Adaptation of satellite navigation for pedestrians with electronic compass

Krzysztof Tokarz, Michał Dzik

***Abstract*—**Despite constantly improving medical techniques it is still impossible to cure many severe vision defects which causes great demand for developing new techniques that could help visually impaired persons to get through chores of everyday life. GPS navigation is the most valuable technology but currently available consumer GPS receivers do not offer good accuracy. At the Silesian University of Technology the research was done for improving the functionality and accuracy of navigation for blind persons. The GPS navigation device has been developed equipped additionally with electronic compass and accelerometer for improving accuracy of determining the azimuth.

***Keywords*—**satellite navigation, GPS, pedestrians, magnetic compass, blind persons

I. Introduction

SATELLITE navigation systems become more and more popular in every day life. Such system can determine user's location in two or three dimensions which can be used in many domains - from geodetic measurements to entertainment (geocaching). But primary application is to provide user information about where he is and how can he get into another, indicated point. Additionally if user is moving and results of at least two previous fixes are known - direction where user is moving can be determined. For such purposes - primarily only for military users - Global Positioning System (GPS) was built. It consist of 30 satellites (at least 24 in use) and 12 ground control stations [9][13]. Currently the GPS system is free to use also for civil users. To use the system, user must only have GPS receiver. Because of great popularity of GPS system, receivers are instantly improved, but main disadvantage of whole system is still low accuracy of determined position.

The primary application of civil GPS receivers is navigation of moving vehicles - on ground, sea or sky. Vehicles, for example cars, are generally moving fast and in concrete direction and contemporary GPS receivers are optimized for this type of move [11]. They get best result of determining position and direction when user is moving with high speed.

Accuracy decreases when receiver is moving slowly or remain in one location - like pedestrians. Pedestrian can also instantly change direction of his or her walk, or turn around, which causes that direction cannot be determined by a satellite navigation system [17]. Some methods of improving accuracy of GPS receivers for pedestrians including use of magnetic compass and accelerometer are described in this paper. Method based on the accelerometers used instead of GPS receivers is described in [14]. These methods were applied in walking assistant device developed for visually impaired persons and this device is described at the end of article.

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K. Tokarz is with the Institute of Informatics, Technical University of Silesia, Gliwice, Poland (e-mail: krzysztof.tokarz@polsl.pl).

M. Dzik is with the Institute of Informatics, Technical University of Silesia, Gliwice, Poland (e-mail: michal.dzik@polsl.pl).

II. GPS system

Navigation satellite system cannot fully replace the white cane because of its small accuracy. In this system, determining position is based on measuring distance between satellites and receiver. It is calculated from time which is taken by the signal to move from satellite to receiver. While space segment (satellites) is well synchronized by atomic clocks and auxiliary data from control stations on Earth, receivers use cheap and not precise quartz clocks, which provides fix errors. Also signals can reflect from high objects around user, interfere with other signals. Accuracy is worsen by influence of ionosphere. Passing this layer of atmosphere can take different time, depending on current conditions. This can be corrected by sending two signals with two different frequencies and comparing their transmission times. These two signals, with frequencies f_1 = 1575,42 MHz and f_2 = 1227,6 MHz are in fact in use, but signal f_2 is encrypted and available only for military users. Other users - including blind people - cannot use such ionosphere correction. Accuracy can be improved by use of DGPS corrections. These corrections are sent by ground station located near to the GPS receiver. This station knows exactly it's location and upon that can determine correction that must be added to location determined by receiver in current time. DGPS corrections are sent by radio, on different frequency than GPS signals [12]. They are used in marine navigations so corrections are usually available in port towns. DGPS signal can be also provided by satellites, other than GPS ones. Such systems are known as SBAS (Satellite Based Augmentation System), and two most popular are:

- WAAS - available in North America
- EGNOS - in Europe and Asia

EGNOS consists of 34 measurement stations spread over Europe, and 4 stations which are calculating corrections. Corrections are then transferred to 3 geostationary satellites and broadcasted to users. Receiving signal might be problematic if satellite is not visible for receiver. Device Tormes in that case used ESA Sisnet - system that relays the signals over the Internet using wireless networks [6]. In the device described in this paper the Sisnet was not used because of no Internet connection.

