Walking assistant device with GPS and electronic compass

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Abstract: - Despite constantly improving medical techniques it is still impossible to cure many severe vision defects which causes great demand for devices that help blind persons to get through chores of everyday life. In this paper there is presented such assistive device developed at the Silesian University of Technology. The main purpose of the device is to help blind persons to move through a town without aid. The device is prepared to be used by pedestrians so it is small and battery powered. The device uses GPS navigation, yet because GPS can determine the azimuth only while moving, the device is equipped with electronic compass that needs to operate independently of the position. The description of the calculation of the azimuth is based on values measured from the compass and accelerometer.

Key-Words: - satellite navigation, GPS, magnetic compass, blind persons, walking assistant

1 Introduction
Electronic devices are entering more and more domains of our lives. One of them is medicine and helping disabled persons. Despite developing science and medical techniques, it is still impossible to cure serious vision defects. That is why devices helping blind persons in everyday life are still being developed.

One of great challenges blind persons face is moving through town without aid. The overall situation is partly improved by various aiding devices, such as well-considered traffic-lights on pedestrian crossing. They can indicate with sound not only the light currently being displayed, but also their location. Still the basic tool for blind persons is white the cane, and it is frequently improved in many ways. There are canes with laser or radar rangefinder, which are able to warn against hindrances with sound or vibration. They can measure distance to obstacle or even determine its texture. However, they do not help in navigation in terrain, cannot determine where the user is and in which direction he should go. Such role can be fulfilled by above mentioned traffic-lights, or a device carried by user with himself, which knows its position. This can be achieved by using dedicated radio beacons, placed in points critical for navigation, or navigation satellite system. The device described in this paper belongs to the latter group of solutions.

2 Concept and functionality
Destination of described device is to help blind persons in moving around. With GPS system it fixes user's position and it is able to guide him to some selected target point. However, such device cannot replace the white cane for blind person and, for example, warn him against stairs or a pothole in the sidewalk. Accuracy of navigation satellite system is too small. Because of that device is used only for pointing direction in which the user should go. The device has greatest usage in urban environment where it can guide its user through the grid of streets and indicate characteristic points like crossroads, building's entrances, or public transport stops. Research has shown that blind persons can efficiently move in some known area if only such characteristic points are indicated to them [1].

2.1 Adaptation for pedestrians
The device is adapted to use by pedestrians - it is portable and powered by battery. Capacity of the battery limits device's operating time without charging. Because of that during construction special emphasis was placed as minimization of power consumption for all modules and circuits in the device. Another adaptation for pedestrians is built-in magnetic compass. It allows to determine direction which the user is facing while not moving, which is very helpful for blind persons. The device is especially adapted to be used by blind persons by using sound user interface, but it can be also used by another users. They can also use auxiliary monochromatic graphical LCD display.

Navigation in the device is based on points defined by the user. Typical maps used in GPS navigations meet
requirements of car drivers. Points defined by users themselves meet their requirements much better. It is also possible to share data with other users. It can be done by copying data into PC computer through USB interface and using dedicated software.

2.2 Functionalities
The primary functionality of the device present is guiding a user to the chosen point. Points are defined by their geographical coordinates and stored in non-volatile memory of the device. Each point has also its name, recorded as voice (in audio file) and written as a text - to be displayed on the screen. The device can operate without names stored as text - for blind persons, or without voice records - for users using only the display. Points are classified in various categories, depending on their type, and in sets called towns - because of their geographical coordinates. Every town contains points form certain area. It minimizes the number of points in menus and makes them easier to find.

Guiding to the target point is done by giving the user information about direction and distance to this point. This information is provided by voice and displayed on LCD screen. Furthermore, points can be put together in a chain, called a route. When using a route, the user is guided through all constituent points. Another important functionality is reading out names of passed points from selected category. As above mentioned, blind persons can efficiently move around in the known area if only some characteristic points are indicated to them. In such situation, reading out names of passed points allows them to walk freely inside such area and they do not need another help. Reading out names of passed points is also designed to be used in public transport. Not all buses or trams are equipped with loudspeaker systems which are reading out names of next stops. After selecting the category "Bus stops", a user can hear names of approaching stops.

A user can also add new points to device's memory by saving geographical coordinates of a place where he is. Advanced editing of all data (towns, categories, points and routes) is available by auxiliary application, which can be executed on PC computer.

