PhotoMap: Using Spontaneously taken Images of Public Maps for Pedestrian Navigation Tasks on Mobile Devices

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ABSTRACT
In many mid- to large-sized cities public maps are ubiquitous. One can also find a great number of maps in parks or near hiking trails. Public maps help to facilitate orientation and provide special information to not only tourists but also to locals who just want to look up an unfamiliar place while on the go. These maps offer many advantages compared to mobile maps from services like Google Maps Mobile or Nokia Maps. They often show local landmarks and sights that are not shown on standard digital maps. Often these 'YOU ARE HERE' (YAH) maps are adapted to a special use case, e.g. a zoo map or a hiking map of a certain area. Being designed for a fashioned purpose these maps are often aesthetically well designed and their usage is therefore more pleasant. In this paper we present a novel technique and application called PHOTOMAP that uses images of 'YOU ARE HERE' maps taken with a GPS-enhanced mobile camera phone as background maps for on-the-fly navigation tasks. We discuss different implementations of the main challenge, namely helping the user to properly georeference the taken image with sufficient accuracy to support pedestrian navigation tasks. We present a study that discusses the suitability of various public maps for this task and we evaluate if these georeferenced photos can be used for navigation on GPS-enabled devices.

Categories and Subject Descriptors
H.5.1 [**Multimedia Information Systems**]: Artificial, augmented, and virtual realities, hypertext navigation and maps, location-based services (LBS)

General Terms
Design, Human Factors

Figure 1: The PhotoMap application in use. The location of the user is highlighted (with a red marker) on a photo of a public map.

Keywords
'You are here' maps, mobile camera devices, pedestrian navigation, GPS

1. INTRODUCTION
According to a recent BBC article [6], Nokia predicts that in the coming year it will sell 35 million GPS-enabled phones and this reflects how personal navigation has become the latest feature to be assimilated into the mobile phone. Similarly, the same article states that Symbian's operating system was shipped on 188 million phones last year and a third of those came with GPS. In line with these developments, a range of "free to download" mobile map applications are currently available. The most popular being Google Maps Mobile [12] or Nokia Maps [22]. Indeed a compelling scenario for the use of GPS (Global Positioning System)

Figure 2: Comparison of a locale map of the campus of Lancaster, UK (middle, right) and a map by Google Maps (right). © 2009 Google - Map data © 2009 Tele Atlas.

enabled phones is support for pedestrian navigation, e.g. enabling a user to glance down at the screen of her mobile phone in order to be reassured that she is indeed located where she thinks she is (see figure 1). While service based approaches to support such navigation tasks are becoming increasingly available – whereby users download relevant maps of their current area onto their GPS enabled phone the approach is often far from ideal [26].

Typically such maps are highly generalised and may not match the user's current activity and needs. For example, rather than requiring a standard map on a mobile device, e.g. using Google Maps Mobile or Nokia Maps, of the area, the user may simply require a map of a university campus showing all departments or a map showing footpaths around the area in which she is currently trekking. Indeed, one will often see such specialised maps on public signs situated where they may be required (in a just–in–time sense). It is interesting to consider how one might enable users to walk up to such situated signs and use their mobile phone to 'take away' the map presented in order to use it to assist their on-going navigation activity. Figure 2 shows a comparison of a map by Google Maps (right) and a local map of the campus of Lancaster, UK (left, middle). The local map (left) shows local landmarks omitted from Google Maps and other web map services, such as departments and info points and detailed information such as footpaths supporting navigation on the campus.

In this paper, we expand upon the concept introduced in [5] of enabling users to walk up to such situated signs and use their GPS-enabled mobile phones to 'take away' the map. This happens by taking a photo of it, in order to use it to assist their on–going navigation activity (see figure 1). The contributions presented in this paper are the analysis of the design and characteristics of public maps we collected, a description of different approaches and implementations for georeferencing photos of maps on the fly, and proof-of-concept evaluation, providing validation of the feasibility of the concept using images of public maps in the context of pedestrian navigation tasks.

The remainder of this paper is structured as follows. Related work in the field of wayfinding and 'YOU ARE HERE' maps as well as location-aware mobile guides is presented in Section 2. Section 3 describes the scenario for the PHOTOMAP application and in Section 4 we analyze a corpus of 93 'YOU ARE HERE' maps we have taken. In Section 5 we show three different methods for enabling users to georeference the maps and we describe the implementation

Figure 3: The usual interaction scheme of a PhotoMap user. A user comes to a public paper map, takes a photo and uses this photo for navigation.

and limitations of our georeferencing approaches. Next, Section 6 presents a proof-of-concept, exploring the possibility to use photos of public city maps for mobile navigation purposes. Finally, Section 7 provides some concluding remarks.

2. RELATED WORK

In the following subsections we discuss the related work in the fields of Wayfinding & YAH Maps and Location -Aware Mobile Guides.

