Blind Navigation via a DGPS-based Hand-held Unit

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Abstract: This research explains the development of a hand-held DGPS (Differential Global Positioning System)-based mobile navigation unit, established for the guidance of blind and partially sighted pedestrians. The designed hand-held unit may easily be carried by visually impaired pedestrians to navigate themselves. In this paper the development of a micro-controller based hand-held unit was demonstrated, that is slightly larger than an average mobile telephone handset. The software development of the hand-held unit was done in assembly language and communication has been established with a GPS receiver and a cellular mobile telephone. The software is developed in two different modes, i.e. DGPS and Inverse-DGPS. Static experiments were performed using the designed hand-held unit. These experiments were performed in GPS mode in both cases, i.e. in the presence of Selective Availability (S/A) and the absence of S/A. These experimental results demonstrated that the performance of the system is much improved in the absence of S/A. Another set of experiments were performed in DGPS mode, that showed the positioning accuracy of the developed hand-held unit well within 5m circle around the marked reference points. The results of these experiments also depict the suitability of developed hand-held system for the navigation of blind and partially sighted pedestrians.

Key words: Blind Navigation, Hand-held, DGPS, Micro-controller, Inverse DGPS, Blind Pedestrian.

INTRODUCTION

In a familiar environment, blind and partially sighted pedestrians successfully navigate themselves using various navigation aids such as white and laser sticks, ultrasonic spectacles, guide dogs and tactile compasses (Shah, et al, 1999b). To help blind, navigate in an unfamiliar environment, various projects are reported using positioning technologies like GPS and DGPS. Outdoor scene interpretation project was proposed to provide blind pedestrians with a smart mobile system, capable of giving simple descriptions and landmarks. This interpretation supplies the blind person with useful landmarks by means of a speech synthesizer (Mecocci, et al, 1995). An infrared wireless communication system named as Talking Signs is proposed to provide remote-directional human voice messages that make independent travel possible for blind and visually impaired pedestrians. The technology was developed at Smith-Kettlewell Eyes Research Institute, Rehabilitation Engineering Research Centre in San Francisco, California, USA. The Talking Signs system is comprised of infrared transmitters, which convey speech messages to small receivers carried by blind travelers. This system is an information system. It is not a safety system. It is not a substitute for travel aids like long cane or guide dog (Crandal, et al, 1995). The navigation system for the blind is designed in Niigata University, Japan. This navigation aid consists of two main parts. The first is the mobile unit for the blind traveler and the second is a base station, for preparing geographical information data after receiving the traveler’s position data through the telephone line. In this system, the GPS receiver outputs the location data every three seconds. The maximum number of satellites that can be received is 4, because of receiver’s limited capability. In this system, the total weight of the mobile unit is 2 kg. The GPS receiver, the controller and the battery were stored in a shoulder bag, and the mobile phone and the GPS antenna were carried in hands of the pedestrian. After the reception of correct GPS data, the automatic speech replay function, using a CRT display and a monitor speaker, is broadcast to the blind user. The maximum error recorded was 16 m. The time taken for the internal set up of the modem, before output of speech began, was more than 40 seconds. Another limitation of the system is that the communication lines were hung up after each speech guidance system because of modem
used (Makino, et al, 1996). Another navigation system is designed, which uses a guide stick and a small wheel at the end of the stick. A device is used in the system to keep the terrestrial magnetic sensors horizontal. To navigate blind and visually impaired pedestrians, this aid proposes a method using auditory signals, consisting of voice sound and buzzer. An answering machine is attached to the guide stick, to provide the required information whenever requested. This system can be used up to the destination of about 620-m (Aono, et al, 1997). MoBIC (Mobility of Blind and elderly people Interacting with Computers) research was carried on from 1994 to 1996 with the support of European Union Technology Commission. The primary objective of the research was to increase the independent mobility of blind and elderly persons in unknown urban environments (Petrie, et al, 1996). In MoBIC system, the blind pedestrians need to carry a body worn or back pack PC. The blind pedestrians will be guided by pre-recorded messages