is moving.

With the radar display the user receives more ambiguous navigation information than with a regular map, but is presumably able to assimilate this information more easily and enjoy his surroundings better while navigating more intuitively.

In Local Buddy's radar display the user is shown as an upward pointing triangle surrounded by orbits that indicate distances. The nearby POIs that match the user's interests are shown as symbols orbiting around the user. When the user changes the direction where he is moving, the POIs rotate on the orbit to match the new direction of

the user. The triangle representing the user does not rotate. In the radar display, the symbols move on the orbits to match their geographical location in relation to the user's bearing.

Picture 7 - In the radar display POIs rotate on the orbits according to user's direction

First orbit is the innermost orbit, also known as *the thumbnail orbit*. It shows three of the nearest POIs inside 50 meter radius. POIs are shown as thumbnails. POIs located in other orbits are shown as icons. POIs are divided to orbits according to the following distances:

1. orbit : 0 – 100 meter

2. orbit : 100 – 200 meters

3. orbit : 200 – 350 meters

4. orbit : 350 – 500 meters

The program defines the direction of the user's movement from GPS data or from magnetometer data. If the direction is calculated from GPS data, it means that the user has to move approximately 10-15 meters for the direction to be accurately defined. If a magnetometer is available the radar view will update in real-time and the user will notice an immediate response.

6.4.2 Evaluating radar display user interface in the pedestrian navigation context

A radar display user interface is not very effective in helping users to navigate from point A to point B as fast as possible, as it doesn't provide route or survey knowledge to the user. However, this kind of user interface has other advantages. The main benefit of the radar display is that it is able to present the user with information about POIs around him. As the user interface is visually very minimalistic, it is easy perceive the relevant information from the screen very quickly.

The easy perceivability of Local Buddy is due to the use of many of the gestalt laws. The law of similarity is in use as the icons representing the POIs are color-coded to make it easy to perceive what kinds of places are around the user. The law of good form is used to group POIs that are on the same orbit. The user can instantly understand that these POIs are located approximately the same distance away from the user because they are all connected to the circular orbit indicating a certain distance. Dark shades of grey are used as colors in the background and the orbits to contrast the icons representing the POIs in accordance to the law of figure/ground. These factors, especially the effective use of figure/ground, make this kind of visual user interface work better in different environmental conditions, such as direct sunlight.

As Local Buddy does not offer any route guidance, it can be beneficial in regards to the requirement of pedestrian's attention. The user can only receive the direction and the distance to his destination, so he will have to direct his attention on his environment more to select the paths to his destination. This can be seen as beneficial also in regards to the traffic safety aspect.

Local Buddy also makes use of the free rotation attribute of a pedestrian. With the use of the accelerometer of the mobile phone, the user can rotate and see what kind of POIs are around him.

7 Summary and conclusions

In this thesis four different methods to provide navigation information on location-aware mobile devices to pedestrians are presented. They have not been analyzed in regards to which of the methods is the best one, as they all have different advantages and disadvantages. The purpose has been merely to present and evaluate them on how well they suit the different aspects of the pedestrian navigation context and without any user field trials it is impossible to state how well they compare against each other.

However, this thesis does provide some fresh angles on how navigation information can be provided to the user with location-aware mobile devices. The use of maps has been the standard for centuries and rightfully so. Consulting a map is probably the most effective way to build survey knowledge of an area and navigate from point A to point B. But for some situations, as it can be e.g. for tourists, it is not always as essential as being able to concentrate on other tasks, such as enjoying one's surroundings, communicating with another person or even eating an ice-cream. In other words, a map is a very effective navigation aid, but using it demands quite a lot of concentration.

The inherent problem of using maps on mobile devices is the size of the device's screen. Maps carry a lot of detail in a visual form which makes it sometimes hard to comprehend on a mobile device. This makes a case for alternatives that provide the information visually in a more simplistic way or using a completely other way than a visual interface to provide navigation information. With the emergence of new generation mobile phones, that have the ability to sense the location and the inertial state of the device, it is possible to skip the cognitively heavy process of comparing the navigation information with the user's mental map of the spatial area. This makes maps' visual referencing to the objects in the surrounding area futile, as the user does not need to correlate them to the actual reality to find his way. However, this can generate a new problem with interfaces that do not provide visual context as maps do. Inaccuracies in e.g. GPS data can result in erroneous information being provided to the user.

The alternative methods presented in this thesis can be divided into two categories: visual interfaces and interfaces that employ other senses. The visual interfaces (augmented reality and radar display) are especially effective in showing information on POIs around the user. The interfaces that employ other senses (auditory and tactile

display) do not require the user's visual attention, which can then be directed to other tasks.

The augmented reality display is quite suitable for tourists and locals as it is effective in providing information about locations of different POIs around the user, but also to present additional information regarding those POIs. With the augmented reality display the user is not shut out of his surroundings, but instead can receive information from it, albeit through the screen of the mobile device. In addition to providing landmark knowledge, augmented reality display can also provide the user with route knowledge, but following the route guidance requires constant attention as only small part of the route can be shown at one time.

The auditory and tactile displays are also suitable for tourists as they provide navigation information without taking the user's visual attention away from his surroundings. The information can be processed in the background. The auditory display can present information more naturally with spatial sound than the tactile display, as the meaning of the tactons used to provide information have to be learned. The auditory display uses non-speech audio to provide information, which makes it possible to communicate with speech at the same time without overloading the user. The tactile display keeps both visual and auditory channel open for other tasks.