A.Module selection

Quality and usefulness of whole device depends mostly on quality of satellite navigation module, because this module is responsible of fixing user's location. Accuracy of GPS module is a very controversial topic because there is no uniform method or scale of measuring this parameter. Popular factor CEP (Circular Error Probable), for example CEP 80%, tells only that 80% of results are in some error range (expressed in meters), but tells nothing about remaining 20% of results. Producers also use different definitions of error. It is difficult to systematize and consider all external phenomenons influencing system operation (visibility of satellites, their configuration, atmospheric effects, disturbances and signal reflections). Moreover CEP factor is given only for GPS chipset, not ready OEM module. It does not consider quality of antenna and applied RF components. The only quite good method of rating satellite navigation receivers seems to be comparison of many of them in the same circumstances.

In the described device there was applied OEM GPS module FGPMMOPA2. 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. Module is capable to receive and use WAAS and EGNOS signals. 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.

B. 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. Availability of signal was serious problem in other navigation solutions for visually impaired persons [15]. To improve the signal strength and avoid blocking it by human's body, GPS antennas were usually mounted on the shoulder, which was rather uncomfortable [5]. There are research for improving the quality and efficiency of GPS antennas [10]. 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.

C. Determining direction of moving

GPS receiver is capable of fixing direction in which a user in 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 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. There are also devices based on technologies other than GPS working inside buildings where satellite signal is unavailable or too weak [15].

III. 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.

A. 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 as shown in the fig 1.

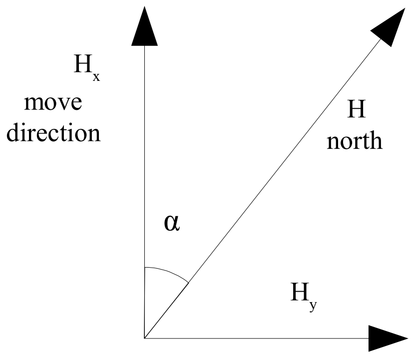

Fig.1 Determining azimuth

Now azimuth (the angle that compass is rotated from the north direction) can be calculated as:

$$\alpha = \arctan \frac{H_y}{H_x} \tag{1}$$

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. Many types of magnetoresistive sensors, with different integration level, are available. There are single sensors or pairs mounted perpendicularly in one casing with more or less auxiliary elements and circuits built in. Auxiliary elements are:

- flip coil and offset coil - for calibration
- set of field-effect transistors to control flip coil
- operational amplifiers to amplify differential signal from sensors
- analog to digital converters (ADC)
- direction determination unit

In the described device Honeywell HMC1052 sensor is used. It is a pair of sensors with flip and offset coil, but with no other circuits integrated. Use of this sensor, external transistors, amplifiers and microcontroller as direction determination unit, is most cost-effective solution. Coils are in side sensor's casing, so they could be placed very close to magnetoresistive elements. It is important, because if coil is closer, it can use smaller current to generate magnetic field with required intensity in sensor. Smaller current can be easier achieved in battery-powered device and allows device to operate longer.

B. Compass calibration

HMC1052 can measure magnetic field from -6 to 6 gauss, and has two analog differential outputs, for two channels. Signals from both outputs are amplified 100 times on operational amplifiers, and sent to the microcontroller of device. Microcontroller has 10-bit ADC, where signals are converted, so they are represented as two 10-bit integers. As mentioned before, parameters can vary in sensors of one type, and differences can be a few orders of magnitude greater than value for Earth's magnetic field. It requires calibration of compass before can be used. It is one of the functions accessible from device's service menu. Calibration is done by laying device on flat and horizontal surface and turning it around. During rotation, compass is measuring magnetic field in both axes and maximum and minimum values captured from ADC are saved. For X axis they are named X_{max} and X_{min}, and for Y axis: Y_{max} and Y_{min}. Maximum value is recorded for magnetic field acting along axis, and minimum for backward field. These two values, X_{max} and X_{min}, allows compass to calculate offset X_0 of magnetic field for X axis' sensor:

$$X_0 = \frac{X_{min} + X_{max}}{2} \tag{2}$$

These values allows also to evaluate amplitude - value of Earth's magnetic field expressed as integer on scale of analog to digital converter:

$$X_A = \frac{X_{max} - X_{min}}{2} \tag{3}$$

Similarly values Y_0 and Y_A is calculated from Y_{min} and Y_{max}.

