Field Trial on the Efficiency and User Experience of GPS based State of the Art navigational Systems for Pedestrians

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Abstract— **Context-enabled applications are more and more establishing on the market. A key feature for those tools is the ability to connect the current user state and position to possible activities nearby. Thus it is crucial to a mobile application to be able helping the tourists to find and guide them to appropriate activities. This paper will separately address the navigational component and evaluate the efficiency of several systems currently available. All of these systems are based on current state of the art approaches and are easily expandable to different locations meaning there isn't any adaptation needed, running the system in other cities. At the end the paper will come up with a recommendation for the most suited system to be integrated into mobile applications under current conditions.**

Index Terms— **Mobile Application, Pedestrian Navigation, Satellite Navigation Systems, User Interfaces**

I. Introduction

Mobile tour guides like the Dynamic Tour Guide (ten Hagen, 2004) aim to provide users access to attractions apart the beaten tracks based on their current position, time frame and interests and thus expanding their awareness of the destination. They strongly depend on the quality of their navigational abilities (Riebeck et al., 2006).

A field trial in Görlitz (Modsching, 2006) analysed the impact of mobile information systems on the behaviour of tourists. The results suggest that tourists using a mobile information system recognise much more attractions and stay longer due to context-driven interpretation than those ones relying on traditional information sources like printed maps and books. Still the biggest challenge identified is pedestrian navigation, whereas digital navigation aid was exposed as one of the most important features to find certain sights in an unknown destination at the same time.

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II. Problem Definition

Currently available pedestrian navigators for mobile devices were found out to raise serious difficulties for users in finding desired locations. One reason is an insufficient accuracy of common GPS receivers within a built-up area due to reflections of GPS signals. Systematic measurements in Görlitz resulted in a mean aberration of 24 metres (Modsching, 2005). The other reason is inadequate concepts for pedestrian navigation, which more or less only provides the additional feature of using one-way-streets in both directions opposite to car navigation. Neither the ambiguity about the user's line of sight nor his/her nescience about distance are taken into account when instructing him/her to go right in 50 metres. These audible instructions are thus often misleading. Such commercially available devices pretend to enable an auditory guidance for pedestrians equal to car navigators which work well and are reliable. But they can't, as pedestrians are moving completely different, e.g. crossing squares in contrast to car drivers which are bound to streets. Furthermore maps on mobile devices are limited to the screen seize and can only display a very small section of a city what additionally hampers orientation. Definitely other concepts are needed for improving pedestrian navigation support. Recent evaluations identified landmarks as the most appropriate navigation method for pedestrians. Due to the high modelling effort their practical relevance is very limited. This study investigates alternative approaches for simpler practical adoption.

III. Related Work

Aslan et al. (2006) analysed the effect of mobile navigation assistants on spatial knowledge in a series of studies. They found no significant differences between audio and text route presentation. Comparing map-based way finding to technology-based navigation, participants using the map showed significant better route memory accuracy than subjects of the mobile device groups. So mobile pedestrian navigation systems seem to convey landmark knowledge but fail to convey survey knowledge. But as map-based navigation is out of the question for a mobile tourist application, this study will compare only mobile solutions, also considering the spatial knowledge factor.

Chittaro & Burigat (2005) compared three different ways of providing navigational information: first a map-only solution, second a map alternating with photographs including perspective arrows and third the same photographs as in the second condition including large arrows showing the direction to follow. The map-only users needed significantly more time for orientation than the other groups. The conclusion is that users find their way more quickly when combining a map with photographs plus perspective arrows or replacing it with directional arrows and photographs. These photographs showing landmarks were identified as the most effective way of navigation. Especially elder people achieved much better results in a study by Godman et al. (2004). Burnett (2000) has even shown that the use of landmarks in vehicle navigation systems can greatly improve their effectiveness. But this approach demands an enormous effort in modelling a city, as photos of all crossroads and for all lines of sight have to be taken and extended by arrows for each possible direction. It is thus not applicable for mobile applications needing to be expandable onto other cities easily.

IV. Objectives

The main purpose of this field trial was to find out which of four different navigation methods is most predestined to be integrated into a commercial mobile context-sensitive system. Therefore, the effectiveness of the navigational concepts had to be analysed. Effectiveness according to a pedestrian navigation component within a mobile guide can be defined as providing the shortest distance to lead the user to his/her targets without demanding all of his/her attention or causing high mental load. The most important research targets are the following:

- Amount of reached and failed targets
- Amount of correct and wrong decisions during the navigation process
- Time and distance needed to reach the targets

Time can also be split into 'time needed for orientation' (standing time) and 'progress time' (walking time) in order to find out whether some applications enable an orientation during walking. Perceived orientation with the system as well as the amount of mental load caused was gathered by surveys. Furthermore the participant's ability of creating a cognitive map of the city and the chosen route has been compared depending on the different applications. Finally participants were asked which problems occurred while testing the system, whether they would recommend such a system to friends, use it for their own or why not.

As misleading audible instructions was considered to be the source of most failure, the following hypothesis was defined: "A renunciation of auditory directives will lead to better orientation as users will be involved into the navigation process actively." The second hypothesis was defined as: "Directives based on street names are more efficient than right or left instructions". A third and last thesis goes: "Active involvement into navigation will also help creating a better cognitive map of the city".

V. Methodology

A. Applications

Four different concepts for pedestrian navigation were compared. The basis was the system used within the current version of a mobile tourist guide, a standard navigation package:

a) Auditory instructions plus digital, dynamic route

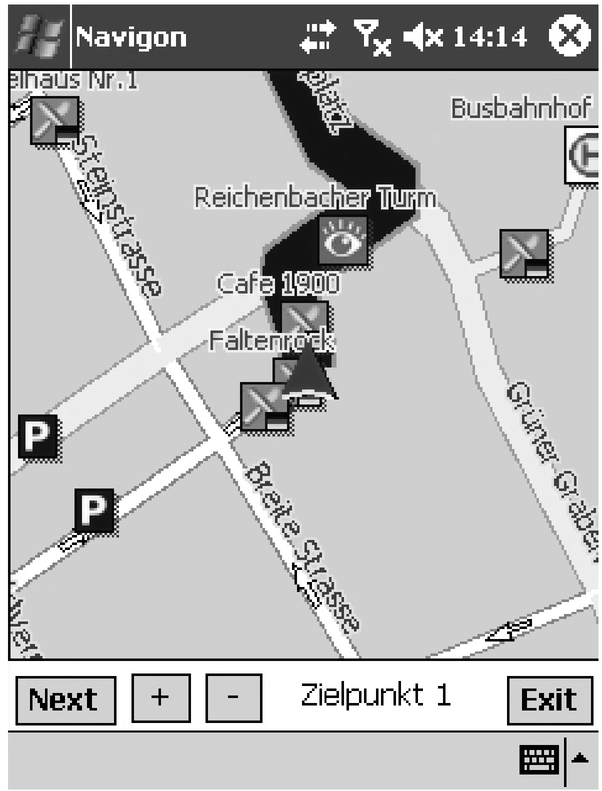

Fig. 1. Audio version

Fig. 1 presents an adapted commercial car navigator providing audio-visual routing information based on the Navigon Integration Kit (NIK)[1]. The map is adapting to the current position which is always displayed centralised by a red triangle. The proposed route is displayed in blue and recalculated automatically while moving. When approaching the next crossroad, the user is alerted e.g. to "turn right in 50 metres". Below the map, a hint on the next target is displayed.

b) Digital, dynamic route

The same application as in a) is used, but providing visual routing information only. Audible instructions are skipped. Another difference of application a) and b) towards c) and d) is that the NMEA data delivered by the GPS receiver are internally corrected, so that the position is always set onto the next street. Situated in the middle of a square, the application

[1] http://www.navigon.de

will set the position onto one of the surrounding streets. This mechanism often improves the localisation as the user can't go through walls and is set back, but sometimes even impairs the situation when choosing a parallel street.

c) Map with position and direction

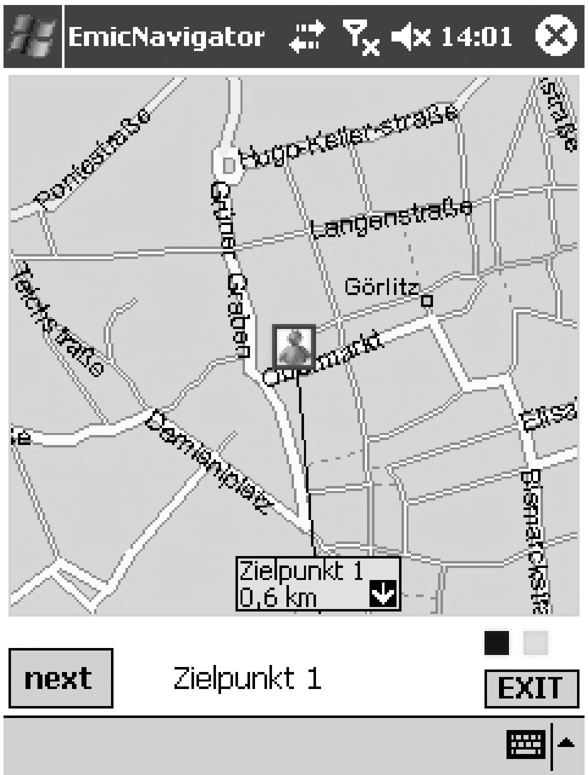

Fig. 2. Direction method

Fig. 2 shows a map-based navigator indicating the current position and the demanded direction, created by the European Microsoft Innovation Center (EMIC)[2].The current position is displayed by a figure which is connected to the target by a line to visualise the direction. The distance to the next target is shown too. The map is fixedly directed northwards. This framework provides the option to exchange the map easily, e.g. aerial maps. Furthermore a history function can be activated, indicating the already walked route.

[2] http://www.microsoft.com/germany/unternehmen/informationen/forschung/emic.mspx

d) Textual description by street names

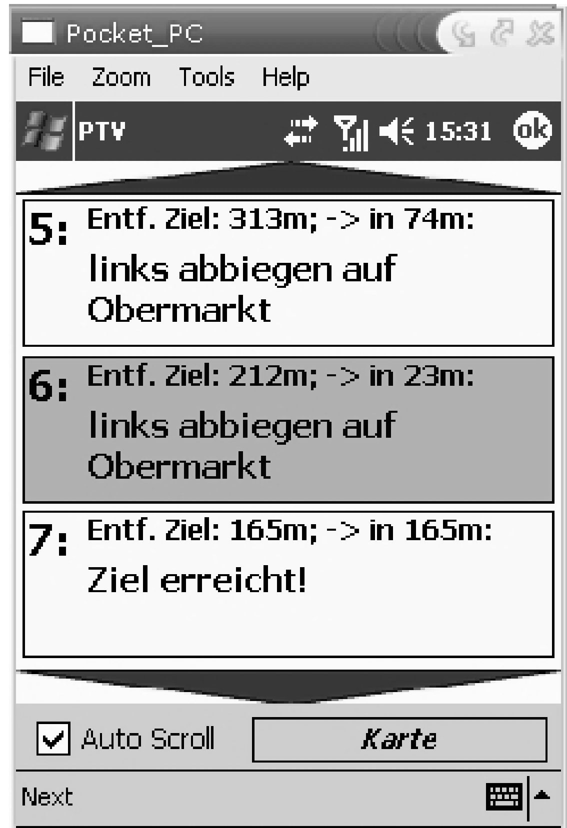

Fig. 3. Description method

Fig. 3 depicts the text-based navigator providing textual, street name based directions created by the PTV[3] web service. The instructions are numbered and the next one always appears at the top of the list with a different colour. They contain the direction to go at the next crossroad, the street name and the distances to the very next instruction as well as to the target. The user can also request a static map with the proposed route and the current position.

B. Setting of the field trial

40 persons who were unfamiliar with the destination environment were selected to attend the field trial. Indeed they have been first semester students not native to the city. They were separated into four groups, each with 10 persons, using one of the different navigation systems.

Three targets were defined and presented as pseudonyms (monument, museum, and fountain). All three targets are situated in the historic city centre of Görlitz, whereas the single sectors differ in the level of difficulty. The route to the first target is the most complex one, containing four squares and many decision points. The second sector only contains one square and only two major decision points and is thus much simpler. Both routes are depicted in Fig. 4 and Fig. 5. They represent extreme cases, whereas the third route lies in between, providing two squares. Squares are the most challenging locations for a navigator, as they usually provide more than two directions to walk into, and pedestrians may

[3] http://www.ptv.de

move crossways.

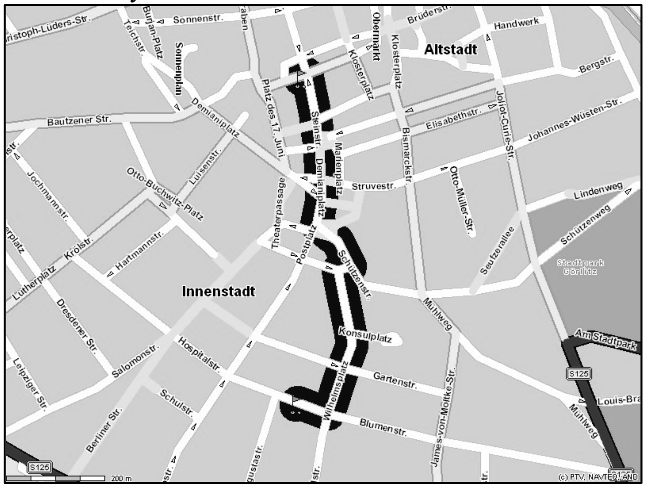

Fig. 4. Route to target 1

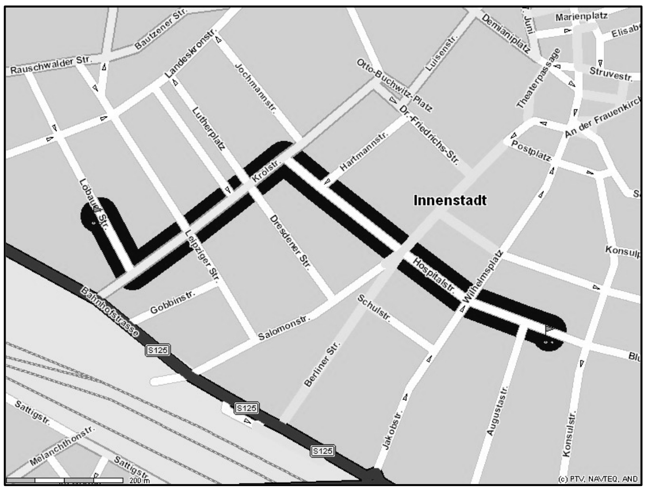

Fig. 5. Route to target 2

Each of the persons was advised to approach the goal directly avoiding unnecessary stops. A pre and a post-test questionnaire should point out the participants' sense of direction, computer literacy, mental load and perceived orientation with the pedestrian navigation system. Finally participants were asked to report about their way finding and to relate photos of landmarks to their chosen route on a paper map. This method enables meaningful outcomes about cognitive maps of users.

There is a mobile base application hosting the four different navigation packages and initializing the targets when started. That base application also records all movements and interactions of the participants. Additionally an observer followed the participants, keeping a distance of at least 10m with the following tasks:

- Drawing the participant's route into a paper map
- Helping in case of total distraction
- Confirming successful arrival at the target

An important issue is to get aware of the participant being convinced to have reached the target. That's why she/he was instructed to press a button. After a break of some seconds while the subject stands still, the next target is loaded. The observer recognizes this stop and counts this target as reached or not when situated at the wrong place.

VI. RESULTS

A. Overview

The mean age of the participants was 21 years. The sample comprehends 21 female and 19 male subjects which were equally distributed to the four groups. In general they were inexperienced with navigation systems at all; two third rarely or never used a car navigator and 98% seldom or never used a pedestrian one. All targets were reached by all participants, so all four systems do work. Differences become visible by a detailed evaluation.

B. Duration analysis

The first and last entry of each log-file was used to compute the duration from the starting point to the last target. The results of comparing the tour durations are listed in Table 1 by the median values in minutes.

TABLE I
MEDIAN TIME REQUIRED TO REACH THE TARGETS

Method	Target 1	Target 2	Target 3
a) Audio	19.4 min	13.7 min	19.1 min
b) Route	16.0 min	16.9 min	16.9 min
c) Direction	13.3 min	16.0 min	16.4 min
d) Description	15.2 min	16.3 min	19.7 min

Methods a) and c) show a difference of about 6 minutes regarding the total duration. Users orientating themselves by a digital map were thus faster than those that were guided by audible instructions. But it must be mentioned that duration has only little expressiveness as it strongly depends on the walking speed of the single participants.

Comparing the single stretches separately, it becomes obvious that audible instructions don't work for the first and third route. Participants needed up to six minutes longer than with the other applications. Whereas on the second and simpler route audio worked fine. Users were up to three minutes faster in this case.

C. Distance analysis

The NMEA data that was delivered by the GPS receiver and stored in a text-file was used to compute the covered distance by summing up the distances between each two values following one another. To minimise errors due to insecure GPS signals, all positions exceeding a certain threshold in distance and time towards the previous one were filtered. The results are listed in Table 2.

TABLE 2
MEDIAN DISTANCES COVERED TO REACH THE TARGETS

Method	Target 1	Target 2	Target 3
a) Audio	1.49 km	1.28 km	1.62 km
b) Route	1.39 km	1.24 km	1.50 km
c) Direction	1.13 km	1.38 km	1.53 km
d) Description	1.11 km	1.36 km	1.57 km

Methods a) and d) show a difference of about 300 meters for the total distance. So audible instructions lead to a worse result again, forcing the users to cover longer distances. But it also must be mentioned that although GPS errors were minimised, they can't be eliminated completely.

Comparing the single stretches separately too, reveals the same effect as in the duration analysis. The distances for the first route are significantly shorter with application c) and d) than with audio guidance a). For the second route it is vice versa, but the differences are very small and aren't significant. The third route only shows little difference.

D. Detours and stops

The reason why method a) was the worst one, especially for the first part of the route, becomes visible in the diagram in Fig. 6, comparing stops and detours. Both criteria were determined manually based on the notes of the human observer.

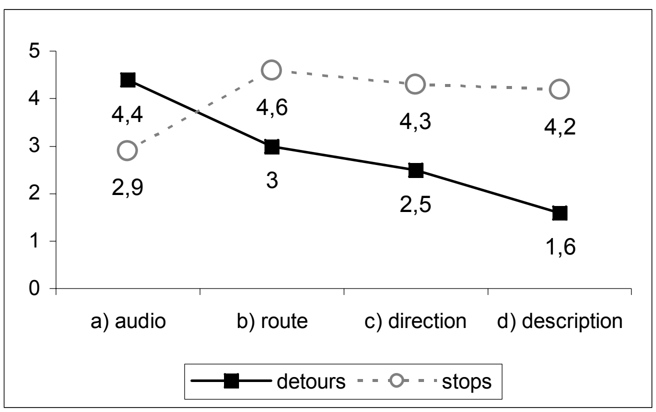

Fig. 6. Comparison of stops and detours

Users of application a) mainly concentrated on the audible instructions and did how the device said. That's why they made fewer stops than the other groups. If the instructions were wrong, the users went wrong as well. And indeed they needed the most detours before reaching the target. There are only minor differences between the other three groups. They needed more stops for orientation like looking for a certain street name or determining the right direction but made fewer mistakes in choosing the shortest way to the target.

All three evaluations show better results for method b) in contrast to method a), although it is the same system, with and without auditory directives. Even if the difference isn't significant, one can conclude that these directives provide a negative value. Instead of improving navigational support it is aggravated. The reason is that too many directives are misleading. Users relying on it walk into wrong directions most often.

E. Mental load

Mental load was captured with a scale including questions about effort, complexity, demanded attention and frustration level caused by the system. Table 3 lists the results.