to reach their desired destinations (Petrie, et al, 1997). An obstacle avoiding system ASMONOC (Autonomous System for Mobility, Orientation, Navigation and Communication) was designed to provide navigation capability for blind and partially sighted pedestrians. The ASMONOC project uses a backpack, worn by the user, to hold the system electronics and sensors. The system is connected directly to two cameras, mounted on two rigid arms, which extend over either shoulder of the user from the backpack. This system is useful for obstacle detection (Molton, et al, 1998). A scientific aid was designed to provide information to the blind users about the obstacles in the travel path, known as Navbelt. This assists the user in selecting the preferred travel path. In addition, the level of assistance can automatically be adjusted according to the changes in the environment, and the users’ needs and capabilities. This aid compares and uses mobile-robot obstacle avoidance system as a guidance device for blind and visually impaired pedestrians. The electrical signals, which are used for the guidance of robot around the obstacles, are replaced by acoustic or tactile signals (Shoval, et al, 1998). An electronic travel aid, known as The People Sensor was designed to address two issues of importance to blind pedestrians: inadvertent cane contact with other pedestrians and objects, and speaking to a person who is no longer within hearing range. The device uses pyro-electric and ultrasonic, to locate and differentiate between human and non-human obstructions in the detection path. The parts of this device are contained within a standard fanny pack fastened about the waste. This belted compartmentalized carrying case houses the major electronic components, batteries and switches (Ram, and Sharaf, 1998). A walking navigation system was proposed for blind navigation, based on comparison of data obtained by a pedometer, a terrestrial magnetic sensor, and a prearranged teaching data of a route to a destination. This system gives an appropriate instruction, using voice and buzzer sound, during a user’s walk. The limitations of the system are that the nodes of a walking route for teaching should be less than 50 m. A magnetic sensor is used for direction determination (Nakamura, et al, 1998). Another proposed system was known as Personal navigation system. In this proposed system, the current position and the orientation of the user are known from the sensors. In addition, key press 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 weight and power requirements of the prototype make it impractical in everyday life of blind pedestrians (Dodson, et al, 1999). A GPS information system Sendero GPS-talk is designed for blind and visually impaired pedestrians (May, 2000). GPS-Talk software includes Atlas talking map software. It has functionality of Atlas and benefit of GPS location information. The Atlas is a talking digital map consisting of street locations of the most parts of the USA. Arrow keys are used to navigate around the map, while a speech synthesizer announces the information; a user wants to hear. The size of the GPS-Talk is the size of a notebook computer plus GPS antenna and GPS receiver. As the S/A is off since May 01, 2000 (Press release, 2000); the GPS accuracy is recorded as approximately 20 m. This accuracy is not sufficient for the guidance of blind pedestrians on pavements of pedestrian paths, as the system does not support DGPS operation. A DGPS reference base station was established at Brunel University based on GPS Builder™ supplied by GEC Plessey (Mittel) semiconductors. To analyze the performance of the DGPS reference station, a mobile unit was constructed, which consists of an SV6 Trimble GPS receiver, an UHF radio receiver and a laptop host PC. (Liu, and Balachandran, 1997). This DGPS base station provided an initial platform to develop the hand-held DGPS-based system. The experimental results conducted within the University demonstrated that the Brunel reference station’s accuracy was not within the required limit i.e. 5m from the reference position on the marked route (Ptasinski, 1999), therefore it was decided to use an alternate DGPS platform for the designed DGPS system. In all the research projects proposed or designed for blind navigation as discussed above, the blind pedestrians need to carry backpack PC or cumbersome electronics, which do not suit their freedom and desired requirements. The market acceptance is low as they are difficult to use and the applications are also limited (Balachandran, 1996). Considering this fact, it was decided to develop a hand-held DGPS System, a prototype Navigation System to help blind solve their navigation problem (Shah, et al, 1999a.)
2. **Aim of the Research:**

The aim of this project is to design a hand-held DGPS-based unit, combining a GPS receiver and a cellular mobile transceiver with the help of a micro-controller based unit for the guidance of blind and partially sighted pedestrians and demonstrate the functionality and usage of the unit for blind navigation.