Compass calibrated with this method is also insensible to magnetic influence of other metal parts of device - their magnetic field value in just added to the offset. It is important, because uncalibrated compass is always pointing at device's battery. Offset and amplitude for each axis are stored in non-volatile memory and loaded every time device is started.

During normal operation values H_x is evaluated from current value captured from ADC - X_{ADC}:

$$H_x = X_{ADC} - X_0 \tag{4}$$

This value can be directly passed to expression (1). Despite magnetoresistive sensors are packed two in one packing, they can have different characteristics in X and Y axis. Because of that value of magnetic field in Y axis must be also scaled:

$$H_y = (Y_{ADC} - Y_0) \frac{X_A}{Y_A} \tag{5}$$

Another part of calibration that need to be done is flipping characteristic of magnetoresistive elements. This type of sensors can operate in two different states - in each state characteristic is mirror image of characteristic in other state. Sensor can change it's characteristic under strong external magnetic field and after that it gives measures opposite to expected. Tests revealed that strong enough magnetic field can be generated by mobile phone kept close to the device. There is no certain method of determining if characteristic has changed or device was rapidly turned backwards, so characteristic is changed to known state. This part of calibration is done after every startup and periodically, every few seconds. To generate strong magnetic field and change characteristic sensor uses built-in flip coil. Although it is very close to magnetoresistive elements, it requires to be powered with 0.4-4A current. It might seem to be impossible to realize in battery-powered device, but coil need to be powered only for 2μs. Such pulse is generated by block of four transistors in H bridge. They can switch plates of capacitor between battery voltage and ground, to charge it and discharge quickly through flip coil. Gates of transistors are controlled by microcontroller and energy for pulses is accumulated in another 1μF capacitor. This capacitor is loaded through resistor and therefore pulses do not cause battery voltage breakdown.

C. Third dimension of magnetic field

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.

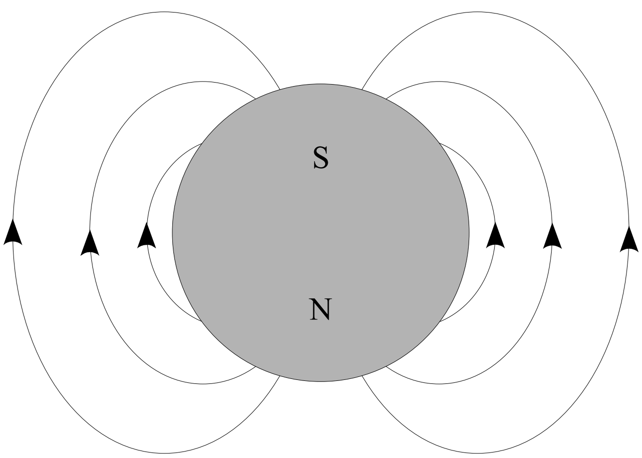

Fig.2 The Earth's magnetic field [3]

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 δ. Real magnetic field vector is shown in Figure 3.

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

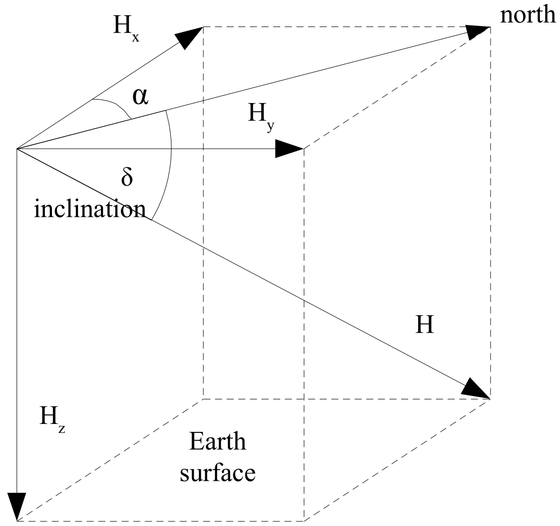

Fig.3 Earth's magnetic field vector in three dimensions.

To realize error, a simplification is used - it is assumed that X axis of compass is parallel to W-E direction and Y is pointing north. In such situation error ε is [8]:

$$\epsilon = \arctan(\tan\delta \sin\phi) \tag{6}$$

Where φ is angle by which compass is rotated along axis X. It means, as expected, that if compass is parallel to Earth's surface, error will be equal 0. Figure 4 shows error value depending on rotation and location on Earth (inclination).