3 GPS system
As it was mentioned before, navigation satellite system cannot fully replace the white cane because of its small accuracy. In the described device there was applied OEM GPS module FGPMMPA2. It is based on chipset MTK MT3318 which has 32 radio channels and high sensitivity of -158dBm. The chipset is based on 32-bit ARM7TDMI microcontroller. The producer of this module declares its accuracy as 3 meters. During tests it turned out to be often worse, and what is more important for a blind user even three meter error might mean that he is in the middle of the roadway instead of the sidewalk. Accuracy is frequently worse because of operating in city canyon - streets surrounded by high buildings, which are covering sky view.

3.1 Sensitivity and accuracy
GPS receiver has very high sensitivity which allows to receive signals from satellites even if sky visibility is bad. In practice, problem of losing communication with satellites does not exist in urban environment. Position can be fixed even in some buildings, obviously with worsened accuracy. High sensitivity causes - similarly as in digital camera - high noise level in received signal. With high noise level, accuracy of determined position is decreasing. Therefore GPS chipsets are filtering results, using various algorithms. Unfortunately most of them are designed for currently the most popular satellite navigation application - vehicle navigation. Vehicles, for example cars, compared to pedestrians, are moving more "clearly" - with greater speed and are not changing their direction so suddenly. That is why GPS receivers are often fixing position with greater accuracy when they are moving, than when standing still. Unfortunately, a pedestrian is moving too slow and irregularly.

3.2 Determining direction of moving
GPS receiver is capable of fixing direction in which a user is moving (azimuth). It happens by keeping in memory some previous results of location's measures. These points make a line that points direction in which the device is moving.

Unfortunately in case of pedestrians, their speed is too low and distance passed between subsequent measures is comparable to error caused by inaccuracy of measures. It causes growing inaccuracy of determined direction (for speed of 4 km/h inaccuracy is about 20-40º). Only speed over 20 km/h guarantees accuracy about 5º or less of determined azimuth (in urban environment).

Because of that, the device is equipped with the classical compass which is using Earth's magnetic field. Such compass can determine how a user is turned toward north direction. With geographical coordinates of a target point, the device itself (fixed by satellite navigation) and direction in which the user is turned, the device can determine direction in which the user should go. With magnetic compass, the device can determine direction even before the user moves. He is guided from the very first moment, when he activates this function in the device. It is very important for blind persons.
Magnetic compass also reacts faster (immediately) to changes of direction when the user is walking.

The device described in this article was constructed despite all these problems with accuracy of satellite navigation system. Various solutions that use GPS system to help blind persons have been produced for a long time (for example Spanish device Tormes designed in 2004) [1]. They were build even in times, when technology and accuracy of GPS receivers were significantly worse. However, even these devices received good remarks from users, which means that such solutions are needed. Designers can only try to use latest technologies and some auxiliary mechanisms to design better and better devices.

4 Electronic compass

Electronic compass uses the same operation principle as classic mechanical compass. In classical compass, the magnetic needle that is placed horizontally, parallel to Earth surface, is arranging along lines of Earth's magnetic field.

4.1 Measuring Earth's magnetic field

Electronic compass usually contains two magnetometers which measure magnetic field in two perpendicular directions.

Such set of sensors allows to measure two components $H_x$ and $H_y$, of magnetic field's vector, which is pointing north. Now azimuth (the angle that compass is rotated from the north direction) can be calculated as

$$\alpha = \arctan \frac{H_y}{H_x}$$

(1)

Measuring Earth magnetic field requires very sensitive sensors. These are magnetoresistive sensors, which use material where resistance changes under external magnetic field [4]. These sensors need special service because of their characteristics. It is only partly linear, dependent of temperature and parameters vary in sensors of one type. It requires special calibration process. In the described device Honeywell HMC1052 sensors are used.

Such compass has one disadvantage, common with classical compass, the surface of two sensors must be horizontal, parallel to Earth surface. Only then $H$ vector is pointing north. The reason for it is the shape of Earth's magnetic field.

Figure 2 shows lines of Earth's magnetic field. Only on the Equator they are parallel to Earth's surface, and only there compass with two magnetometers can operate independently of its position. Closer to poles, lines are getting vertical. Inclination angle of these lines is called magnetic inclination $\delta$. Real magnetic field vector is shown in Figure 3.