The radar display is suitable for locals and tourists as it concentrates on providing information about surrounding POIs. It focuses only on providing low-level landmark knowledge and does not provide any route guidance. The minimalistic interface makes it possible to perceive the information with a quick glimpse so it can be seen as requiring little visual attention. The user does not have to know the exact route, because he can always check the correct direction and make his way to his destination.

In the course of writing this thesis I learned a great deal on this subject and it raised has my interest even more. In the future I aim to continue developing the Local Buddy concept and possibly doing some user field trials on this subject if possible.

References

Brewster, S. and Brown, L.M. 2004. Tactons: structured tactile messages for non-visual information display. Proceedings of the fifth conference on Australasian user interface-Volume 28, 15-23. Australian Computer Society, Inc.

Darken, Rudolph P. & Peterson, Barry. 2001. Spatial Orientation, Wayfinding and Representation. Handbook of Virtual Environment Technology. Stanney, K.Ed.

Eaton, Kit. Article. http://www.fastcompany.com/blog/kit-eaton/technomix/augmented-reality-round-navigation-apps (Read: 10.11.2009)

Elroi, D. 1988. GIS and Schematic Maps: A New Symbiotic Relationship. Proceedings GIS/LIS '88, San Antonio, TX, 1988.

Gartner, Georg & Radoczky, Verena. 2005. Schematic vs. Topographic Maps in Pedestrian Navigation: How Much Map Detail is Necessary to Support Wayfinding. AAAI 2005 Spring Symposia.

Gehring, Bo. Why 3D Sound Through Headphones? Article. http://www.fp3d.com/papers/WhyHeadphones.pdf (Read: 10.11.2009)

Golledge, R. G. (Ed.). 1999. Wayfinding behavior: Cognitive mapping and other spatial processes. Baltimore, MD: Johns Hopkins Press.

Holland, Simon, Morse, David R. & Gedenryd, Henrik. 2002. AudioGPS: spatial audio in a minimal attention interface. Personal and Ubiquitous Computing. 6 (4), 253-259.

Hunt, E. & Waller, D. 1999. Orientation and wayfinding: A review. ONR technical report N00014-96-0380. Arlington, VA, Office of Naval Research.

Jones, M., Jones, S., Bradley, G., and Holmes, G. 2006. Navigation-by-music: an initial prototype and evaluation. Proceedings of the International Symposium on Intelligent Environments. Microsoft Research (ISBN: 1-59971-529-5), 1849–1852.

Kraak, MJ & Ormeling, F. 2003. Cartography: visualization of geospatial data. Addison-Wesley Longman Ltd.

Layar. Website. http://layar.com/ (Read: 10.11.2009)

Lin, M., Cheng, Y., and Yu, W. 2008. Using tactons to provide navigation cues in pedestrian situations. In Proceedings of the 5th Nordic Conference on Human-Computer interaction: Building Bridges (Lund, Sweden, October 20 - 22). NordiCHI '08, vol. 358. ACM, New York, NY, 507-510.

May, A. J., Ross, T., Bayer, S. H., & Tarkiainen, M. J. 2003. Pedestrian navigation aids: Information requirements and design implications. Personal and Ubiquitous Computing, 7, 331–338.

Moore, B.C.J. 2003. An introduction to the psychology of hearing. Emerald Group Pub Ltd.

Nasir, T. and Roberts, J.C. 2007. Sonification of spatial data. The 13th International Conference on Auditory Display (ICAD 2007), 112-119. Citeseer.

Pyssysalo, T., Repo, T., Turunen, T., Lankila, T., Röning, J. 2000. CyPhone - bringing augmented reality to next generation mobile phones. Proceedings of DARE 2000 on Designing augmented reality environments, 11-21. ACM New York, NY, USA

Society for Gestalt Theory and its Applications (GTA). Article. http://gestalttheory.net/gtax1.html (Read: 5.12.2009)

Strachan, S., Eslambolchilar, P., Murray-Smith, R. 2005. GpsTunes – Controlling Navigation via Audio Feedback. Proc. of MobileHCI '05, September 19 – 22, Salzburg, Austria.

Rohs, M., Schönig, J., Raubal, M., Essl, G., and Krüger, A. 2007. Map Navigation with Mobile Devices: Virtual versus Physical Movement with and without visual context. ICMI'07(Nagoya, Aichi, Japan, November 12-15,2007).

Walther-Franks, Benjamin. 2007. Augmented Reality on Hand-helds for Pedestrian Navigation. Master Thesis, Digital Media (Fachbereich 3 – Informatik) University of Bremen.

Werner S., Krieg-Brückner B., Mallot H.A., Freksa C. 1997 . Spatial cognition: The role of landmark, route, and survey knowledge in human and robot navigation, in: W. Brauer (Ed.), Informatik'97. Informatik als Innovationsmotor, 27, Jahrestagung Gesellschaft für Informatik, Springer, Berlin.

Wikipedia. Accelerometer. Article. http://en.wikipedia.org/wiki/Accelerometer (Read: 5.11.2009)

Wikipedia. Auditory Display. Article. http://en.wikipedia.org/wiki/Auditory_display (Read 10.11.2009)

Wikipedia. Magnetometer. Article, http://en.wikipedia.org/wiki/Magnetometer (Read: 5.11.2009)

Zwick, C. and Schmitz, B. and Kuehl, K. 2005. Designing for Small Screens. Edited by AVA publishing SA.