3. **Design of DGPS-based Hand-held Unit:**

A DGPS system was designed that consists of Focus FM DGPS corrections based reference station, a modem and a PSTN landline telephone on base station side and a micro-controller based handheld mobile unit, that can easily be carried by blind pedestrians for navigation purpose. The designed hand-held mobile unit is slightly larger than the mobile telephone handset and consists of the following:

![Designed DGPS-based Handheld Unit for Blind Navigation](image)

### 3.1 The Micro-controller:

An Intel 8051 micro-controller is selected for this hand-held unit. The main features of the micro-controller are 4K bytes of ROM, 128 bytes of RAM, 32 I/O lines, two 16-bit timers, 2-level interrupt structure, a full duplex serial port, and on-chip oscillator and clock circuits. It has TTL and CMOS compatible logic levels and can access up to 64K external program memory and 64K external data memory (Ayala, 1991). The micro-controller used is available in 40-pin DIP package. The 8051 instruction set is optimized for the one-bit operations desired in real-time control systems, the Boolean processor provides direct support for bit manipulation, and bit addressing can be used for test pin monitoring or program control flags. This makes it efficient for real time processing and binary input/output conditions as the requirements of the research. In addition, it is a low cost device, and there are a wide range of variants available from a number of manufacturers, all using the same op-codes, binaries and same development tools. This means that it is easy to find a variant, which is suited for the task, and there is no supply problem. The two types of variants worth considering for this research were those with FLASH PROM (or EEPROM) and those with an extended number of I/O lines. FLASH PROM variants are well suited for development and prototyping as reprogramming the chip is virtually instantaneous as opposed to UV-erasable EPROM.

### 3.2 Other Chips Used in the System:

The main considerations with memory selection were layout, access type, size and speed. An octal latch (74AC373) is used to extract the address, and the ALE pin on the 8051 enables the latch. CY6264 static RAM was selected, that uses a low power CMOS design, which is suitable for battery operated and battery backup operation. The RAM is 65536-bit, organized as 8192 words by 8 bits (8 Kbytes memory, which is sufficient for the research circuit) and has an access time of 200 nanoseconds. It is a high performance CMOS static RAM organized as 8192 words by 8 bits (Shah, et al, 2000b). An AM27C512 EEPROM (Electrically Erasable Programmable Read Only Memory) is selected to use in the system, which can be programmed in few seconds.
using an EPROM programmer. This is a 64Kbit EEPROM, organized as 65536 x 8 bits. It is low power
dissipation and uses hardware and software data protection to prevent inadvertently overwriting data. The
EEPROM used is in PDIP (Plastic Dual in-line) package. Access times as fast as 70 nanoseconds allow
operation with high-performance. A MAX-235 is used, which is a +5V powered high-speed multi-channel
driver/receiver, to convert CMOS levels into RS232 standard and vice versa. An 11.0592 MHz quartz
crystal is used in the circuit to generate the exact required baud rates of 1200, 4800 and 9600 bits/second. Fig. 2
shows the circuit diagram of the micro-controller unit. It is composed of an 8051 Micro-controller, a latch,
program memory, data memory, a crystal clock, logic gates, a signal level converter and three serial ports.

![Fig. 2: The Circuit Diagram of Micro-controller based Unit.](image)

3.3 Expanded Serial Interface and Multiplexed Serial I/O:

The micro-controller has interfaces with three RS232 ports in the system, one port is used for mobile
telephone (transmission and reception), and two ports are used for Micro GPS receiver. One is to transmit and
receive GPS data from the receiver, and the other is to transmit DGPS corrections from the micro-controller
to the GPS receiver. The 8051 has only one full duplex serial port, therefore a suitable method was adopted
to find an appropriate way to expand this serial port to communicate with three RS232 devices. It is not
necessary to have the simultaneous operation of all the serial ports. As the micro-controller has full control
of serial communication (transmit and receive), therefore it is possible to know which device needs
communication and when. Therefore, it is possible for micro-controller to select when to transmit. The
important consideration needed is when it is necessary to receive the data (i.e. when the connected devices
actually transmit data information). The GPS receiver provides a TTL level output to indicate when it is ready
to output data, and the mobile telephone can be set to use hardware flow control. It is clear that the micro-
controller can choose when to receive data from the mobile telephone and use a flow control line to tell it
when it is ready, so it can be interrupted when it requires to receive data from the GPS receiver. Therefore,
it is feasible to have only one serial link operational at any single moment in time. This was achieved by using
logic gates and I/O lines from the 8051 as control lines. One line is provided per device, and set high when
the device is connected and low when it is disconnected, AND gates were used to connect/disconnect the
devices from the serial ports. The gates used in this research were NAND gates (7403), OR gates (7432),
AND gates (7408) and Inverters (7404) as shown in Fig. 2.