![Figure 2: The Earth's magnetic field [3]](image)

![Figure 3: Earth's magnetic field vector in three dimensions.](image)

Compass with two magnetic sensors, when rotated in various directions, will generally show direction to the center of Earth. It points north only if is kept horizontally, and even slight deflection causes considerable error ($8^\circ$ at deflection $5^\circ$ at European longitudes) [2].

In some applications, for example when a user is used to classical compasses, it is acceptable to use compass
that needs to be horizontal. But sometimes it is impossible to require so much from the user. It concerns mostly devices which use satellite navigation system, where the user is even not aware of using magnetic compass and the consequences of this fact. It is necessary to make compass operate independent of its position.

4.2 Making compass operate independently of its position

If compass is rotated along axis X by angle \( \phi \) and along axis Y by angle \( \rho \), as the result we get a rotated coordinate system, where components of vector \( H \) will be named: \( H_{xc} \), \( H_{yc} \) and \( H_{zc} \).

Further calculation can be done in two different ways: the third magnetometer is added to obtain \( H_{zc} \) value, or this value is evaluated. Using three magnetic sensors increases cost of the whole device and complicates its construction - additional magnetometer needs additional calibration circuit and amplifier, and must be perpendicular to the printed circuit board. Also calibration process would be much more complicated. Value \( H_{zc} \) can be also evaluated from equation (4):

\[
H_{zc} = \frac{H_x + H_{yc} \sin \phi - H_{yc} \cos \phi \sin \rho}{\cos \phi \cos \rho}
\]  

(6)

In the Figure 3 it also can be noticed that

\[
H_z = H \sin \delta
\]  

(7)

where \( \delta \) is magnetic inclination.

Inclination value is dependent on location on Earth and varies between -90º and 90º. However, it can be assumed as constant in some areas (several degrees of longitude), where compass will operate. It can be evaluated if only geographical coordinates of this place are known. In the described device longitude and latitude are provided by GPS receiver. Software contains arrays with pre-calculated inclinations (precisely: tangent of \( \delta \)) for various geographical coordinates.

If inclination is known, magnetometers provide values of \( H_{xc} \), \( H_{yc} \), and angles \( \phi \) and \( \rho \) are known, azimuth can be evaluated from equations (7), (6) and (5).

4.3 Determining compass position

To determine angles \( \phi \) and \( \rho \), accelerometers are used. They are measuring gravitational acceleration, as it is always perpendicular to the Earth surface. Such sensors are available in sets of two accelerometers in a single casing. The device is capable to use sensor ADXL202E, or MXD7202. Sensors should be mounted on the same surface and in the same axes as magnetometers. They provide pulse width modulated signal, which is connected to timer/counter of microcontroller. If the signal is scaled to range \([-1 ; 1]\) (zero for sensor parallel, 1 or -1 for sensor perpendicular to the Earth surface), it can be treated as sine of appropriate angle (\( \sin \phi \) and \( \sin \rho \)). There is no need to calculate the angle itself, as it has large computational complexity. Cosine can be calculated from sine by using

\[
sin^2 \phi + \cos^2 \phi = 1
\]  

(8)

Function \( \arctan(x) \) must be also implemented in microcontroller, to implement formulas (5), (6) and (8). Because of small computation capability of microcontrollers and small accuracy of magnetometers,
the best solution is to calculate values of \( \text{arctan} \) before compilation and store them in program memory. Resolution 1° of pre-calculated values seems to be adequate.

5 Voice user's interface

Users and designers of computers and electronic devices got used to communicate with them with eyesight via (more or less advanced) screen. Designing device for blind persons needs completely new approach. Sight messages must be replaced by sounds, or - if device will be kept close to user's body - vibrations. It should be also considered that blind persons are using in everyday life mainly the sense of hearing therefore this sense cannot be occupied only by one device. It is very important while moving around in urban environment, because such conditions require special attention and control of surroundings.

All messages were previously recorded and are stored in device as audio files. Device itself is unable to synthesize speech. Speech synthesis has large hardware requirements, is labour-intensive in implementation and synthesized speech has low quality. All records are stored on flash memory card. This kind of non-volatile memory is currently the cheapest. Cards can be also - if necessary - used in another device. Because of large capacity, such cards can store many audio records of high quality.

5.1 Hardware

Urban environment is rather loud and because of that sounds from loudspeaker might not be clearly heard. In the device sound is issued by earphones. Earphones also guarantee more privacy and can be used to play stereophonic sounds. To not disturb the user, device also has one button designed only to turn down all sounds. It is important not only for user's comfort, but also for safety. Sound volume can also be adjusted and new sounds can be recorded by built-in microphone.

