Guiding Blind Pedestrians with a Personal Navigation System

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With the assistance provided by the white cane or guide dog, most blind pedestrians can find their way to known destinations along familiar routes. Finding new or known destinations along unfamiliar routes is more challenging. Before such a journey is attempted, detailed instructions must be acquired. The difficulty of obtaining and then reliably following such instructions deters many blind pedestrians from travelling alone in unknown areas. This paper demonstrates a technological approach, by way of field trials, that supplements the existing aids and eliminates the need for sighted guides. The approach has the potential to offer greater independence to the blind person. The investigation suggests that the methodology used in personal navigation systems for the sighted is sub-optimal for guiding the blind pedestrian. Suitable extensions are introduced, and the results show the proposed methodology is efficient for guiding the blind individual to unknown destinations in the chosen field trial environment.

1. INTRODUCTION. Navigation involves several tasks. These include specifying destinations, planning routes and following routes. This paper introduces automatic methods that concentrate on solving the two latter tasks. Here it is assumed that the automatic system can access the current and destination positions such that route planning can take place. To follow a route, a guidance (control) method must be used. The methods demonstrated here compare the desired (route) trajectory with the user's intended trajectory and try to set them equal. Since a blind human is the intended navigator, a speech interface is used to implement route guidance.

2. SYSTEM DESCRIPTION. The system is most conveniently envisaged by considering the information required as input from, and output, to the user. The primary inputs are the current position and orientation of the user from a number of sensors. In addition, key presses and speech information is input to control the navigation system. The sole output to the blind individual is guidance via speech instructions. A processor is used to relate the inputs and outputs such that the guidance process is entirely automatic. The system concept is depicted in Figure 1.

To enable demonstration of the guidance algorithms, a prototype system was built using current commercial technology. A 35 mm square Global Positioning System (GPS) patch antenna was mounted on top of a stereo headphone set. A Rockwell Jupiter GPS receiver was utilised in conjunction with Radio Data System differential corrections (service provided through Focus FM of Newport Pagnell, Bucks). After

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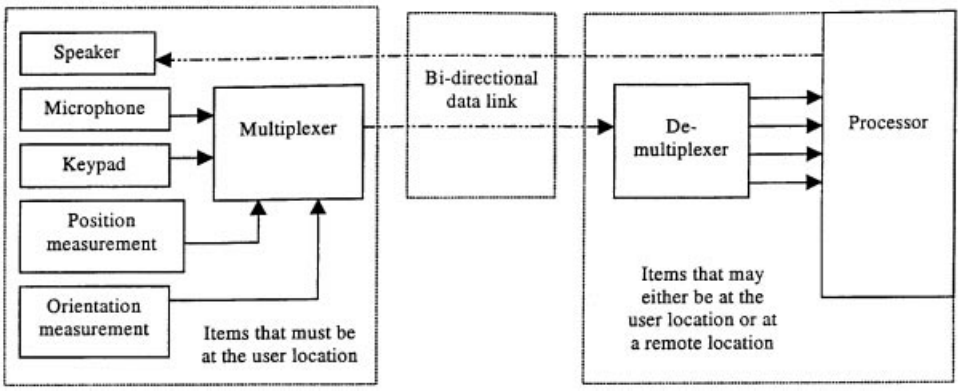


Figure 1. System concept of the Speech Navigation System.

transformation to Ordnance Survey grid coordinates, the static Expected Horizontal Position Error (EHPE) was estimated to be about 4 metres. Orientation was obtained from a KVH C100 magnetic compass with quoted accuracy of $\pm 0{\cdot}5$ degrees in the horizontal plane. The compass can either be held in the hand and pointed or hung around the neck. The compass orientation has an advantage over GPS heading information since it remains valid when the user is static. This is beneficial to the application since it is quite natural for pedestrians to stop to orient themselves. A portable PC, carried by the user, acts as the processor, and the bi-directional data link is implemented by a direct cable connection. This configuration is heavy and requires considerable power but is adequate as a 'proof of concept' demonstrator.

3. DIRECT GUIDANCE. Personal navigation systems for sighted people commonly allow a user to select a single (destination) 'waypoint' from a waypoint list. A display then relays the relative direction, θ, and distance, d, to the destination thereby enabling the user to travel towards it. If this information is instead given aurally, then it is also available to a blind pedestrian. Alternatively, the destination could be displayed in a virtual acoustic display as suggested by Loomis (1993). This method requires the user to wear stereo headphones so that sounds associated with objects appear to come from their actual location in space surrounding the user. The method of providing direct guidance information used here is a combination of speech and virtual methods. The relative direction is displayed in a virtual manner that only requires monaural audio. When the magnitude of θ is greater than a pre-selected value, ∇ (typically 30 degrees), the output of the system is silent. When the magnitude of θ is less than ∇, the distance is spoken. Since the resolution of the angular output instructions are dictated by the value of ∇, the volume is varied so that it is a maximum when the compass is oriented towards the chosen waypoint. The volume reduces to half (-6 db) at the point where θ equals ∇.

To demonstrate the characteristics of the direct guidance instructions, an open site was chosen. Since no obstacles are present on this site, the blind volunteer could concentrate exclusively on following the instructions. Eight destinations were mathematically generated to reside on the circumference of a circle at equal intervals. Each destination was assigned a label, namely a letter from A through H. The user was then guided through the waypoints in alphabetical order; the start point was H. As each destination was reached, the next was manually selected. The position of each

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progress to the destinations (grey circles).

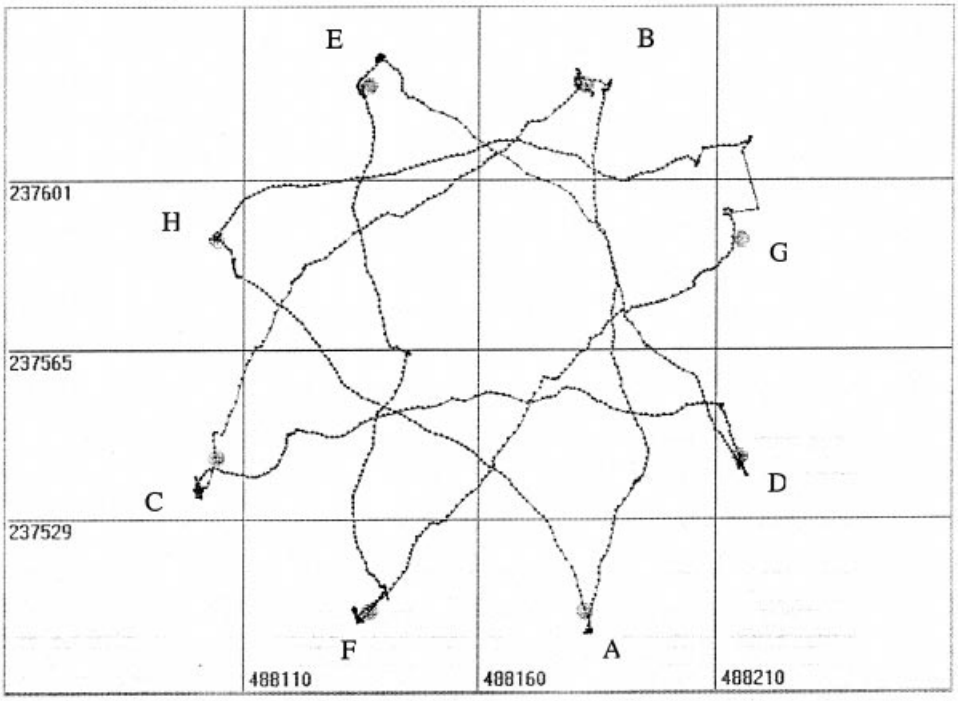


Figure 2. Volunteer 1 uses direct guidance to find 8 destinations on an open field.

destination and the order of traversal were chosen such that eight different directions of travel were encountered. One in the direction of each cardinal point; N, NE, E, SE, S, SW, W and NW. Figure 2 shows the GPS plots (black dots) of the blind volunteer's progress to the destinations (grey circles).

4. REPRESENTATION AND PLANNING OF ROUTES AND PATHS. In order to provide guidance to a destination along an indirect path, a spatial model of the path is required. In many navigation systems, a sequential list indicates the order in which waypoints should be traversed. Such a list is usually called a 'route'. Often a user manually selects the desired waypoints to create a route. The user must therefore be familiar with the route before it can be created. Greater benefit of such systems will be realised when routes can be automatically generated, given only knowledge of the destination and current position. The MoBIC project (MoBIC, 1997) examined this process, using a road/path network vector structure for the purpose. Using this method, the shortest path is calculated through the road network and waypoints are automatically generated at each junction. Each waypoint can be assigned an instruction label, such as 'turn left into Bloggs Road and continue along the left hand side of the road for 200 metres'. For this approach to be successful, an identifiable path network must exist and the instructions should be given in a timely manner. The approach is problematic in areas of wide-open space such as pedestrian areas and parkland. In order to solve these problems, additional unlabelled waypoints may be used and arranged such that direct travel is possible between any two neighbouring points in the sequential list (Loomis, 1993). The route

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then defines a geometric path. Additional instructions, as will be described in Section 4, can be used to keep the user from deviating from the geometric path.