4. The Software Design and Implementation: The software implementation of the micro-controller circuit was
done in assembly language. Serial communication routines were designed for asynchronous data transmission.
For convenience, the software has been broken down into separate functions where possible. Communication has been established with Micro GPS receiver and the GS18 cellular mobile telephone by using individual codes for each device (Shah, 2002).

4.1 Software for Micro GPS Receiver:
The communication with the Micro GPS receiver is made by using serial routines. The GPS receiver outputs data every second, therefore that data is to be read and the appropriate bytes are to be checked to read the longitude, latitude and type of fix i.e. GPS or DGPS. The receiver emits a SPS output, when a reading is ready, which has been used as an external interrupt. The actual GPS receive function can be called from the interrupt routine, or the micro-controller could wait until the data has been arrived (Micro-GPS, 1996).

4.2 Software for Cellular Mobile Telephone:
The cellular mobile telephone is used to receive DGPS correction data from the land line telephone connected via modem to the reference base station. The mobile telephone transmits the DGPS or GPS position back to the reference station in similar fashion. The software is designed in a way that when the micro-controller unit is turned on, the mobile telephone (connected with micro-controller) dials the number of base station. As soon as the connection is established, it receives the DGPS correction data via asynchronous transmission from base station.

4.3 Final Software and its Operating Modes:
The final software demonstrates the above routines by combined programmes. This enables all the functionality to be developed and tested individually. Then those codes were combined to develop complete programs to achieve the tasks. The software program of the designed micro-controller circuit is written in two different modes, i.e. DGPS mode and Inverse DGPS mode.

4.3.1 DGPS Mode:
This is the standard mode of the micro-controller unit and is used in this research to transmit differential corrections from base station to mobile and compute DGPS position. In this mode, when the micro-controller unit is turned on, it will initialize the GPS receiver and set it into DGPS mode. As soon as the Micro GPS receiver is set into DGPS mode, the micro-controller unit establishes the communication through the mobile telephone, with the reference base station. A landline telephone is connected via modem with the PC-based reference station. When the connection is established between the telephone at the reference station and the mobile transceiver of micro-controller unit, the base station starts transmitting differential correction data to the micro-controller unit. The micro-controller unit transmits those correction data to the GPS receiver, which calculates the position of the unit with the DGPS accuracy. The calculated position of the unit is then transmitted back to the reference station via the cellular mobile telephone. At the base station, that calculated position is combined with the digital map of the corresponding geographic area to observe the overall performance of the system (Shah, 2002). The flowchart of the software program is shown in Fig. 3.

4.3.2 Inverse DGPS Mode:
In Inverse DGPS mode, the rover receiver transmits the GPS position to the reference base station, where differential corrections are added with the GPS position to find the position of the rover receiver with DGPS accuracy. This programme will be used in future Inverse DGPS system to be designed in future. In this mode, the operation of the micro-controller unit is relatively simpler. As soon as the unit is turned on, the mobile telephone dials the telephone number of the landline telephone connected with the reference base station. When the connection is established, the micro-controller unit receives the GPS data from the Micro GPS receiver and transmits those data via mobile telephone to the reference base station. At the base station, these data are combined with the differential corrections obtained by the reference base station and the position of the micro-controller unit is calculated with the DGPS accuracy. That calculated position is then combined with the digital map of the corresponding geographic location to observe the performance of the system. The flow chart of this program is shown in Fig. 4.