The input to the device constitutes the keyboard. The only difference to the regular keyboard are characters written in braille. Special attention was put on easy use of the keyboard. Because of that all functions of the device can be used with just 4-directional joystick and three buttons of volume control. There is also the numerical keyboard, but it is used only for faster moving in menus with large number of items. It is not necessary to use this keyboard.

5.2 Software

Voice user interface is based on three main elements:

- voice menu,
- sounds guiding user in proper direction,
- information and error messages.

Voice menu contains a few seconds-long records for every item. They are played whenever an item is selected. Error, information and battery level messages are also played. To not disturb the user, battery charge level is read out only if it achieves one of predefined levels. The user can add his own item to the voice menu - he can also record own messages with microphone. Guiding in proper direction is done by a single tone played by stereophonic headphones. This sound is spatial – the user can hear it from this direction in which he should turn. Tones are played only when the user is going in a wrong direction. This solution seems to be better and more natural than used in some similar devices where messages say how many degrees the user should turn to left or right. Device is designed not only for blind persons so all information is also displayed on the screen.

6 System architecture

The primary element in the device is microcontroller. It is 32-bit AT91SAM7A3 processor with ARM7TDMI core. It contains USB controller (device mode) and to communicate with USB must be clocked with 48MHz. When this bus in not in use, the processor is clocked with only 12MHz to minimize its power consumption.

\[
\text{gravitational acceleration} = 1 \sin \phi
\]
Data about user position is sent from described before GPS module through the serial port. Magnetometers with supplementary circuits (calibration circuit and amplifier) provide analog signals. Additionally the processor controls calibration process. Acceleration sensor does not need any calibration signals. It provides two pulse width modulated signals. They are connected to two universal timers/counters in microcontroller, which are measuring fill ratio.

The element responsible for playing sound records is dedicated audio processor - VS1053b. It is integrated codec, two channel digital to analog converter and two high quality earphone amplifiers. It also contains microphone amplifier and analog to digital converter. Earphones and microphone can be connected to the chip with only few external passive elements. Codec can decode files in various audio formats (MPEG 1 & 2, audio layer III, MPEG4, Ogg Vorbis, WMA, WAV) or even play MIDI files. Sounds recorded with the microphone can be encoded to PCM, IMA-ADCP or Ogg Vorbis format. Audio processor is communicating with microcontroller through SPI bus. The only action that the microcontroller must take to play sound is to send the whole audio file through the bus.

LCD display and audio processor are connected to the same SPI bus. Another SPI interface is connecting microcontroller with SD memory card. The card operates in SPI mode, so it can be connected directly. Use of two buses prevents overloading them when audio file with big bit rate is sent from the card to the audio processor.

Keyboard contains 17 keys and is designed as matrix keyboard with 4 columns and 5 rows.

### 6.1 Communication with PC computer

The device is communicating with PC computer to exchange all navigation data. Then this data can be edited, shared with another users or backed up. To ease the use of the device, it employs standard USB class Mass Storage Device (MSD). This class is supported in most modern operating system, so a user does not have to install any additional drivers. After connecting the device a user gets access to all files stored on memory card. Some of them contain navigation data, other language data, so data can be easily edited and device language changed. Card contains also data management application. USB port is also used to charge battery - directly from computer or universal charger.

### 7 Summary

The device is powered by lithium-polymer battery with capacity of 1500mAh. It allows device to operate approximately for 10 hours. Most of the power is consumed by GPS receiver so it cannot be minimized, but 10 hours seems to be adequate time.

During tests in urban environment the accuracy of fixed position was mainly between 3 and 10 meters. It allows to navigate to crossroads, but not to some specified point at this crossroads. The device is useful in public transport, when it signalizes next stops. Magnetic compass is rather not working in a bus or tram, because of many metal parts of vehicles and magnetic fields coming from engine and trackage, but it is not required when reading out stop names. As mentioned before, availability of GPS satellite signal is very good, so the signal can be received in vehicles too.

The main disadvantage of the device - its low accuracy - can be improved in future by use of new satellite navigation modules. They are being developed continuously to get better results. Accuracy can be also improved by changed policy of satellite systems owners - currently greater accuracy of GPS system is available only for military users. Another systems, like European Galileo, when launched, can provide better position accuracy.

### References:


