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A robotic guide for blind people. Part 1. A multi-national survey of the attitudes, requirements and preferences of potential end-users

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This paper reports the results of a multi-national survey in several different countries on the attitudes, requirements and preferences of blind and visually impaired people for a robotic guide. The survey is introduced by a brief overview of existing work on robotic travel aids and other mobile robotic devices. The questionnaire comprises three sections on personal information about respondents, existing use of mobility and navigation devices and the functions and other features of a robotic guide. The survey found that respondents were very interested in the robotic guide having a number of different functions and being useful in a wide range of circumstances. They considered the robot's appearance to be very important but did not like any of the proposed designs. From their comments, respondents wanted the robot to be discreet and inconspicuous, small, light weight and portable, easy to use, robust to damage, require minimal maintenance, have a long life and a long battery life.

Keywords: robotic guide; blind people; survey; end-user; requirements analysis

1. Introduction

This paper presents and discusses the results of a multi-national survey involving a questionnaire in five languages, as a preliminary investigation of whether blind people might be interested in using a robotic guide and the type of design and features they would like it to have.

The idea of such a robotic guide was one of the potential solutions (Hersh 2009b) that emerged from research carried out recently by the first author (Hersh 2009a, 2009b) to investigate the mobility and travel experiences of blind and visually impaired people, the problems and barriers encountered and the need for new travel aids and more accessible environments, as well as their spatial knowledge and means of learning new routes. This research included nearly 300 interviews with blind, visually impaired and deafblind people in seven different countries and a number of technical visits.

Although the first electronic travel aid was developed in 1897, serious work in this area started in the 1960s. Since this date, a large number of electronic travel aids have been developed. Most of these projects did not get beyond the prototype stage. For the majority of this period, attention focused on obstacle avoidance devices. Older devices, which have been commercialised, include the laser cane and the mini guide, and more recent developments include the Ultracane, Tom Pouce and Télétact (Farcy and Damaschini 2000; Hersh and Johnson 2008a). However, manufacture of the Ultracane ended after only a few years in production. Although end-users are satisfied and in some case extremely enthusiastic about these devices, they are only used by relatively small numbers of people, and the most widely used obstacle avoidance aids are still the long cane and the guide dog.

More recently, attention has shifted to the provision of environmental information to blind and visually impaired travellers. This has led to the development of two distinct approaches based on information technology, though in practice they have overlapping functionality (Hersh 2009b):

- Satellite navigation, currently global positioning systems (GPS; May and LaPierre 2008), which locate the user.
- Environmental information beacons, which locate a point in space (Hersh and Johnson 2008b; Hersh 2009b).

A number of GPS systems have been designed or modified to be used by visually impaired people, including Trekker, BrailleNote and VoiceNote GPS, Mobile Geo, Lodestone, Wayfinder Access, Geotact, EasyWalker and Kapten. They provide a range of functions, which generally include route preview through simulation in advance of a journey, a searchable database of points of interest and real-time (audio) instructions to enable the user to follow a route

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to a particular destination. However, GPS lacks precision and cannot be used, for instance, to locate the door of a building. An environmental information beacon contains a transponder with a stored message, a transmitter and signal processing. The message signal decoded by the user's reader or receiver is generally output to the user as speech through a speaker on the receiver or beacon or through an earphone. It identifies the facility and may provide additional information about it. Increasing signal strength as the user approaches frequently aids in locating the facility. Near the beacon, the user can receive other active signals, such as warnings about escalators or road works. They can also transmit a signal to activate other functions, such as audio indications at traffic lights or level crossings. Hybrid systems with the functions of both GPS and environmental beacons are also being developed (Hersh 2009b).

Awareness of the fact that many high-tech travel aids are not used by blind and visually impaired people and that they are not obtaining the maximum possible benefit from technological developments motivated the first author to undertake the research mentioned above. Preliminary findings of this research will now be briefly discussed (Hersh 2009a, 2009b). Independent mobility requires considerable concentration and can be very tiring. Many blind and, to a lesser extent, visually impaired people only feel confident in travelling on familiar routes and try to avoid or use a sighted guide for unfamiliar routes or seek training if required to regularly travel to a new destination. A number of them have negative feelings about the use of a long cane and will restrict their activities rather than use one. This may involve not going out at night if they only need an aid then or only travelling accompanied. Some will even risk accidents rather than using a long cane. Some non-cane users would find a guide dog more acceptable and consider that people react differently to a blind person with a guide dog than to one with a cane. Guide dog use can also be less tiring, require less concentration and allow users to walk faster and feel more secure. However, guide dogs have the disadvantage of requiring considerable care and attention and cannot just be left in the corner and ignored like a long cane. In addition, some potential users are afraid of or do not like dogs. There are also large numbers of blind and visually impaired people who only go out accompanied and/or who rarely go out at all.

One potential solution for blind and visually impaired people who do not go out at night, only go out accompanied or try to avoid unfamiliar routes could be a robotic guide that has similar functions to a guide dog but does not have its disadvantages and also has some additional functions. End-user involvement from the start of product design is essential to obtain a successful outcome. Therefore, a survey was carried out to investigate the attitudes, requirements and preferences of potential end-users for such a device.

The methodology and results of this survey are presented in Sections 3–5. It is introduced by a brief discussion of existing work on robotic guides in Section 2. Discussion of the results and conclusions are presented in Section 6. An analysis of the gender and national dimension of the results is presented in Part 2 of the paper. In addition, Part 2 applies the results presented in the two papers to derive design specifications for a robotic guide.

2. Robotic guides and other mobile robots

2.1. Robotic guides or travel aids for blind and visually impaired people

Work on robotic travel aids for blind people started with the MELDOG project in 1977 (Tachi et al. 1985). This ended after 7 years, without producing more than a first prototype. A small number of projects have developed since then. About half of them are designed for specific, generally indoor, environments. Guido (Rodriguez-Losada et al. [cited 2008]; Guido [cited 2009]), renamed from PAM-AID (Lacey and MacNamara 2000) when it changed its design, additionally provides physical support, particularly for elderly people. Guido is the only one of these devices which has been commercialised or otherwise distributed to users, but production of Guido seems to have ceased.

Most robotic guides for blind people work on the principle that the robot changes direction when it detects an obstacle in its path and communicates this change of direction by having enough mass for the user to feel the movement haptically through the handle. All current guides are wheeled rather than legged and generally based on existing mobile robot platforms. While wheeled robots are considerably easier to design and inherently more stable than legged robots, they have the disadvantage of, unlike legged robots, being unable to move upstairs and downstairs and may also have difficulties on uneven terrain. Little attention has been given to appearance, though this may affect user acceptance of the guide.

Current designs include a motorised wheelchair platform which the user follows (the HARANOBU Series; Mori and Kotani 1998; Mori et al. 1998), a robotic wheeled base at the end of a cane which the user holds (GuideCane; Ulrich and Borenstein 2001), an unnamed robotic guide (Song and Huang 2001) and a commercial robotic platform to which the user is connected by a dog leash (the RG Series; Kulyukin et al. 2006; Gharpure and Kulyukin 2008).

RoboCart (Gharpure and Kulyukin 2008), which is designed specifically for use in supermarkets and shopping centres, provides the additional functionality of locating products by using an omnidirectional barcode reader. However, the process is time consuming, since a large number of barcodes need to be scanned, and it is possible to miss the item. Most robotic guides try to use off-the-shelf components. They have some combination of laser range finders, ultrasonar and infrared sensors and (video) cameras for obstacle detection and to support robot localisation, with lasers considered the most accurate but more expensive.

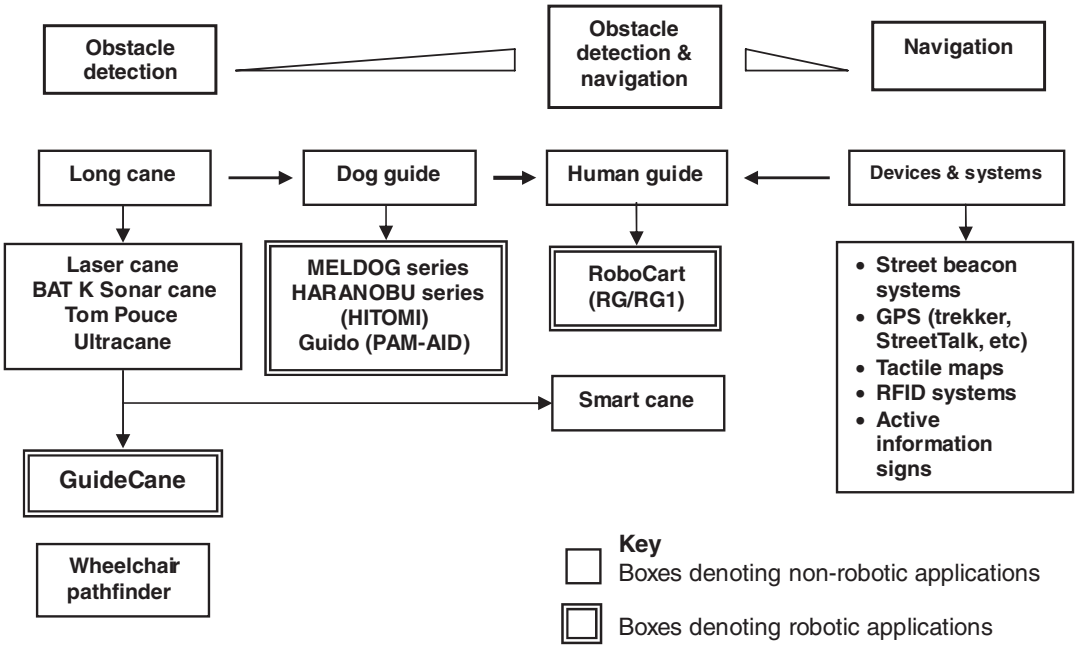

Figure 1. Travel guide context for a robotic guide for blind and visually impaired people.

While many of them have on-board central processing units or laptops, others, such as Rhino and RoboCart, only or additionally have off-board processing. This either reduces the robot's range or requires the user to carry a laptop in a backpack. Some guides, such as the RG and RG1, additionally have radio-frequency identification (RFID) readers which enable them to read RFID tags displaying a unique ID on doors and other potential destinations (Kulyukin et al. 2006). However, RFID tags may fail in unstructured open spaces (Gharpure and Kulyukin 2008), and their deployment could raise privacy issues (Weis et al. 2004). HARANOBU 6 includes a geographic information system that is used in navigation. It detects pedestrians by their rhythmic movement and cars by the characteristic shape of the shadow under them.

This survey shows that very little progress has been made in developing a robotic guide for blind and visually impaired people. A global view of this development work and its relationship to conventional travel aids is shown in Figure 1.

2.2. *Other mobile robotic devices*

Other mobile robotic devices which provide navigation or guidance functions to the general population or physical or other support to disabled people include robotic tour guides, particularly in museums, robotic wheelchairs and scooters and mobile robotic aids for physically disabled and/or elderly people, with navigation and other functions, but they will not be discussed further here. Figure 2 shows the context of these developments.

2.3. *End-user acceptance of robotic guides and other robotic devices*

Prior to this paper, there has been minimal work on the user acceptance of robotic guides. However, this was one of the considerations in the design of the PAM-AID mobility aid for elderly blind people, with particular attention given to user preferences for the user interface (Lacey et al. 1998). Research on user acceptance of other types of (mobile) assistive robots for disabled and/or elderly people has also been sparse and investigation of the factors that affect the degree of user acceptance even more limited.

A few studies have considered acceptance by elderly users, generally in nursing homes. For instance, one study found that users preferred the more 'sociable' of two versions of the iCat personal assistant robot (Heerink et al. 2006a, 2006b). Significant gender differences were observed, with male participants wanting the robot immediately and to learn how it worked and female participants preferring to try to remember and to do things themselves rather than using an aid. Limited investigation of the attitudes of elderly people in nursing homes to a mobile robotic guide and assistance robot found that users showed a high level of excitement (Montemerlo et al. 2002; Pineau et al. 2003). However, further work would be required to determine whether this excitement was due to the robot per se or factors associated with the experimental situation, such as receiving more attention and stimulation than usual, as well as the factors, if any, that affect user acceptance. A study of the attitudes of elderly people to household robots found that they recognised their potential usefulness but

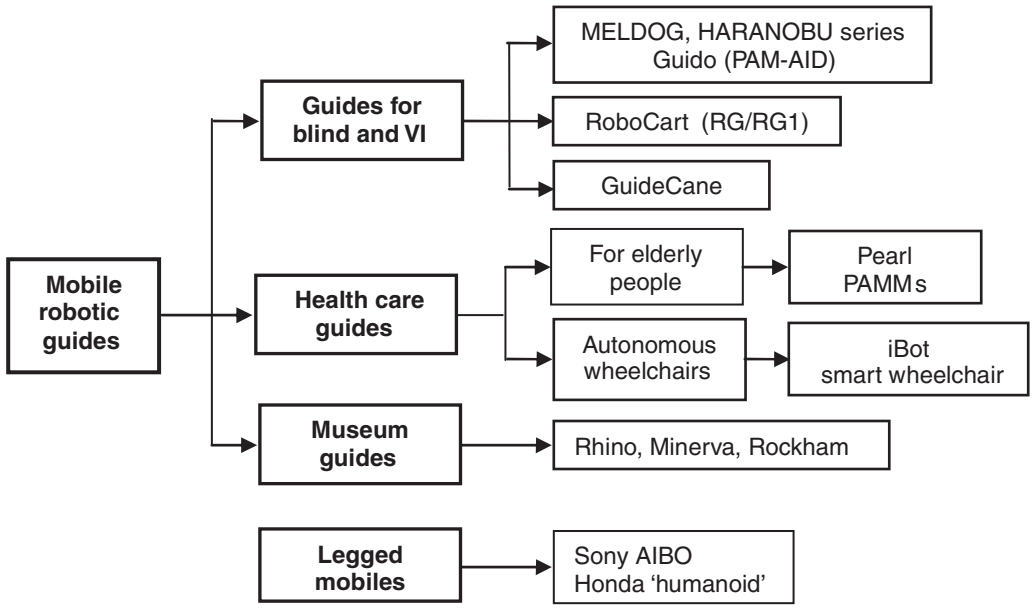

Figure 2. Range of mobile robotic guides (VI, visually impaired).

were concerned about potential damage by the robot and intrusions on their privacy (Scopelliti et al. 2004). In the areas of appearance and behaviour, their preferences were for a small serious looking robot of one colour with slow movements with programmed rather than free movements.

Some evaluation of user acceptance of the CERO robot, designed to assist physically disabled people by transporting light objects, has been carried out. This involved a 3-month trial period by one user in an office environment followed by a feedback questionnaire (Hüttenrauch and Severinson-Eklundh 2002; Severinson-Elkundh et al. 2003). Although less explicitly studied, the authors note the importance of studying the work situation rather than just the individual and the importance of acceptance by the user's colleagues. A related area of research is user acceptance of rehabilitation aids and medical devices. For instance, Ceccarelli (2009) briefly discusses the importance of patient acceptance of a robotic device used in rehabilitation physiotherapy but reports a study focusing largely on technical features of the system. A survey of 2000 people at a robotics exhibition included questions on the acceptance of robotic prostheses and showed that people who accepted robots in other applications were more likely to accept robotic prostheses, but there was much less acceptance of robotic neuro-prostheses (Arras and Cerqui 2005). However, the survey respondents were not current users of prostheses.

3. Methodology for the investigation of end-user views and requirements

An overview of the literature indicates that there has been relatively limited consultation with end-users in the development of robotic guides and that little attention has been given to the type of appearance and functionality end-users would like. Therefore, a survey was carried out of blind, visually impaired and deafblind people to ascertain their views. This involved a questionnaire divided into three sections with a mixture of quantitative and qualitative questions and available in equivalent English, French, Italian, Polish and Spanish versions.

The following information was sought:

A. Personal information: gender, age, type and onset of visual impairment, country and whether living in a city, town or village.
B. Use of travel aids:

    1. Whether an aid is generally used.
    2. Which aid, how well it enables the user to avoid obstacles, speed and safety.
    3. Whether users feel they could benefit if they do not use an aid and the reasons for non-use.
    4. Whether an aid is used *en route* for navigation and orientation, which one, when it is used and users' confidence that they will reach their destination.
    5. Frequency of asking for directions, how easy it is to do this and whether the replies are useful.

C. Robotic guide:

    1. Desired functions.
    2. Attitudes to different possible designs for a robotic guide.
    3. The importance of the robot's appearance and suggestions for its appearance.

Table 1. Respondent characteristics.

Gender (%)		Country (%)					Age profile (%)					Visual status (%)	
Female	Male	France	Italy	Poland	UK	Other	16–25	26–40	41–60	61–70	71+	VI	Blind
40.0	60.0	16.3	26.3	30.0	18.8	8.8	13.3	37.5	37.5	12.5	1.3	28.8	70.0

Note: VI, visually impaired.

4. Evaluation of the usefulness of the guide in a number of different circumstances.
5. The means of communicating with the robot and the type of information the respondent would like when the robot avoids an obstacle.
6. Comments on the features that the respondent would like and those that should not be included in a robotic guide.

Methodologies for surveying blind and visually impaired or other groups of disabled people are incomplete, and an accepted best procedure has not yet been developed. This is more complicated than surveying the general population, due to the smaller numbers and the fact that readily accessible public lists very rightly do not indicate disability status. Therefore, surveys of groups of disabled people are generally carried out through a combination of contacting organisations, using relevant email lists and research contacts, posting on websites and advertising in relevant media. The questionnaire was sent to blind, visually impaired and deafblind people in France, Italy, Poland, Spain and the United Kingdom, for whom the first author had email addresses from her previous research, and email lists for blind and visually impaired people in France, Italy and Poland were posted on the first author's website. Some of the respondents distributed the questionnaire to their own contacts. It was decided not to send the questionnaire to organisations of blind, visually impaired and deafblind people because of time constraints. The option was provided to return the English language version by email or post, whereas on account of time constraints, only a return by email option was provided for the other versions.

Sections 4 and 5 will discuss the results of the questionnaire, with Sections 4.1 and 4.2 considering the results of Part A, Section 4.3 of Part B and Section 5 of Part C.

4. Results: end-user characteristics and current use of travel aids

4.1. Respondent characteristics

84 responses were obtained, of which 80 could be used, with the other four totally or nearly totally blank. As shown in Table 1, there was a slight preponderance of male respondents, with two-fifths female and three-fifths male. Three quarters of the respondents were in the 26–50 (37.5%) or 41–60 (37.5%) age ranges, with the remainder approximately equally split between the 16–25 (11.3%) and 61–70 (12.5%) age ranges and only one respondent 71 or over. Over two thirds of the respondents were blind (70.1%) and only just over a quarter (28.8%) visually impaired, with one respondent not replying to this question. Well over two fifths (45%) were blind or visually impaired from birth, nearly a fifth (18.8%) from childhood and just over a quarter (28.8%) from early adulthood, with only 6.3% becoming blind after the age of 45. The largest national group (30.0%) was from Poland, followed by Italy (26.3%), the United Kingdom (18.8%), France (16.3%), the United States (3.8%), Spain (2.5%) and Belgium and Canada (each 1.3%). Nearly half the respondents (47.5%) were from a large city, just over a third (36.3%) from a medium-sized town and only 16.3% from a village.

4.2. Discussion of respondent bias

It is very difficult to avoid some degree of respondent bias in this type of sampling with respondents most likely to respond if they had strong positive feelings about the idea of a robotic guide, followed by those with strong negative feelings. However, sufficient responses were obtained, and respondent characteristics such as gender, age and age of onset of blindness or visual impairment, were sufficiently varied to constitute a reasonable cross section of the end-user community of blind and visually impaired people.

In addition, the aim of the survey was to obtain feedback on the degree of interest amongst blind and visually impaired people in a robotic guide and information as to their preferences for the robot's functions and appearance. Owing to these aims and the fact that the viability of a robotic guide only requires interest from a significant section, but by no means the majority of the potential end-user community, respondent bias is not a problem as long as sufficient responses are obtained and form a reasonable cross section, as is the case here.

4.3. Use of travel aids by respondents

This section reports and analyses the results of Part B of the questionnaire.

Table 2. Use of navigational aids.

Use of navigation aid		Type of navigation aid used				
Yes	No	GPS	Talking beacon	Tactile map	Large print map	Other
46.3%	53.1%	70.3%	8.1%	2.7%	2.7%	40.5%

4.3.1. Obstacle avoidance aids

Well over four fifths (83.8%) of the respondents generally used a travel aid, with well over four fifths (86.6%) of these respondents using a long cane, just over a tenth (13.4%) a guide dog and a tenth (10.4%) another aid. Other aids included a map with a closed-circuit television (CCTV), though this is not really an obstacle avoidance aid, and a sighted guide.

The respondents were approximately equally divided between those who found the aid they use: a very significant help in avoiding obstacles (29.9%), a significant help (35.8%) and some help (29.9%). Only 1.5% found it very little help and no respondents no help. Over half (55.2%) of the respondents walk at a moderate pace with this aid and very nearly a third (32.8%) at a fast pace. About a tenth walk slowly (9%) or are unsure how fast they walk (1.5%). While nearly two thirds feel either safe (53.7%) or very safe (11.9%), nearly a third (29.9%) feel neither safe nor unsafe and a small minority (4.5%) actually feel unsafe.

Over half (53.7%) of the 13 respondents who did not use an aid felt that they could benefit from one sometimes and nearly a quarter felt they could benefit always (7.7%) or most of the time (15.4%). Nearly a quarter (23.1%) felt that they could benefit at night only. No respondents felt that they could never benefit from an aid. Two respondents who did not use an aid restricted their travel to daylight, when they could manage, and another had no problems during the day but more difficulties at night. Two further respondents used a white cane for unknown routes or sporadically but otherwise could manage.

Another respondent was unskilled in using a cane and felt it was more of a hindrance than a help and that their living conditions were not really suitable and that they felt nervous about the responsibility, presumably due to worries about safety. They felt that electronic aids are relatively expensive, particularly as they did not have the option of trying them out before buying one. One respondent only used a magnifying glass or a small telescope discreetly for reading street names. One respondent, who could benefit particularly at night and has had some accidents which show the 'need', puts non-use down to 'pride', being 'stubborn' and not wanting to use an aid, despite knowing it would help.

4.3.2. Navigational or orientation aids

As shown in Table 2, just under half (46.3%) of the respondents used an aid to help them find their destination or work out where they are on a route, with the majority (70.3%) using a GPS. Nearly 8.1% of these respondents used a talking beacon, 2.7% a tactile map and 2.7% a large print map, with just over two fifths (40.5%) using other aids, including a monocular, a standard map with magnification (not clear whether this was while travelling or before setting out) and a sighted guide.

Some of the responses related to obtaining preparation in advance of travel rather than aids used en route, including use of the internet with magnifying software, Google maps with the help of a sighted person or a text description to prepare the route in advance or learning the trajectory by doing it first with a sighted person. Another non-aid-based response was asking passers-by.

Just under a third (32.4%) of the respondents who used a navigation aid used it on most journeys and nearly half when travelling for the first time (24.3%) or first few times (21.6%) to a new destination, with the remaining just over a quarter using it always (13.5%) or always on complex routes and once or twice on simple routes (13.5%). While just over half were either confident (37.8%) or very confident (16.2%) that they would reach their destinations without problems when using this aid, just over a third (35.1%) were neither confident nor unconfident, and a small minority were either unconfident (2.7%) or very unconfident of this (2.7%), with another 2.7% unsure.

Nearly three fifths (57.5%) of the respondents asked for directions at least once on a trip, with a fifth asking several times. Just over two fifths (40.2%) only asked rarely, and only 1.3% never asked. Of those who asked for directions, just over two fifths found this easy (26.6%) or very easy (13.9%) and another two-fifths neither easy nor difficult, leaving just under a fifth who found asking either difficult (13.9%) or very difficult (5.1%). Just over two thirds found the replies useful (59.5%) or very useful (8.8%), with most of the remainder (31.6%) finding the replies neither useful nor unhelpful and only 1.3% finding them very unhelpful.

5. Attitudes to, requirements and preferences for a robotic guide

This section will discuss the responses to Part C of the questionnaire which considers what functions, design and other features respondents would like from a robotic guide. Section 5.1 considers desired functions and design; Section 5.2 circumstances in which the robot would be useful and

Table 3. Percentage of respondents interested in the different functions.

Number of respondents	Obstacle avoidance	Location	Navigation	Location of goods	Reading street names	Average on functions
80	88.8%	91.3%	88.8%	75.0%	90.0%	86.8%

communication with the robot and Section 5.3 features to be included and avoided.

Where statistical significance is discussed without further qualification, this is always at the .05 level, though in a few cases the p values indicate that significance also holds at the .01 level. The Fisher exact test with software developed by Langsrud (undated) was used to determine statistical significance in the case of the data on functions (question C1) and communication with the robot (questions C5a and C5c). A contingency table χ^2 test with five degrees of freedom was used for the data on design (question C2), appearance (question C3a) and circumstances (question C4) with software developed by Kirkman (1996). Where the presence of zeros across a row prevented the use of a test with five degrees of freedom, data have been combined, and a test with four degrees of freedom was used.

5.1. Desired functions and design

Table 3 shows that most of the respondents were interested in the robotic guide having all the suggested functions, with about 90% wanting each of the following functions: information on the current location (91.3%), reading street names (90.0%) and obstacle avoidance and navigation (both 88.8%) and three quarters the facility to locate goods. On average, well over four fifths (86.8%) of the respondents were interested in each function. The differences in the percentages of the respondents interested in locating goods and the other functions were statistically significant ($p \leq .02$), but the differences in interest in the functions of information on current location, reading street names, obstacle avoidance and navigation were not ($p \geq .78$).

Two fifths of the respondents suggested additional functions, with most of these functions suggested by several respondents. Some of the functions in the following list were proposed in response to question C6a on desired features, but it seems more logical to consider them here:

- Location and points of interest: current (GPS) position with accuracy of a metre. Information on facilities in the surroundings or that the user is going past. Finding the entrances to buildings and other facilities.
- Public transport: finding bus and tram stops, taxi stands and metro entrances. Reading the numbers and destinations of approaching and stationary buses, trains and trams and stops and stations, as well as information boards at stations and airports. Indicating when the user can get on a bus as there are no longer passengers getting off. Information about public transport and useful connections, such as taxis, for the location. The ability to memorise train and bus timetables, addresses and routes.
- Crossing roads: locating pedestrian crossings and informing the user of the status of traffic lights and when the light changes.
- Support and/or emergency: contacting police, ambulance, an emergency centre and/or the user's family and giving them the user's location, as well as the provision of help when the user gets lost.

Several respondents suggested additional functions that were related to functions proposed in the question:

- Obstacle avoidance: avoiding pedestrians, large puddles, trolleys and wire bins in supermarkets, overgrowing bushes and overhanging branches, detecting vehicles and their speeds, programming the locations of obstacles to within centimetres and the shape and outline of pavements.
- Reading information: street names, house numbers, names on house doors (and bells), building names and announcements and information boards in or in front of buildings.
- Navigation and wayfinding: when travelling on foot and by public transport, finding a particular address and advice on safe routes. Information about the distance and time to the destination and the route, such as steps up or down, a bridge or a crossing. A recording and/or memory function for routes to help the user retrace the route, learn from their mistakes and prepare for future journeys. Informing the user of conditions in all weathers and on all terrains to support long distance walking and walking in unknown or little known areas.

A number of suggestions for additional functions, which are not directly related to mobility, were made and included the following:

- Finding objects, such as keys, glasses and the phone in the house and books in a library.
- Reading books, correspondence and the prices of goods in a shop.
- Identifying their child from a distance by means of an identifier which the robot can recognise easily.
- Recognising the colour of clothes.

Table 4 shows that respondents considered the appearance of the robot to be very important, with an average mark

Table 4. The average grading of different robot designs and the importance of robot appearance.

Number of respondents	Robotic dog	Humanoid	Robot	Mobility scooter	Robotic scooter	
78	2.1	2.1	2.5	2.2	2.0	
Frame with seat+	Frame	Robotic shopper	Lawnmower	Base with cane	Average over designs	Importance of appearance*
1.4	1.3	2.2	0.3	1.8	1.8	3.8

*77 respondents.

of 3.81 out of 5. However, they were not particularly enthusiastic about any of the proposed designs, with a maximum mark of only 2.5 out of 5 given, somewhat surprisingly, to an obvious robot and an average mark over all the designs of 1.8. The obvious robot was followed fairly closely by a robotic shopper and mobility scooter (both 2.2) and then by a robotic dog and humanoid robot (both 2.1). Only the difference between the humanoid robot and the obvious robot was statistically significant ($p = .04$). The clearly unpopular designs were a wheeled frame with (1.4) or without (1.3) a seat and shopping space and a lawnmower (0.8). The differences in the preferences for these designs and the more popular ones were clearly statistically significant, with a range of p values less than .05.

Nearly 72.5% of the respondents provided suggestions for the robot's appearance or other comments about it. One of the most frequent comments from respondents was the need for the robot to be as inconspicuous and invisible as possible and not to draw attention to them or make them look like an 'exhibit'. For instance, a robotic dog or scooter would be satisfactory if of the right colour. There was also concern about the device being lightweight, stable and robust and not taking up too much space to enable it to be taken easily on trains and planes and/or into restaurants, theatres and workplaces. It was suggested that, possibly after folding, it should fit into a pocket or bag or be able to be hung round the neck. However, one respondent wanted it to be sufficiently high to feel its presence.

Respondents wanted the robot to be elegant and attractive, with a choice of colours, but not look expensive, which presumably related to the concerns about the device not being stolen expressed by some respondents. Several respondents suggested the need for a brake. Despite the relative popularity of the obvious robot amongst the options listed, views both for and against the device looking like a robot were expressed in the comments. There were also comments both for and against the robot being humanoid or dog-like. However, one respondent commented that aesthetics were of secondary importance and wanted the device to move itself so that they did not have to push it.

Some of the more practicable suggestions for the robot's appearance included the following:

- incorporated into or having the form of a small hand-held device;
- a cane or an attachment to a cane;
- a mini scooter with a stiff telescopic rod attached for the user to hold and
- integrated into an everyday object such as a suitcase or trolley.

5.2. *Circumstances in which the robot would be useful and communication with the robot*

As shown in Table 5, respondents considered that the robot would be very useful in all the suggested circumstances, particularly for going to new destinations (4.8 out of 5) and railway stations (4.6) and also very useful in supermarkets (4.4), airports (4.2), public buildings (4.1) and everyday use (4.0). However, one respondent noted that security concerns might prevent the device being used in airports. The fact that the device was given a high rating for usefulness in all these circumstances is relevant here rather than the specific ordering. However, the moderate and larger differences in perceived usefulness were statistically significant with, for

Table 5. The average grading of the usefulness of the robot in difference circumstances.

No of respondents	Supermarket	Airport	Railway station	Public buildings	New destinations	Everyday use	Average
77	4.4	4.2	4.6	4.1	4.0	4.8	4.3

Table 6a. The percentage of respondents who would use particular types of input.

Number of respondents	Speech	Keypad	Joystick/switch	Other
80	67.5%	41.3%	27.5%	11.3%

Table 6b. The percentage of respondents who would use particular types of output.

Number of respondents	Speech	Braille	Other
78	87.2%	14.1%	14.1%

instance, $p = .017$ for railway stations and airports but $p = .69$ for airports and supermarkets.

Other suggestions included the following:

- large public buildings and campuses, including hospitals, museums, information centres, academic, research and corporate campuses;
- the countryside and open spaces, including beaches, mountain tracks, woods, large parks and open country;
- the unknown, including other countries, continents and unknown areas;
- urban use, including 'shared spaces' in streets and town centres, road works and works on buildings, underpasses and the underground and
- leisure facilities, including cafes, theatres and swimming pools.

From Tables 6a and 6b, speech was the most popular method for communicating with the robot, with just over two thirds (67.5%) of respondents preferring it for giving instructions to the robot and well over four fifths (87.2%) for receiving information from the robot. Just over two fifths (41.3%) wanted to use a keypad and just over a quarter (26.6%) a joystick or switch for giving instructions, with several respondents suggesting a combination of methods and 10.1% providing suggestions for other methods. Only 14.1% of the respondents wanted to receive information in Braille, and this figure is likely to be lower for the general population of blind and visually impaired people, due to the relatively high percentage of respondents to this survey who were blind from birth. Several respondents commented on the fact that Braille output would not be a very useful format, as few blind people know Braille and the time involved in reading Braille while travelling would slow the user down. In the discussion of features to be included and avoided, these comments were repeated and related to haptic interfaces as well as Braille, and the additional comment was made that the hands are not free when travelling.

Suggestions for other types of input included the ability to connect the robot to a computer via universal serial bus (USB) or wireless for route planning, configuration and software updates; buttons to be used with programs for the scanner and GPS, colour tester and light recognition device; as well as combined speech and keyboard. Suggestions for other types of output from the robot included sounds or other audio outputs, specific types of sounds to indicate particular obstacles, vibration of the handle to indicate approaching obstacles, a combination of speech and vibrotactile signals, choice of synthetic voice, Braille and other options, a text message on a mobile phone or palmtop and different types of feedback to indicate different obstacle directions. One respondent noted that a vibratory output was useful for hearing impaired users.

About 82.5% of the respondents commented on the type of information they would like to receive when the robotic guide encounters and avoids an obstacle. Many respondents wanted information about the obstacle, such as the type of obstacle, e.g. pothole, roadworks or street signs, its distance and direction, size and type and/or clear directions to avoid it. One respondent suggested that a humanoid robot could provide the same sort of information as a human guide. A few respondents wanted information of the type 'attention', 'obstacle at head height on the left' or 'stairs going down on the right'. One respondent noted that a robot that is able to move can navigate round obstacles so that the user only needs to follow it. If this is not the case, they would prefer an indication of direction and distance through sounds, as speech would be too slow. Several respondents wanted information on distance and direction on request. In addition to speech, vibration, possibly of the handle, was mentioned. Some respondents wanted to be informed when they had passed an obstacle.

5.3. *Features to be included and avoided*

About 70.0% of the respondents commented on the features they would like in a robotic guide and 48.8% on the features to be avoided. The most frequent comments in both categories related to appearance and size, and this fact further highlights the importance of these features to respondents, particularly since they had already had the opportunity to comment on the robot's appearance in question C3b. In particular, respondents were concerned that the device should be discreet and unobtrusive and not attract (undue or unwelcome) attention, including by making unnecessary sounds or noisy operation, or looking exotic, unusual or like medical equipment. They wanted the robot to be attractive and elegant, possibly with a choice of different colours, but in an understated rather than attention grabbing way. However, one respondent wanted it to be visible enough for other people to move out of the way rather than the user having to move to avoid them. The robot should be small, lightweight and easily portable so that it can be taken on public transport and easily stowed away in restaurants, at work and on aeroplanes and trains. However, 'small and portable' was understood in differing ways, with one group

of respondents wanting a pocket-sized device and another a briefcase or backpack-sized one. The comments made in this section gave a clearer idea as to what sort of design respondents would like than their evaluations of the design suggestions made by the authors in the questionnaire.

Other frequent comments were related to robustness, battery life, ease of use and communication with the robot. The robot should be simple and intuitive to use and look after, including by older people. It should be robust, last a long time and not require maintenance, as well as resistant to damage, pressure, knocks and bumps, water and weather. The design should have few crevices and bends where dirt accumulates and which are difficult to clean. White was considered a colour to be avoided for this reason. The user should be able to move fast with the robot, including upstairs and downstairs and in busy situations, and the robot should be able to move over grass. Respondents wanted rechargeable batteries with a long life between charges, for instance a minimum of 16 hours or several days, and an indication well in advance of when the battery would need recharging to avoid it becoming discharged while travelling. The suggestion was made of extending battery life by the device only being powered for steering round obstacles and not for forward motion.

Several respondents wanted a combination of methods for receiving information from and giving instructions to the robot, though one respondent felt that speech output was the most accessible to all blind and visually impaired people. However, this does not take account of the communication needs of deafblind people. The suggestion was made that there should not just be one method for receiving feedback and that the robot should be re-programmable for the particular user, including to accommodate the requirements of users with learning difficulties or other impairments. Suggestions for receiving information from the robot included various combinations of speech and vibrotactile signals, choice of a synthetic voice and Braille, as well as a written message on a mobile phone or palmtop.

Some respondents suggested the use of an earpiece and felt this would be more discreet, whereas others felt that headphones should be avoided, as they cover the ears and disorient the user. The compromise suggestion of both a loudspeaker and an earpiece was also made. Any speech recognition system used should be of good quality and work well in noisy environments. Respondents wanted some choice as to when they received information, particularly spoken information, to avoid irritation to them and other people and attracting attention. One respondent suggested that the user could be alerted to a message by the handle vibrating and press a button to hear it.

Suggestions for giving instructions to the robot included speech, a joystick with a scrolling menu and pushbuttons. Respondents wanted speech to be of good quality, sound human not mechanical and be pronounced clearly, with options to change the voice and regulate the volume and rate of delivery. A small display to enable sighted people to read the information was also suggested, as well as the use of large visual and tactile symbols.

Concerns about security and safety were also expressed, and suggestions included a security system to avoid theft, a connection to the user to avoid losing the robot, a manually operated brake, the avoidance of cables and metal parts and that the robot should have knowledge of self-defence. One respondent, who was an electric wheelchair user, wanted the ability to attach the robot to a wheelchair. An acceptable price was another consideration. Several respondents wanted a USB port and/or wireless connection to update software and/or load data, text and music, whereas one respondent wanted the software to automatically upgrade on contact with wireless internet. Suggestions included a multi-function device with GPS for orientation, a barcode or RFID reader to read information from barcodes and RFID tags, a camera for detecting obstacles, a digital scanner for scanning and reading documents and an internet and/or PC connection to update data and the software. It was further suggested that functions, such as reading supermarket labels, which are not required for mobility, should not be included. One respondent suggested that not all obstacles should be indicated. Respondents wanted to be able to use the robot together with a guide dog and thought it might eventually replace the cane. It was also felt that the robot should only require one hand to use.

6. Discussion and conclusions

This paper has presented the results of a multi-national survey to investigate the requirements and preferences of potential end-users for the functionality, design and appearance and circumstances a robotic guide would be useful in and means of communicating with it. The work was introduced by an overview of the literature. This showed that, though there have been a number of projects, only one, Guido, has gone beyond the prototype stage, and this is no longer manufactured. Again, with the exception of Guido, few of these projects have paid much attention to the robot's appearance or involved end-users to a significant extent. This has resulted in designs which are large, cumbersome and unattractive.

The survey resulted in 80 useful responses with a 40:60 female–male split, more blind than visually impaired respondents and more respondents in the ranges 25–40 and 40–60 than other age ranges. However, the respondents were sufficiently varied to give reasonable coverage of the end-user community. The overwhelming majority of respondents used a mobility device, generally a long cane, and two thirds to four fifths of these respondents felt this device was a significant help in avoiding obstacles, were able to walk at least at a moderate pace with it and felt safe when using it. About three quarters of the respondents who did not use a mobility device felt that they could benefit

from one at least sometimes. Just under half of the respondents used a navigation device en route, most commonly a GPS, and most of the respondents were confident about reaching their destination with it.

About 90% of the respondents were interested in the robotic guide providing information on the current location, reading street names and obstacle avoidance and navigation, with three quarters wanting the facility to locate goods. A number of additional functions were suggested, generally by several respondents. These included information about the location and points of interests; information about the status of traffic lights and support in finding pedestrian crossings, as well as the ability to contact the emergency services or the user's family and give them the user's location. There were also numerous suggestions for supporting the use of public transport and specific functions in the areas of navigation (and wayfinding), reading information and obstacle avoidance.

Respondents considered the robot's appearance to be very important. However, most existing projects developing robotic travel aids have paid very little attention to device appearance and could therefore experience poor user acceptance and take-up if commercialised. The most highly rated designs were an obvious robot, a robotic shopper, a mobility scooter, a robotic dog and a humanoid robot, but respondents were not enthusiastic about any of them, with the highest mark 2.5 out of 5. The obvious robot received the highest rating, but the difference between the designs in the group of most highly rated designs was generally not statistically significant.

The comments provided under features to be included and avoided gave more insight into what respondents wanted. They nearly universally wanted a robot which was discreet and inconspicuous, resembling an object in everyday use, as well as small, lightweight, easily portable and attractive, though one respondent suggested that other people should be able to see and avoid it. One group of respondents had a preference for a pocket-sized device, whereas the other wanted a device that would fit on or under a table. One of the respondents expressed the relative benefits very clearly: 'A guide you can hold discreetly would be good but (a) there'd be a lot of technology to get into a small gadget and (b) it would rely on the user holding it correctly, so contact with the ground is better as sensors would be in constant alignment.' Contact with the ground and a certain minimum weight would be required for the user to respond instinctively to changes in robot direction to avoid obstacles. Thus, one possible design would resemble a briefcase or suitcase on wheels with a telescopic handle, so it can be folded away, and which the user pushes in front of them. Respondents were also concerned about the robot having a long battery life, with suggestions made of 16 hours and several days between charges, being robust, lasting a long time, not requiring maintenance and being easy and intuitive to use, as well as to clean.

Respondents considered that the robot would be very useful in all the suggested circumstances, with most interest in using it for going to new destinations, followed by railway stations, supermarkets, airports, public buildings and last, but still evaluated very highly at 4 out of 5, everyday use. Suggestions of other circumstances in which the robot would be useful included large public buildings and campuses, the countryside and open spaces, 'shared spaces', navigating round roadworks and leisure facilities.

Speech was the preferred method for communicating with the robot, with just over two thirds wanting to use it to give the robot instructions and nearly 90% to receive information. Just over two fifths wanted to use a keypad, and just over a quarter wanted a joystick or switch for giving instructions. Only 14% wanted to receive information in Braille. Respondents were divided into those who wanted information about the obstacle and its location, clear directions on how to avoid it and information of the type 'attention' or obstacle on the left'.

Part 2 of the paper will discuss the gender and national analysis of the results and apply the comprehensive assistive technology model (Hersh and Johnson 2008c) to the results to develop a design for the robotic guide.

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