2.1 Wayfinding and YAH Maps

Lynch defines the term *Wayfinding* in his book The "Image of the city" [21] as – a consistent use and organization of definite sensory cues from the external environment. In his book he also considers how users perceive and organise spatial information while performing wayfinding tasks in the city by forming mental maps typically comprising five elements including landmarks. In [33] the concept of spatial mental models is introduced which reflect the ability of individuals to carry a mental model that supports spatial relations amongst elements, e.g. landmarks, but does not allow accurate metric judgements to be made. Traditional 'YOU ARE HERE' maps, i.e. maps that explicitly indicate the position of the map reader [17,

Figure 4: Different local 'YOU ARE HERE' maps (top) compared against Google Maps (bottom). From left to right: Centre of education of the finance school in Gievenbeck, Germany; Botanic garden in Münster, Germany; Zoo of Münster, Germay; Central Station Amsterdam, Netherlands; Hofgarden in Innsbruck, Austria. All maps at the bottom © 2009 Google.

18, 23] enable the user to orient themselves spatially to their current environment and acquire survey knowledge. Being a form of map they can support wayfinding and provide their reader with an appreciation of nearby landmarks.

2.2 Location-Aware Mobile Guides

A thorough overview of location-aware mobile guides that rely on maps or map–like representations in providing their services is presented in [2]. Research into the general area of mobile device support for pedestrian navigation/wayfinding has undergone an evolution over the last 15 years from the early research prototypes to the now common "mobile maps" shipped as standard on many new GPS-enabled mobile phones. Foundational research into the technical and human factors issues arising from the use of mobile devices and the concept of location-awareness to support pedestrian navigation was conducted under the CyberGuide[1] and GUIDE [4, 8] projects. Both utilized some form of graphical map representation as part of their functionality. The Cyberguide project [1] was responsible for two mobile guides, one to support navigation inside buildings, the other outdoors. Both enabled the user to view a schematic map of the area, automatically updated according to the position of the user. The position was determined by means of infrared sensors (indoors) or GPS (outdoors). The GUIDE project [4, 8] led to the development of different prototypes of mobile tourist guides for the city of Lancaster. GUIDE allowed the user to request a sketch-like map of their surrounding area with a simple animation to highlight the path required by the user to navigate to their next chosen attraction. One of the later studies relating to GUIDE involved a Wizard of Oz type study in which the user could select an attraction, e.g. Lancaster Castle, by taking a photo of the attraction with a camera equipped PDA device (see [7] for more details).

A detailed investigation into the implications of supporting Wayfinding through the use of mobile maps is presented by Willis et al. [19]. In this paper, Willis and colleagues describe the results of an experiment which examined the types of knowledge acquired by an individual, depending on whether they used a physical paper map or a mobile map (Nokia 6630 mobile phone running Route 66 mobile mapping software application) to assist them. Her study revealed that mobile map users tended to perform worse than paper map users, particulary on wayfinding situations and route distance estimation. The study proved that this was a consequence of the format

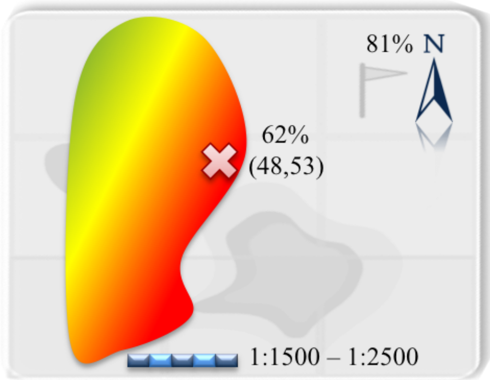

Figure 5: 'YOU ARE HERE' maps properties. From our collection of 93 maps 81% had the correct northing; 62% had a 'YOU ARE HERE' dot mostly positioned in the middle. The colored area indicates the most frequently used positions for 'YOU ARE HERE' dots on a map. The color indicates the frequency of the dot placement from green (low) to red (high). In average the maps had a scale from 1:1500 to 1:2500.

and presentation of the spatial information.This work considers the nature of wayfinding as a "complex, purposive and motivated spatial activity" [10] and one in which the support provided by mobile devices can often introduce errors (e.g. due to poor GPS signal) leading to the need for users to stay engaged in the wayfinding task.

Other researchers have concentrated on the combination of paper maps and mobile (camera) devices in several ways. Reilly et al. [25] use maps equipped with an array of RFID (Radio Frequency Identification) tags to realize the link to the paper map. This method was enhanced by using computer vision techniques [25], resulting in a higher spatial resolution and enabling more interaction techniques. MapSnapper [24] is an application that takes a picture of a paper map and sends it to a central server for analysis. The resulting map, which is sent back to the user, contains details on all nearby personalized points of interest. Schöning et al. [30, 31] introduced a method that uses an optical marker for map interaction.