4.4 Testing the developed System:
Testing of the system is carried out using oscilloscope and then by connection to a PC. The system was constructed by soldering onto copper strip board. It provides semi-permanent connections but also allow the removal and changing of connections if required. To protect the chips from the heat damages while soldering,
Dual In-Line sockets were used in assembly and then the chips were simply plugged in. The designed mobile navigation unit was suitable to observe the impact of various parameters over the performance of navigation system with few limitations. Its main limitations were its incorporated built-in antenna, therefore it has to be in open space every time and can not be connected to any external antenna to do experimental tests inside the building (Shah, 2002).

![Flowchart of Micro-controller Program in DGPS Mode](image)

**Fig. 3: The Flowchart of Micro-controller Program in DGPS Mode.**

**RESULTS AND DISCUSSIONS**

The experiments were performed by placing the hand-held mobile unit at various places at different areas. These experiments were sub-divided into GPS and DGPS modes. These experiments were conducted with the designed Micro-controller based handheld unit.

### 5.1 Experiments in GPS Mode:

For measuring the performance of the system in GPS mode, only hand-held mobile receiver was used. Fig. 5 shows the performance of the GPS system when the S/A was on and Fig. 6 shows the performance of the system in GPS mode when S/A was off. The experimental results show the improvements in the results when S/A was turned off.

In Fig. 5 and Fig 6, the inner small circles represent 5m area around the position of the antenna of the mobile unit and the outer large circle shows 100m radius area. The continuous pink line shows the recorded positioning results measured by the system. The analysis of the recorded results was conducted following the GPS performance characteristic criteria discussed (GPS Navstar, 1995). Statistical analysis of the experiments revealed that when the S/A was on, the predictable accuracy of the system was 78.0 m and when the S/A was off; the average accuracy was recorded as 21.0 m. According to SPS performance characteristics, the accuracy of GPS system should be under 100 m in the presence of S/A and be nearly 25 m in the absence of S/A (Parkinson, et al, 1996).
Fig. 4: The Flowchart of the Micro-controller Program in IDGPS Mode.

Fig. 5: The Performance of the system in GPS mode when S/A is On

5.2 Experiments in DGPS Mode:
These experiments were performed by the developed hand-held Micro-controller based unit and Focus FM DGPS reference base station with cellular mobile data link. The results of these experiments demonstrate the performance of developed DGPS system. Fig 7 shows one of the experimental results conducted to find the accuracy of the system. The “Current Position” at the right hand bottom corner gives the numerical position result in Easting and Northing. The inner circle shows 5m distance and outer circle shows 20m distance from original position (Shah, 2002).
Fig. 6: The Performance of the system in GPS mode when S/A is Off

Fig. 7: The Performance of the system in DGPS Mode.

The current position of the mobile navigation unit shown in Fig. 7 is:
\[ x \text{ (Easting)} = 505883.50 \text{ m}, \ y \text{ (Northing)} = 182564.90 \text{ m}. \]

The pink scattered lines in smaller circle of 5m show the positional results calculated by the unit. The statistical analysis of the recorded data following the criteria (GPS Navstar, 1995) reveal that the 2s i.e. 95% accuracy of the system was 4.6m.

Conclusions:
A Differential GPS-based hand-held unit was established consisting of a GPS receiver, a cellular mobile telephone and a micro-controller based unit. The software was designed to implement the system in GPS, DGPS and Inverse DGPS modes. The experimental results were performed on the handheld DGPS system by placing the unit at various places to check the performance of the system. The experimental results demonstrate the accuracy of the GPS system equivalent to 78.0 m in the presence of S/A and 21.0 m in the absence of the S/A, which confirm the performance of the developed system as per SPS characteristics. The experimental result also showed the accuracy of the system in DGPS mode equivalent to 4.6 m. The experimental results also recommend the suitability of the developed system as a hand-held carried unit for the navigation of blind.
and partially sighted pedestrians.

**Expected Future Enhancements:**
The following enhancements are proposed for further modification of the developed system.

Combination of Electronic Compass with Handheld Unit

- Use of Javad JGG20 GPS Receiver as a Combined GNSS Receiver.
- Applying Kalman filtering technique to the positioning Results (Shah, et al, 2000a)
- Combination of voice and data via cellular mobile Telephone (Mahdavi and Tafazolli, 2000).
- Establishing a navigation service center with trained navigation staff.
- Conducting Field Experiments using real blind pedestrians.

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