In our approach, vector representation was rejected because of the difficulty of acquiring suitably structured path network information. Instead, a point-based representation of routes is used. The vector representation explicitly stores all possible routes between two points that reside on the network such that the shortest route can be extracted from the network. In the point-based representation, viable alternative routes must instead be deduced. A finite number of points can be connected in a finite number of combinations and thus a graph theoretic approach can select routes that satisfy specified criteria. The route-planning algorithm adopted uses a composite measure consisting of three criteria. The first is to maximise the density of waypoints along a route; the geometry of a route is well represented by a high density of waypoints. The second is to minimise the variation in separation of waypoints; equally spaced waypoints are considered more desirable than routes containing excessively long/short legs. The third is the shortness of a route. These criteria are applied such that, where two routes have equal density and equal separation of waypoints, the shortest route will be preferred. Therefore points spaced at equal intervals along all routes will provide optimal representation. Figure 3 shows one example of an estimated path (black points and line). A path coincident with lines on a football field was walked 30 times. All positions from the GPS receiver were recorded (grey points). Note that the estimated route avoids outlying points.

5. PATH GUIDANCE. Once a route is available to represent a geometric path, guidance instructions can be generated. A route can be regarded simply as a convenient method of storing destinations in a specified order. This suggests that guidance to the next destination could be achieved in exactly the same manner as was used in the direct guidance mode (Section 3). The technique must be modified so that when the next point in the route is reached the following point is automatically selected. The question arises as to what criterion should be used to determine when the next point has been reached. Given that the primary piece of information required for guidance is based upon the bearing, α, between current, R, and guidance positions, P, the uncertainty in this value could be used as such a criterion. When the uncertainty in α reaches a particular threshold, the next point can be selected. Assume that the variance in each orthogonal axis of R and P is equal. Then it can be shown that the uncertainty in the bearing, σ_α^2, is dependent upon the Expected Horizontal Position Error (EHPE) of the two points; $EHPE_R$ and $EHPE_P$. This can be expressed in terms of the differential EHPE, $EHPE_\Delta$.

$$\sigma_\alpha^2 = \frac{EHPE_\Delta^2}{2|RP|^2}.$$

If all distances are quoted in units of $EHPE_\Delta$ the variance of the bearing is solely dependent upon the magnitude of RP in units of $EHPE_\Delta$,

$$RP = g \times EHPE_\Delta (\mathrm{m}).$$

Since g is independent of the magnitude of $EHPE_\Delta$ for any particular σ_α^2 it can be used as the guidance criterion. If points are closer than RP they can be rejected for guidance. The remaining question is: what specific value of g will provide the best guidance for a user? Rather than trying to estimate a theoretical optimal value of g,

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various values were tried experimentally to find a value that gives the best performance in practice.

To allow the blind volunteer to be free to follow the guidance instructions, the field trial was again performed in an open area with no obstacles. In the trial, a reference route must be used, in this case the constituent points of the estimated route in Figure 3. For each candidate multiplier of EHPE, the user must attempt to follow the route.

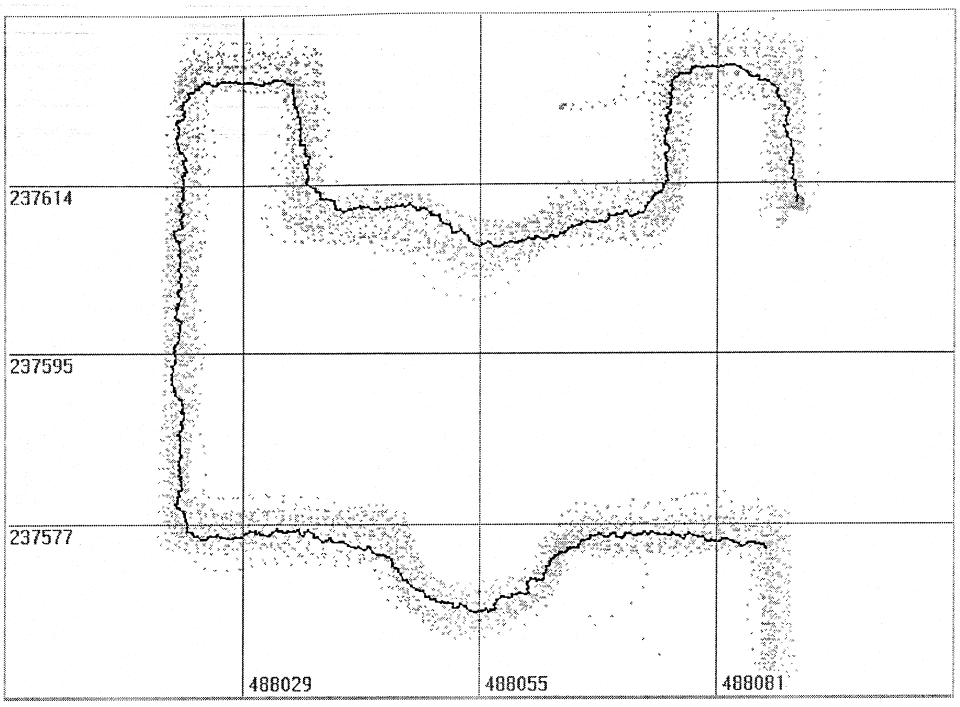


Figure 3. Estimation of a path that follows the lines of a football pitch.

First, the initial route is estimated and will be identical to that in Figure 3. Then the first waypoint in the list is compared with the current position; if the distance between the two points is greater than their $EHPE_{\Delta} \times g$, it will be selected as the guidance point; if the distance is less than $EHPE_{\Delta} \times g$,the next point will be selected as the guidance point and so on until the destination is reached. But if the user walks past a selected guidance point at a distance further than $EHPE_{\Delta} \times g$, the next point in the route will not be selected. In many navigation systems a function called 'waypoint bypass' is used to circumvent this problem. However, where waypoints are densely spaced as for the route in Figure 3, this is impractical. The chosen solution to this problem uses the automatic route estimation algorithm to re-plan the route continuously such that a suitable route from the current position is always available. The method used to achieve this is analogous to that described by Claussen (Taylor, 1991) for road vehicles. After each re-planning of the route, a new guidance point must be selected as already described.

A different format of instructions, related to the direction to take, was used for this path guidance trial. When the user pointed the compass to one side of the desired

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direction, high resolution correction commands of the type 'left, 110 degrees' were used. The user was given the objective of keeping the corrections as small as possible whilst simultaneously walking forwards. The result for various guidance criterion multipliers is shown in Figure 4.

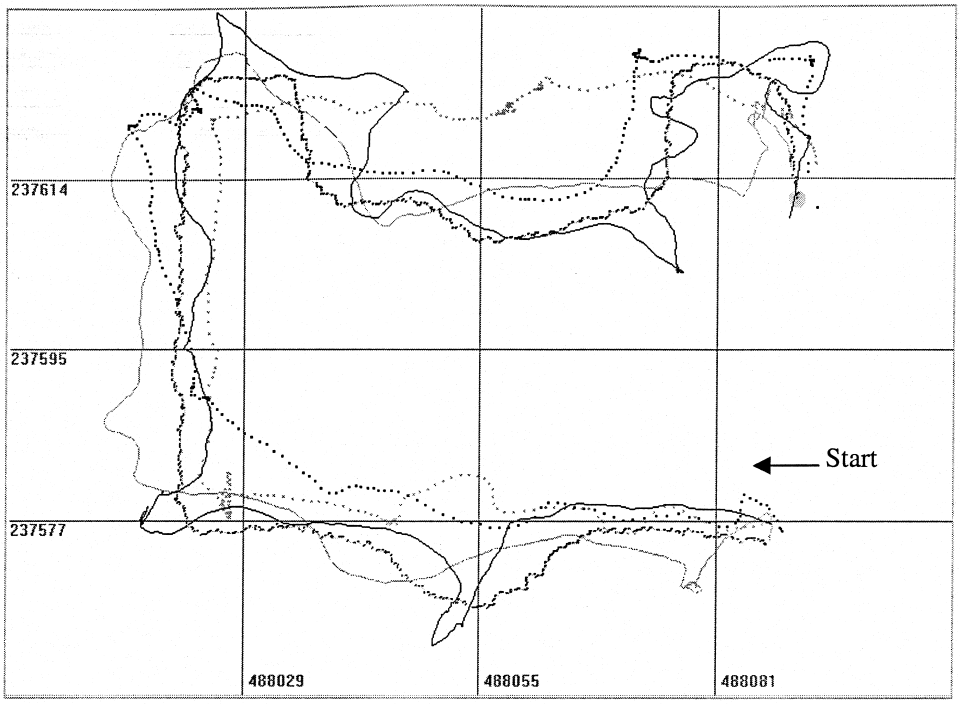


Figure 4. Volunteer 1 guided along a path using high resolution instructions and guidance multipliers of 6 (grey dot), 4 (black dot), 2 (grey line), and 1 (black line).

The continuous sound output of the high-resolution instructions obstructs sounds from the natural environment and is annoying to the user. The method chosen to alleviate this problem attempts to announce instructions only when the user is not oriented towards the guidance point. A silent (masking) sector centred on the bearing to the guidance point is used such that when the difference in user orientation and guidance bearing is within a specified angular constant ($\pm 30°$ in the prototype), the device is silent. When the difference is above this constant, a correction direction is announced (left/right) together with a correction magnitude. The magnitude is a number between one and eighteen, representing the most significant digits of the angular correction. For example, to command the user to turn 113 degrees to their left following command would be used, 'left, eleven'. If the heading is maintained in the direction of the compass forward axis then the user is walking in the correct direction when the output from the system is silent. The path guidance trial in the open field was repeated using these guidance instructions and the plots of the user's progress for various g values are shown in Figure 5.

An attempt was made to analyse the plots objectively. To do this, the off-path error, E, is defined as the distance between an off-path point and the nearest point on

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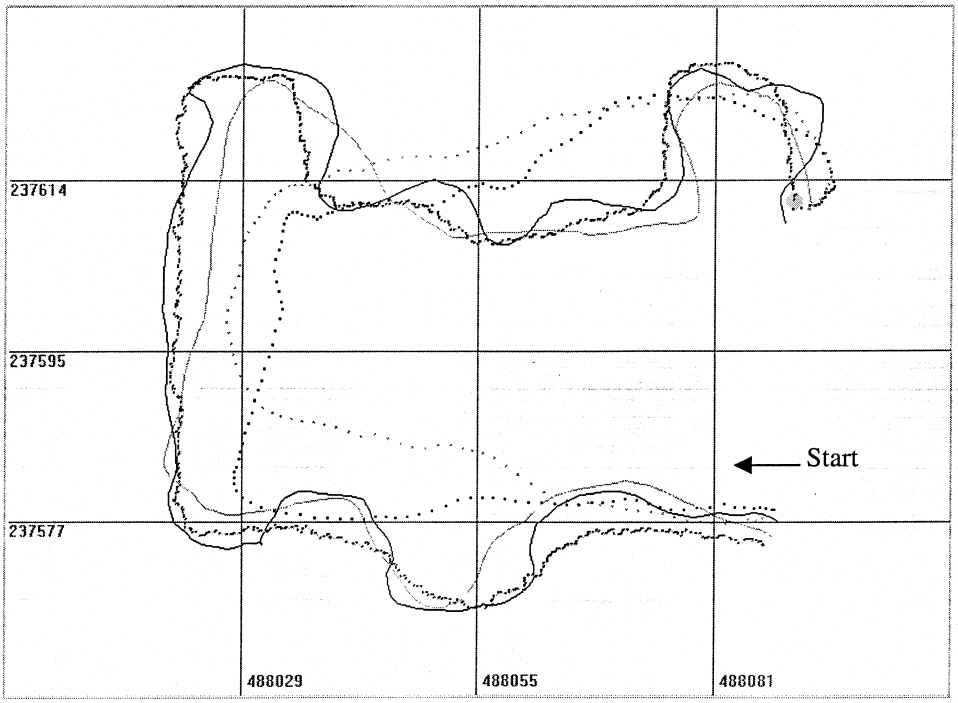


Figure 5. Volunteer 1 guided along a path using a masking sector of 60° and guidance multipliers of 6 (grey dot), 4 (black dot), 2 (grey line), and 1 (black line).

Table 1. Relationship between the guidance multiplier and RMS off-path error using (1) high-resolution instructions and (2) low resolution instructions with a masking sector of 60°.

g	σ_α^2	T_1 (s)	$E1_{rms}$ (m)	T_2 (s)	$E2_{rms}$ (m)
6	6·7	341	6·57	125	9·09
4	10·1	344	4·71	158	8·07
2	20·2	393	3·71	184	3·06
1	40·5	534	2·32	254	1·99

the reference path. The coordinates of the recorded (estimated) reference path can be substituted for the true path since it was recorded in an open space. The user can be considered as trying to follow the coordinates of the estimated reference path rather than the actual reference path. The off-path errors then consist of the error in the estimation of the off-path point and the actual off-path distance. The minimum off-path error associated with each reference path waypoint is equal to the distance to the closest recorded point of the journey. The root mean square of these off-path errors is used as a measure of error for the entire journey. The results for each pass for both continuous (E1) and masked sector (E2) format instructions are displayed in Table 1. The off-path points were collected once per second and thus the number of recorded points is the traversal time (T_1 and T_2) of each pass of the path. Note that the results are only valid for this particular path and for the chosen masking sectors (0 and 60°). Therefore, relative errors between criteria are of primary interest. The non-user induced compass errors should be constant for all tests.

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As expected, the values of E1 decrease with g but, more interestingly, the journey time increases drastically. The decreased rejection distance for selecting the guidance point causes instructions to become much more sensitive. Small movement in the guidance point and/or errors in the positioning system result in large directional corrections for the user. A value for g of 0·5 was also tested but the system became unusable. Despite the lower resolution instructions, the E2 root mean square results are better for the lower values of g. More importantly, at all values of g the journeys were completed in less than half the time of those that used the high-resolution instructions. For optimum guidance by speech, a compromise between resolution, quantity and quality of instructions is required.

6. FIELD TRIAL IN THE RURAL ENVIRONMENT. It has been established that a blind user can be guided along an arbitrary path through an open space. The pedestrian also encounters other environments such as rural and residential areas. Navigation through both of these environments has much in common in that most often people create and use path networks. To avoid the added problem of the user detecting and avoiding traffic, it was decided to choose a rural environment for the next field trial. The rural environment also has an advantage since a wider range of path junctions is typically found in a compact area. Of particular interest are Y junctions and junctions where multiple paths meet/cross. A paper map of Milton Keynes was used to select a suitable trial site (in the area of Ouzel Valley Park), Figure 6.

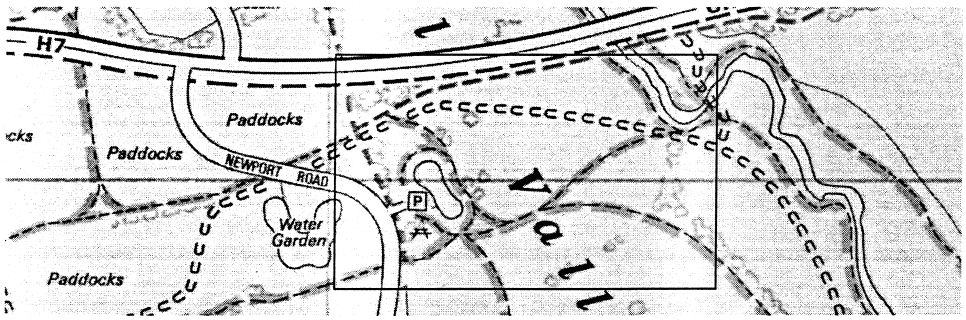


Figure 6. Scanned map showing the features of the trial area. Map reproduced by kind permission of GEOprojects (UK) Ltd of Reading, Surrey.

The path network in the area was walked, and the GPS positions recorded using the prototype software. This method of data collection would be tedious in a practical system but is ideal for field trials. For this trial, path points with an EHPE greater than 30 m were rejected. The recorded path waypoints can be seen as the small grey dots in Figure 7. The larger grey circles show the locations of the chosen destinations for the trials. This selection gives a high density of junctions and varying types of junction. The trial structure was designed in two parts to test the direct guidance and path guidance modes. In the first part of the trial, the volunteers used the path guidance mode to travel to all destination waypoints in alphabetical order, from A through to E. The last path being from E back to A. The format of the guidance instructions was the same as those used to produce Figure 5. In addition however, the

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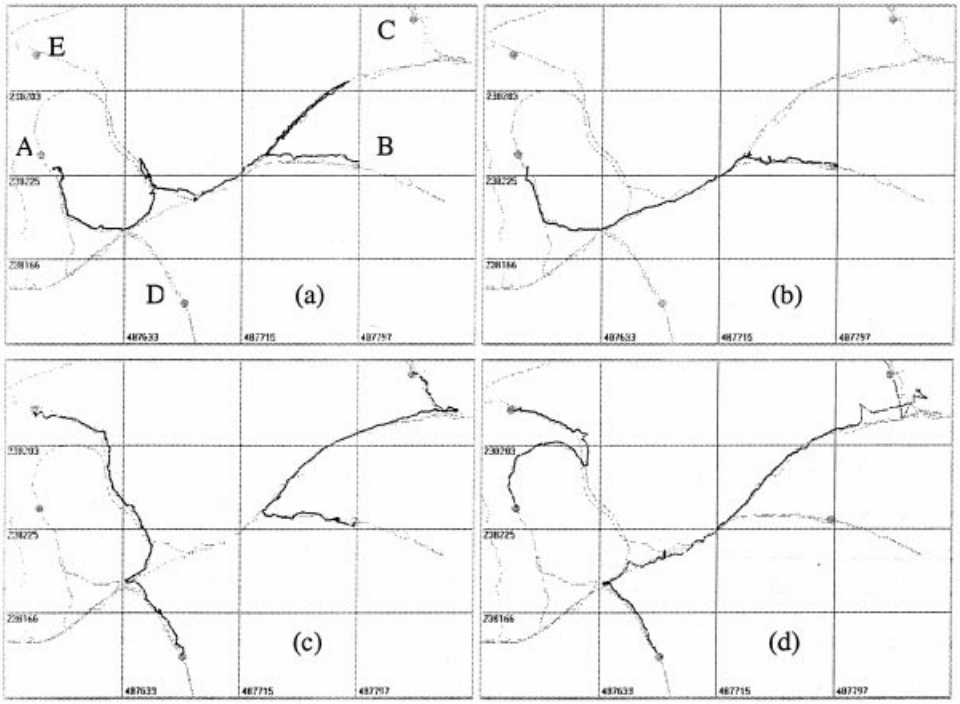


Figure 7. Journeys of Volunteer 2 from (a) A to B; using direct guidance. (b) A to B (c) B to C and D to E (d) C to D and E to A; using path guidance.

distance to the destination was announced as the user approached the destination, this being done when they arrived within $3EHPE_{\Delta}$ of the destination and thereafter each time the minimum distance halved. This made it very hard to pass the destination without the volunteers noticing. At the start of the path guidance trial, the output of the system was explained to the volunteers. The primary instruction was, 'try to travel in the direction of the silence'. Where this was not possible they were told to search for a junction on the side of the path specified by the guidance instructions.

Once back at A, the volunteers switched to using the direct guidance mode for the second part of the trial. Because of the slowness and difficulty in even reaching the required destination in this mode, only the journey between A and B was tested. The purpose of this part of the trial was to show at least one situation where this mode is less than desirable. The speech output format in the direct guidance mode was described in Section 3. Before the direct guidance part of the trial, it was explained to the volunteers that the instructions should not be interpreted as guidance since it would be impossible to travel direct to the destination. Instead, the users were told to use the information to identify the relative location of a destination. To avoid missing essential junctions it was suggested to follow the side of a path that most closely matched the direction to a destination. For both parts of the trial, the volunteers were told that they could reach all destinations without leaving the paths.

7. RURAL TRIAL RESULTS. Four volunteers with different visual disability profiles were thought to be adequate to demonstrate the potential of the

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system. All the chosen volunteers have had adequate mobility training and are accomplished travellers along known routes. The four volunteers were in the age range between 40 and 54. All used the short cane throughout the trial. The degree of success for one volunteer can be judged subjectively in Figure 7, where the black dots are positions obtained from DGPS during the journeys.

The most important objective measure that can be used is the route completion rate. This measure was not used however, since in these trials all volunteers managed to find their way unaided to every specified destination. To be objective about how efficiently users managed to reach the specified destinations, two measures were devised. Both measures assume that a planned route to the destination is available. The first measure is simply the number of junctions that a user was considered to have 'missed' when trying to follow a route through a path network. The second measure is called the distance efficiency, E, which is calculated thus:

$$\mathrm{E} = \frac{\text{Planned journey distance (m)}}{\text{Recorded journey distance (m)}} \times 100\ (\%).$$

The recorded journey distance is a composite measure of the distance due to the users' actual movement combined with a distance component due to the errors in the positioning system. It is calculated by summing the distance between consecutively recorded points from the positioning system. For routes with random geometry of sufficient length, the recorded journey distance should tend not to be less than the actual journey distance. The efficiency measure in these circumstances will be pessimistic to some extent (this being dependent upon the characteristics of the positioning system and dynamics of the user). A journey can then be said to have been completed with an efficiency of at least (or no worse than) E. By summing the planned and recorded distances for each of the journeys the results can be presented in terms of each volunteer and each route, Table 2.

Table 2 suggests that junctions are more likely to be negotiated correctly when using path guidance. More importantly, when a junction is missed, the mistake is corrected quickly. These factors contribute to a distance efficiency estimate for path guidance that is double the equivalent measure for direct guidance, for the same journey (A–B). The group efficiency for all users, over all routes, approaches 90%. This is higher than was expected considering that these were the first multiple user field trials. Very little user training was given. There was heavy rain throughout the trial of volunteer 1, and volunteer 4 encountered heavy wind (50 mph gusts) and rain.

8. CONCLUSIONS. The user interface of personal navigation systems for sighted people can be adapted so that the technology becomes accessible to the blind pedestrian. Assuming that the current position is available, this technology allows a blind user to find destinations reliably in an open field environment. However, use of this technology in the rural or urban environment is often inefficient, and possibly a journey may be aborted before completion. To improve the efficiency of journeys, routes can be used such that direct travel is possible between each of the constituent waypoints. To ensure that the user can deviate from an initial route (as happens when positioning is lost), the route should be continuously re-planned from the user's current position. This can be achieved by use of a vector representation of the path network. Because of the difficulty of acquiring such a representation, this research concentrated on using suitably spaced points to represent the path network. Routes

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Table 2. Grouped trial results.

Type of guidance/ volunteer	Journey	Time (s)	Planned dist. (m)	Recorded dist. (m)	E (%)	Number of junctions	Missed junctions
Direct guidance							
2	A–B	900	270·99	572·4	47	5	2
3		660	265·04	626·30	42	5	1
1		835	266·65	596·15	45	5	1
All	A–B	2395	802·68	1794·94	45	15	4
Path guidance							
All	A–B	1244	1073·27	1208·04	89	20	3
	B–C	1219	1081·64	1199·11	90	8	1
	C–D	1543	1414·37	1645·49	86	20	1
	D–E	1243	992·08	1134·07	87	16	1
	E–A	709	610·82	767·82	80	4	0
2	All	1673	1233·46	1416·42	87	17	2
3		1136	1311·03	1466·32	89	17	2
1		1339	1321·83	1485·11	89	17	1
4		1750	1305·86	1586·73	82	17	1
All	All	5898	5172·18	5954·58	87	68	6

can automatically be recovered for use with guidance algorithms. The results suggest that this approach, when applied to a rural trial area, can be used to guide blind individuals to previously un-visited destinations along unknown routes.

Several limitations of the prototype system have been identified. The weight and power requirements of the prototype make it impractical for daily use. It is expected that commercial development of mobile phones will provide one solution to this problem; a mobile phone will contain all items at the user location in Figure 1. The use of point positioning systems (such as GPS) to collect path information limits the system to local, pre-prepared areas. However, commercial development is underway that will allow national databases of path-points to be created easily. There is however one prominent problem that requires further research. A method is required to allow blind users to select their required destination with ease from a national destination database.

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REFERENCES

MoBIC. (1997). *Final Report*. Published by The Royal National Institute for the Blind on behalf of the *MoBIC Consortium*. RNIB, London. ISBN 1 86048 006 3.

Loomis, J. M., Golledge, R. G. and Klatzky, R. L. (1993). Personal guidance system for the visually impaired using GPS, GIS, and VR technologies. *In Proceedings of the First Annual International Conference*, '*Virtual Reality and Persons With Disabilities*' June 17-18, p 71-74, California State University, Northridge.

https://doi.org/10.1017/S0373463399008450 Published online by Cambridge University Press

Taylor, D. R. F. (editor). (1991). Geographic Information Systems: *The Microcomputer and Modern Cartography*. Pergamon Press. ISBN: 0-08-4278-X. (A collection of chapters written by different authors)

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1. GPS 2. Human Navigation 3. Automation

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