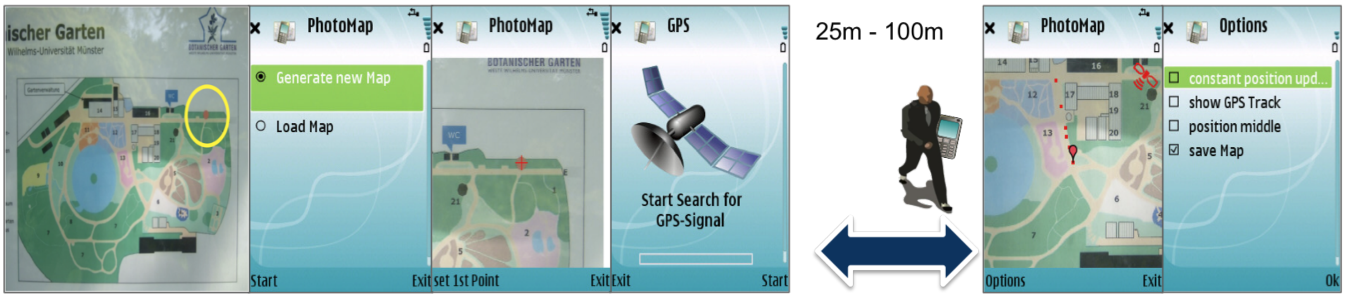

Figure 6: The "Two Point Referencing" approach: The user takes a photo of a public map (left) (the 'You are here' dot is marked with a yellow circle). Marks the dot with a cross-hair and connects it with current GPS position. The user walks away from the map (about 25m to 100m) and repeats the process after. After that he is able to use the photo of the map for navigation tasks. The screenshots (right) show the working application and the options menu.

This allows for the display of additional geoinformation, such as georeferenced vector or raster data, on the map. One disadvantage of this approach is that valuable map space is obscured. Subsequent work addressed this problem [27]: In order to align the overlay graphics with objects in the camera view, the video stream of the camera is continuously analyzed. The position of objects on the map has to be tracked to accurately align the graphical overlays with the real-world view. To simplify the task of real-time markerless tracking on a mobile phone with limited computing resources, the map is modified in our prototype setup: it contains black dots arranged in a regular tiny grid [27]. Using the correlation between a precomputed map and the camera image, the system computes the actual position of the mobile device over the map. Using this technique we implemented the mobile applications Wikeye [14] and Wikear [29] try to improve the understanding of places by combining digital Wikipedia content and paper-based maps and evaluated in user test [28]. From a slightly different perspective the approach described here can be considered, in part, as a form of Note taking [3] whereby a mobile user walks away with information that they believe will be of later utility.

In contrast to other map alignment software such as Microsoft's Map Cruncher [9] or HPs Map Aligner, PhotoMap is designed to support spontaneous interaction with 'You are here' maps in the environment without the need of downloading map data on the mobile device beforehand. Following the ideas of Weiser [34], of *spontaneous interaction*, the PhotoMap application can support users, because one will often see such specialised maps on public signs situated where they may be required (in a just-in-time sense) on the go. Microsofts Map Cruncher [9] is a Microsoft Research project which uses the Virtual Earth API to import supplemental maps into Virtual Earth as a desktop tool. The Map Aligner from HP is a map aligned tool for a PDA. It requires that the user downloads map material beforehand on the device to georeference it in the field.

3. SCENARIO

The following scenario illustrates the concepts more fully: Maximilian is walking through the city of Münster, Germany. He approaches the botanic garden behind the castle of the city. Standard maps of this area just show a grey (not even a green) area (see Figure 4; 2nd from left), but fortunately there is a paper 'You are here' map at the entrance of the garden containing all details and POIs of the garden. Maximilian takes a picture of the map of the botanic garden with his GPS-enabled phone and performs some additional actions (three different methods are described in detail in Section 5) to do the georeferencing in an easy and appealing way. For that we utilize the current GPS positions where Maximilian took the photo in order to establish the map's scale and extent (and northing). This can be verified by the current lat/lon coordinates coming from the phone's GPS unit. The map remains as an image on Maximilian's phone (see figure 1), because it contains height information and additional useful local information, but is now georeferenced and can be used for navigation. For instance, it might provide information on the different flowers or vegetation that is not available in standard map applications. Note that the 'You are here' dot shown in the screenshots reflects that shown in the physical map and serves as a useful reassurance to Maximilian regarding his current location. For this approach we *only* have to tackle one main challenge. Namely that the users have to georeference (also referred to as rectifying) the map photo on-the-fly on their mobile device. This is described in detail in section 5.

4. PHOTOMAP CORPUS

In order to explore the variety and characteristics of 'You are here' maps we collected 93 maps in 21 cities (in 8 countries in central Europe and North America). The cameras used for this process comprised the built in cameras of the Nokia 5500 (with 2 megapixel), the Nokia N95 (with 5 megapixel) and a Nokia E71 (with 3.2 megapixel camera). Figure 4 gives an impression of the variety and density of these maps and their superiority against standard map services. 36% of the maps we collected were city maps showing POIs and important sights in the inner city areas. 31% of the maps were showing local areas at a large-scale, e.g. campus maps, surrounding maps at train stations or bus stops, and maps showing local shops, or sports areas. 16% of the maps in our corpus were hiking maps showing different hikes through national parks or mountain areas. 14% of the maps showed gardens, parks and zoos. 2% of the 'You are here' maps showed larger regions (e.g. 1% were historic maps of a local area. It was interesting that about 96% of the maps were spatially correct, meaning they were designed using underlying map data and had scales ranging from 1:1500 to 1:2500. 81% had the correct northing and 62% of the maps had a 'You are here' dot. As can been seen in figure 5 the 'You are here' dot was mainly positioned in the middle of the map. We analyzed the (x, y) positions of all 'You are here' dots in all maps with a 'You are here' dot and normalized the position to a scale from 0 to 100 in the x- and y-direction. Also figure 5 shows

Figure 7: The "Smart Alignment" approach: User takes a photo of a public map and connects the 'You are here' dot position to his actual location (the left images, the 'You are here' is marked with a yellow circle). After that the photo is overlayed on a digital map and the user can adjust it by scaling it (right). This can be done by using the standard 4-direction joystick (as indicated with the yellow arrows). After completion of this appraoch the user can use the the photo for navigation - the user's position is indicated with a blue marker (marked with a yellow circle right).

the area of distribution of the 'You are here' dots. As noticed above most of the 'You are here' dots were positioned in the middle. Another "hot zone" was the lower middle edge. Having the dot at that position has the advantage that the user is in front of the area she can explore. Most of the other 'You are here' dots were positioned on the upper left quarter of the map, probably because of the reading direction in central Europe and North America.

5. GEOREFERENCING APPROACHES

The georeferencing step needs to be supported by the users themselves. For that we developed two approaches explaining a trade off between user interaction and system complexity, namely the "Two Point Referencing" and the "Smart Alignment" approach. In the first version, the map is rectified in two steps and the user has to move physically between these steps before being able to use the map. Our second implementation allows the user to adjust his photo of a YAH-Map to an already referenced map on her GPS trace and then use it as a foundation for navigation.

Generally the projection of the map and the image distortion (caused by the tilting angle between map and mobile device) should not be too extreme. An optimal photo would be taken by a mobile device held parallel to the map (see figure 3). Reference points (assigning real world coordinates to the image pixel) need to be given by the user and need to be combined with the current GPS-coordinates provided from the GPS-module of the mobile phone. Currently we have implemented the following approaches for our PhotoMap prototype. Both implementations are shown in the video `http://www.youtube.com/watch?v=sVjZ_8kxd28`.

5.1 "Two Point Referencing"

Directly after the user has taken the image of the map she should either indicate where she is on the map or mark the 'You are here' dot to determine her actual position. So, she positions a crosshair over the dot using the standard 4-direction joystick of the mobile device. Then she has to wait for a GPS-Signal, at which point her actual position is connected to the x-, y-coordinates of the 'You are here' dot in the image. After she has moved a sufficient distance the phone should request another indication of position from her. In this second step she must repeat the process (see figure 6) again. After that PhotoMap rectifies the map and allows her to look up her location or create a GPS trace or record a GPS-Track (see figure 6 right). She is able to pan around the map and can either obtain her actual position and/or her GPS trace. In the actual implementation the screen of the mobile device is about four times larger than the photo of the map. This is a trade off between photo resolution and map scale. A world file is stored for the taken photo

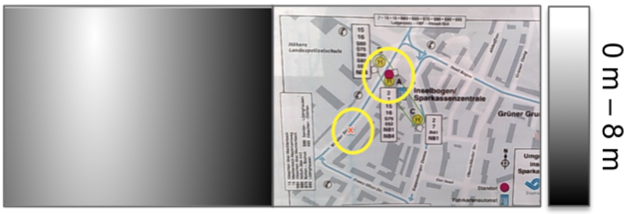

Figure 8: Mean error introduced by the "Two Point Referencing" approach. The error range (from 0m - 8m) was mapped on 255 grey-scale value (white pixel 0m error; black pixel 8m). The mean error was about 5m.

so it can be read by a Geographic Information System (GIS)[1]. The "Two Point Referencing" method is implemented in Jave ME [32], so it is compatible with most mobile devices. For testing proposes we mainly use the Nokia N95 and E71 due to their build-in GPS and their reasonable quality cameras.

5.2 "Smart Alignment"

To significantly reduce user interventions we developed a second georeferenzing method called "smart alignment". After taking a snapshot of a YAH-Map the user has to indicate again where she is on the map or mark the 'You are here' dot to determine the actual user's position. After that the photo of the map is displayed semi-transparently over the map data. The 'You are here' dot is anchored to one corresponding position on the map. From our map corpus we utilise the knowledge that the scale is normally about 1 : 1500 to 1 : 2500 and that about 81% of the maps have the correct northing. Hence the photo is roughly adjusted depending on the scale. The user has to perform the fine adjustment of the photo on the map. This can be done by scaling the image in every direction using the touch screen, rotating (if necessary in 12% of all cases) can be done by pressing additional keys on the keyboard. Because of its seamless integration of Google Maps Mobile [12] we chose the Android platform [11] using the developer version of Google G1 for our implementation. After adjustment, the photo should be rectified to high accuracy after which it can be used for precise navigation. Again the photo is stored with the corresponding world file for further use in GIS or lightweight systems like virtual globes.

[1]A world file is a plain text computer data file used by geographic information systems to coordinate raster map images introduced by ESRI, one of the leading GIS companies. These world files are six-line ASCII files with decimal numbers on each line [36].

Figure 9: The photo of the hospital area that was used for the navigation for all users (left with a dashed red border). Example of photos users took using the PhotoMap application. Out of 20 photos the users took just one photo was not usable for navigation (right).

A slightly modified version of the "smart alignment" method utilises the GPS trace of the user. Instead of overlaying the photo of the map over a digital map, the GPS trace is displayed. If the device is equipped with a touch screen, such as the Google One, the user can directly draw on the PHOTOMAP the path on which she approaches the map, otherwise she needs to indicate way-points with the help of a crosshair. Of course, here it is assumed that the user's trace overlaps with the spatial extend of the photo of the map. As we can conclude from our map corpus this is the case in nearly half of the cases (about 48%). Problems will occur if the 'YOU ARE HERE' dot is positioned at an edge of the map.

5.3 Comparison of both Approaches

Both georeferencing approaches have several advantages and disadvantages. A general major problem of this method is the inaccuracy of the GPS-Receiver, which potentially leads to a wrong or imprecise rectification. As reported from the literature [15] a standard GPS can achieve an absolute accuracy of 5m to 10m. Of course, the GPS signal can be improved by using Assisted GPS (A-GPS) [35] with the disadvantages of requiring a data connection to a server.

In addition the user can introduce additional error sources: they can introduce an offset between the 'YOU ARE HERE' dot and their position indicated by the crosshair (see figure 6.1). In the first version they can also indicate a second wrong position. In the second "smart alignment" version they can choose a wrong scale, but the error sources in the first approach are significantly more critical. To estimate the error introduced by the user we let 5 users select a 'YOU ARE HERE' dot and a second point on a bus stop map near our institute. The map can be seen in figure 6.1 (middle). Both locations are marked with a yellow circle. Figure 6.1 (left) also shows the resulting error maps. The rectified maps were overlayed on cadastre data and the pixelwise offset was calculated for each pixel. The error range (from 0m - 8m) was mapped onto 255 greyscale value (white pixel 0m error; black pixel 8m). The mean error was about 5m. So it doubles the inaccuracy of the GPS in the worst-case scenario. Other disadvantages of the first version are:

- Only northed maps are supported (81% of the maps we collected had the correct northing).
- It may take up to the second point until the georeferencing process produces results. Until then, users have no navigational support.
- At remote locations or in urban canyons the user needs to indicate her position on the PHOTOMAP at least three times at sufficiently remote locations to obtain good results for the two-point version. Of course the user can improve the results by adding more than the required reference points.

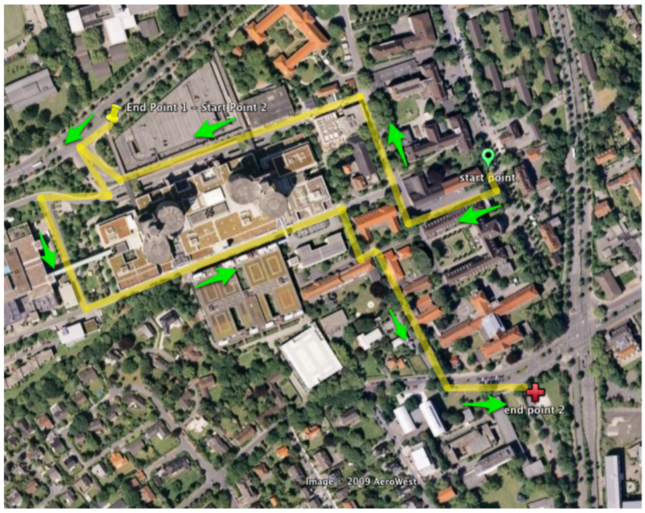

Figure 10: Map of the start and end Points for the navigation task. First the user had to navigate from the green marker (right) side to the yellow pushpin (0.8 km) (middle) and down back to the red cross shaped marker (1.3 km). © 2009 Google and Areal Image © 2009 AeroWest.

To overcome these limitations, we developed the second georeferencing version. We see many more possibilities how the georeferencing could be improved with minimalizing user interaction, for example, the user could easily limit the degrees of freedom by indicating the scale or the northing of the map (using our knowledge gained from the map corpus).

The big advantage here is that georeferencing starts immediately after the interaction and it is expected that the quality of the georeferencing process increases because the user just has to adjust the scale in most cases (in some cases also the rotation). But the downside of this technique is the additional requirement for a digital map and the costs that are caused by either downloading or storing it. Using the GPS trace for this proposes can overcome these problems (as present in the modified version of the "smart alignment" method), but of course the GPS trace is again reintroducing the error from the GPS device. The optimal solution of course would be to modify one of the presented georeferencing approaches to reduce the user interaction to a minimum.

6. PROOF-OF-CONCEPT & EVALUATION

Pre-tests revealed that the usage of a standard map client, such as Google Maps Mobile, did not support the users. Users had to memorize the paper map and the mobile map client was of little use. The PHOTOMAP application outperformed the mobile map client. Therefore we decided not to compare a mobile map client against our PHOTOMAP application.

Instead for the initial field evaluation, our goal was to validate the feasibility of the concept using images of public maps for pedestrian navigation tasks. Ease of navigation and task performance with mobile maps is influenced by map alignment to the orientation of the user [37]. To eliminate these side effects we chose a north oriented map that centred the user in the middle of the map (photo). We were interested how a photo taken by a user could be used for navigation tasks and exploring any issues raised by inaccuracies caused by the different ways of georefercing the photos on-the-fly.

6.1 Participants & Apparatus

The study took place in the hospital area in the city of Münster, Germany with 10 participants, 5 males and 5 females with an average age of 24.3. The participants where undergraduates and graduates from the local university. The study was conducted over a period of one week in early January 2009. All of the user had used a mobile camera device before. 45% of the users used a GPS navigation system (e.g. a car navigation system or an ordinary GPS for pedestrian navigation of geocaching activities). The test was performed on a Nokia E71 Symbian GPS enabled camera phone with a 3.2 megapixel camera with autofocus and flash running a J2ME PHOTOMAP version modified for the user test. To eliminate side effects of inaccuracy caused by the different ways of georefercing the photos on-the-fly we did the following: The photo the user took was stored on the mobile device and replaced with

(1) a correct georeferenced photo of the map of that area and

(2) a photo with an inaccuracy normally introduced through our application (see section 5.3 and section 6.1).

The test consisted of two navigation tasks. All participants performed the test with the precise photo of the map (1) and with the inaccurate georeferenced version of the photo (2) (we introduced an inaccuracy of 5m on average (see figure). Half of the users used the map (1) for the first navigation part and half of the user the map (2). The order was reversed for the second navigation task. As participants walked the route the experimenter shadowed them. Their route and the duration were automatically logged by the system. Also the photo the user actually took were stored on the mobile device (see figure 6.1). If the user took a wrong turn, the experimenter did not correct the user.

After the actual test users were asked to rate the map navigation techniques by filling out a modified version of the "user interface evaluation questionnaire" of ISO 9241-9 [16] with only a single Fatigue category. The ISO questionnaire is a seven-point rating evaluation. Higher scores denote a better rating. The total time each participant took for the whole study was about 50 minutes.

All users had to navigate by foot to two Points of Interests (POIs) on the hospital area. The shortest path for the navigation was about 2.1 km long and consisted of a route with 15 turning points. The

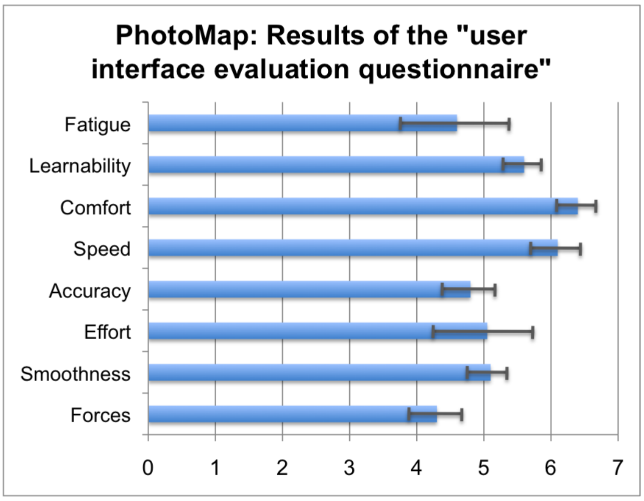

Figure 11: Results of the "user interface evaluation questionnaire". Users rate the factors comfort, speed and learnability best.

participants were introduced to the PHOTOMAP system at a public paper map not showing the hospital area. After that the experimenter walked with the user to the starting point and showed the first POI on a public paper map. The user took a photo of that map and started to navigate to the first POI (about 0.8 km and 6 turning points, in average every 133m a turning point). The main goal was to investigate the general suitability of photos of maps for navigation and not to compare the different georeferencing approaches or investigate the effect of the inaccuracy introduced by the users in the georeferencing process. Arriving at the first POI the same procedure was repeated with the same map of the area (obvisouly with antother 'YOU ARE HERE' dot position) and the user had to navigate to the second POI (about 1.3 km and 9 turning points, in average every 144m a turning point). The second route was longer but had the same characteristic than the first one with the same ration of route length/ turning points. After completion of the test the users had to fill out the "user interface evaluation questionnaire" in the field.

6.2 Results

All participants were able to complete all navigation tasks. The users took 20 photos of the same 'YOU ARE HERE' map in the hospital area. Figure 9 show the original map (left) and four of the 20 maps the users made. It is interesting to observe, that the users nearly took a photo of the same area. Just one photo was unusable for the navigation task (see figure 9 right). None of the users noticed that the photo they took of the map was replaced with a pre-georeferenced photo. The main performance measures taken were trial time and error rate. Trial time is the time from the start of a navigation task until the destination was reached. Overall we collected 20 trails (10 user $\times$ 2 navigation tasks). Both trial times and errors were derived from the recorded GPS traces. One trial of one user was removed for calculating the error rate and trial time, because this user had used a building entrance to shorten his path to the destination. The building entrances were marked on the map and this user took advantage of these shortcuts.

The error rate indicates the number of wrong turns taken by a user. The overall average trial time was 1745 sec. (95% confidence inter-

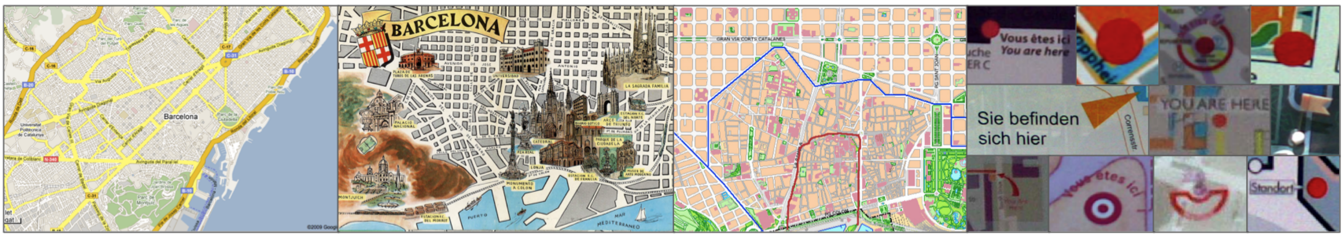

Figure 12: 'YOU ARE HERE' maps of Barcelona, Spain slightly rotated compared against Google Maps (left), so that the coastline was at the bottom of the map and the streets were lined up as a more or less regular grid. © 2009 Google. A collection of 'YOU ARE HERE' dots (right).

val: 1568 - 1922 sec.) and the overall average error rate was 2.1% (95% confidence interval: 1.7 -2.5%). There was no significant difference in trial time and error rate comparing the map condition (1) and (2) (trial time $F(1,19) = 56.42$, $p > 0.05$; error rate: $F(1,19) = 54.11$, $p > 0.05$). Both differences are within the limits of the 95% confidence interval and thus not significant at the 5% level. So the map condition (2) with the inaccuracy of up to 5m did not affect user performance.

The results of the "user interface evaluation questionnaire" were very promising. The users gave high grades for the factors: comfort, speed and learnability. Furthermore, some users pointed out that the system was very easy to use compared to other navigation systems. "Just a couple of button presses are needed and I have the right map on my mobile - I hate searching the right map portion on a digital map". " It is great that you can even use it wearing gloves, because you mainly have to press the middle button." Users also pointed out that the barrier to entry was significantly lowered compared to other mobile maps services. The inaccuracy in the (2) condition was not noticed by any user and subsumes under general GPS inaccuracy. This is also reflected in the equal error rate of both conditions.

7. DISCUSSION & FUTURE WORK

In this paper, we have presented our initial explorations into the technical feasibility and associated usability implications of allowing GPS-enabled mobile phones to support the capture, georeferencing and subsequent display of traditional 'YOU ARE HERE' map signage. In particular we have made the following novel contributions:

1. **Analysis of 'YOU ARE HERE' photo corpus:** we have investigated 93 maps in 21 cities, taken with different cameras of off-the-shelf mobile phones. By doing so we could infer that most 'YOU ARE HERE' maps can indeed be in most cases easily georeferenced by non-expert users.

2. **On-the-fly georeferencing methods:** we have presented two on-the-fly georeferencing methods that can be carried out on the mobile device, namely the "Two Point Referencing" and the "Smart Alignment" method. Both methods require only little intervention from the user. While the first method just needs two clicks and a physical displacement of the user, the second method can be performed on the spot without the need of additional movement by the user.

3. **Conceptual evaluation**: we have presented results of a first user trial, where we collected evidence of the general applicability of 'YOU ARE HERE' map photos to pedestrian navigation tasks, given the expected mobile georeferencing error.

4. **PHOTOMAP application**: we have presented a first technical implementation of the PHOTOMAP concept. The "Two Point Referencing" approach was implemented in J2ME [32]. The "Smart Alignment" was developed for the Android platform.

Especially the user studies with the working prototype provided encouraging feedback (as well as revealed interesting insights into the advantages and drawbacks of the different geo-referencing methods which we employed),which encourages us to further explore this novel approach to exploit traditional map signage with mobile devices. Since this we just presented the first steps to investigate this interesting combination of traditional and digital map usage, each of the above mentioned contributions lead to a couple of interesting research questions:

The first contribution directly leads to the question how to archive and collaboratively manage and collect YAH maps. One specific avenue, which we intend to explore, is the potential utility of collaborative approaches, whereby users could profit from the work of other users who have already carried out the geo-referencing process. This could yield, in a novel way, to provide coverage of urban areas by customized maps. One idea would be to apply a web 2.0 approach allowing users to upload maps to a web site. This applies to photos that have been georeferenced by the user as well as to photos that have not been georeferenced. One could imagine that, if the same 'YOU ARE HERE' map has already been uploaded by another user it could be found (by an image similarity match) and used instead of the original photo. One could even try to use the matching function to perform the georeferencing of the newly take picture by using the information from the already uploaded version. This can also help us to collect a richer corpus with maps uniform distributed all over the world, because we noticed differences of 'YOU ARE HERE' map properties between different countries (e.g. in Germany more than 81% of the maps had the correct northing (nearly 92%) compared to the maps of Spain (there we just had 5 sample maps from Barcelona and Palma de Mallorca)). In addition such a photomap web 2.0 portal can also be used to get more knowledge about local reference system. We noticed that all 'YOU ARE HERE' maps of Barcelona, Spain we took were not correctly northed, but slightly rotated so that the coastline was at the bottom of the map and the streets were lined up as a more or less regular grid (see figure 12 (left)). This phenomenon is also known in the literature [13]. A bigger photomap corpus would help to investigate such effects. In addition a set of 'YOU ARE HERE' dots can be used to automatically detect the 'YOU ARE HERE' dot using com-

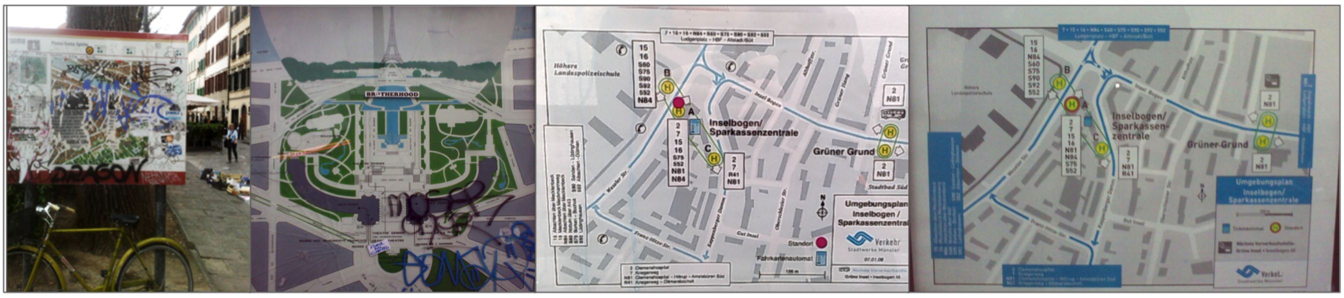

Figure 13: Example of vandalism to a 'YOU ARE HERE' type map in Florence, Italy and in the city of Paris, France (left). Dynamic character of these public maps shown with a map at a bus stop in the city of Münster, Germany photographed in late 2008 and early 2009.

puter vision algorithms (see figure 12 (right)). It is interesting to see that public maps are certainly not static. Here, we would like to investigate the dynamic character of these public maps. In Figure 13 (right) two maps from the exact location are shown. One photographed end of 2008 and the other was photographed in early 2009 (right). For example the POIs indicating telephone booths are no longer shown in the map of 2009.

In deepening of the second contribution, we also plan to apply more sophisticated georeferencing approaches. The most promising direction to follow is to use the GPS-trace of the user recorded by the device before the picture has been taken. By matching structural properties of the trace (e.g. turns and distance travelled) with structural properties of the map (e.g. pathways and streets) it could be possible to perform the georeferencing automatically in the background.

Of course, we intend to carry out additional field studies to explore the concept of PHOTOMAP from the user perspective and extend our findings of contribution 3. Here we plan to contrast the different referencing methods to understand their advantages and drawbacks in terms of general usability. Again we think that is was very important to first investigate the feasibility of the concept using images of public maps for pedestrian navigation tasks. A pretest showed that navigating with the PHOTOMAP application outperformed a mobile map application such as Google Maps mobile for the navigation on a hospital area. The implementation of PHOTOMAP (contribution 4), although already fully functional, can be further improved. We plan for example to allow users to access additional georeferenced information (such as Points of Interest) directly from the PHOTOMAP. This would integrate even further the paper based map with digital information available online. Unfortunately, an additional challenge for the approaches described in this paper is the vandalism that can occur to public signage. Figure 13 (left) shows an example of such damage to a 'YOU ARE HERE' type maps in the city of Florence, Italy or in the city of Paris, France and these examples are certainly not rare. With a web 2.0 styled online map collection tool different users can collect, share and merge their PHOTOMAP. With that we can address the problem of vandalism by looking for *older* and undamaged PHOTOMAP in the online map library. This tool can also be used to retrieve the georefering of other users' photos applying algorithms like SIFT [20] to compare a taken photo with already georeferenced images in the web application. Finally, it would be interesting to include additional information on the 'YOU ARE HERE' map usage available from the physical environment. For example information about where people have physically touched the map could be utilized. As can be seen in figure 14 certain areas of the map are hackneyed. Of course the actual position, but also other areas of the map were touched by many people. This information could be extracted with computer vision methods to get information about the importance of a point.

Figure 14: A hackneyed 'YOU ARE HERE' map.

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