TABLE 3
MENTAL LOAD (5=VERY POSITIVE RATING, 1=VERY NEGATIVE RATING)

Method	Mental load
a) Audio	3.7
b) Route	4.1
c) Direction	4.2
d) Description	4.3

Version a) was rated worst; d) received the best rating. Although this effect is not significant it can be assumed that the misleading auditory instructions had a negative influence on mental load.

F. Perceived orientation

The perceived orientation scale included questions about whether participants did always know where they were, which way to go next or whether they often felt lost. The evaluated ratings are shown by Table 4.

TABLE 4
PERCEIVED ORIENTATION (5=VERY POSITIVE RATING, 1=VERY NEGATIVE RATING)

Method	Orientation
a) Audio	3.7
b) Route	4.1
c) Direction	3.4
d) Description	3.6

Descriptively, testers with version b) stated the best perceived orientation, especially compared to group c). That may be caused by the navigational concept as group c) has been the only group which was not offered a concrete route suggestion but only the direction to the next target. Participants in this group had to find the way on their own which seemed to cause insecurity whether they took the right or wrong way.

G. Cognitive map

The cognitive map is supposed to indicate how intensive participants got aware of their environment while testing the navigational systems. Therefore the users' task was to relate diverse photos of landmarks along their walked route to positions in a map. Table 5 shows the percentage of correctly related landmarks for each method.

TABLE 5
RELATIVE NUMBER OF RIGHT RELATED LANDMARKS

Method	Correctly related landmarks
a) Audio	69 %
b) Route	72 %
c) Direction	88 %
d) Description	80 %

Participants using version c) related most of the landmarks (88%) to the right position on a map. Groups a) and b) only did 69 % and 72 % respectively correct. The users of version d) matched 80 % of the landmarks to their true position on the map. Therefore, it can be concluded that users in group c), characterised by the navigational concept of knowing the direction but finding the way on their own, were most involved in the navigational process, experienced more sights, had a higher activity level and finally recognized more sights within the post-test.

H. Summary of user comments

Participants were also asked which problems occurred while testing the navigational systems and which information they had missed while trying to find the target. Users testing version a) Audio and b) Route missed street names, the distance to the next target and more information about distinctive objects on the way (landmarks). Problems caused by the GPS inaccuracy was the rotating map and the inaccurate directions which were often presented too early or too late and made the users choose wrong ways. Participants using c) Direction missed cardinal points, landmarks in the map and information whether they were on the right way or not. Also they wanted the map to be orientated into their walking direction. Group d) Description did use the textual descriptions less often but preferred the map which they wanted to be more detailed and dynamic adapting to their current position and walking direction. Also in group c) and d) the GPS inaccuracy caused wrong distance information mentioned negatively by the participants.

VII. Conclusion

In general most of the found differences aren't statistically firm, but the problem of the audio method becomes very clear. By relying on the systems' instructions users are led to make errors and when realizing that the system leads them wrong, e.g. by instructions to turn round, they are frustrated. Audible instructions need to be reliable to be of supportive value; otherwise they cause only more confusion to the users. Street names or an approximate direction were thus identified to be more effective than absolute instructions to turn right or left now when looking for a certain target. Due to failures in positioning caused by GPS inaccuracy, users blindly following instructions of digital navigators are led wrong more often than users who have to orientate and plan a route themselves by a map or a textual description.

Results have also shown that users who are forced to find the way themselves by knowing the direction or the street name keep a better model of the city in their minds. That is because they take part at the navigation process actively. But they are also insecure about having chosen the right way and would ask for more assistance. Providing a route, the users follow it straight but don't keep in mind the places of landmarks that well as they only play a passive role. But it can decrease the insecurity about the shortest way and help the users in making a decision.

None of the four pedestrian navigational concepts can be said to be the optimal one. All of them can be useful according to the respective goal. If the route is very straight without many squares, version a) or b) seem to be the appropriate navigational concepts. For a town (especially in the city centre) with many narrow or one-way streets and a lot of squares, concepts like c) or d) are adequate. If the system wants to focus the user's attention on something e.g. sights, concept d) seems to be the best one. Bigger differences could have been proven statistically by increasing the number of participants or repeating the trial.

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