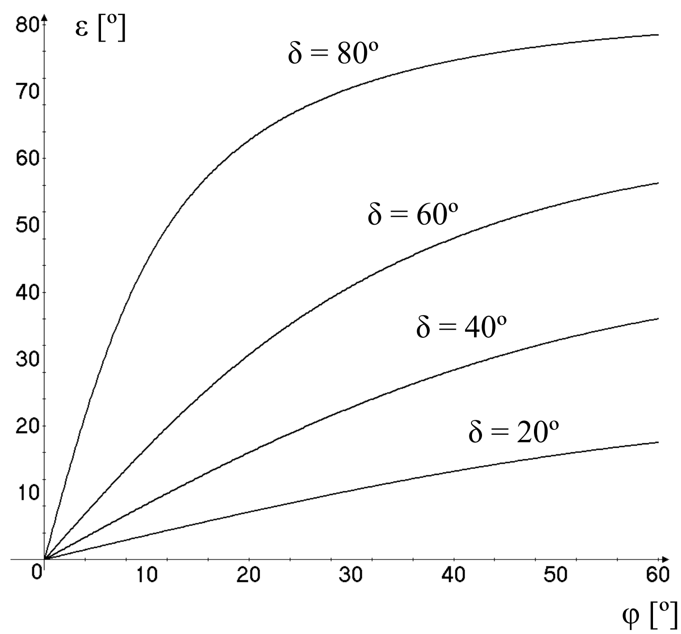

Fig.4 Error of determined azimuth, caused by compass rotation [8]

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.

D. Making compass operate independently of its position

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

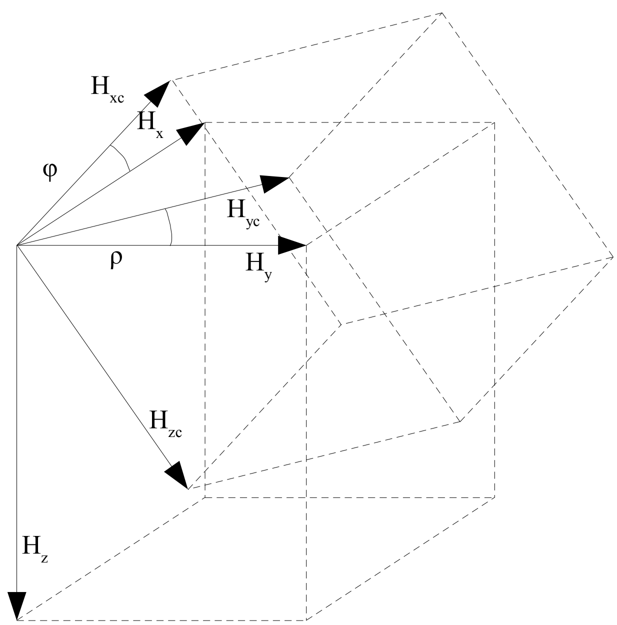

Fig.5 Components of Earth's magnetic field vector in different coordinate systems.

With trigonometric transformations it is possible to determine components H_x, H_y and H_z of vector H in the coordinate system known before, parallel to the Earth surface [2]:

$$\begin{bmatrix} H_x \\ H_y \\ H_z \end{bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi\sin\rho & \sin\phi\cos\rho \\ 0 & \cos\rho & -\sin\rho \\ -\sin\phi & \cos\phi\sin\rho & \cos\phi\cos\rho \end{bmatrix} \begin{bmatrix} H_{xc} \\ H_{yc} \\ H_{zc} \end{bmatrix} \quad (7)$$

It can be split into three equations:

$$H_x = H_{xc}\cos\phi + H_{yc}\sin\phi\sin\rho + H_{zc}\sin\phi\cos\rho \quad (8)$$

$$H_y = H_{yc}\cos\rho - H_{zc}\sin\rho \quad (9)$$

$$H_z = -H_{xc}\sin\phi + H_{yc}\cos\phi\sin\rho + H_{zc}\cos\phi\cos\rho \quad (10)$$

After using in equation (1):

$$\alpha = \arctan\frac{H_{yc}\cos\rho - H_{zc}\sin\rho}{H_{xc}\cos\phi + H_{yc}\sin\phi\sin\rho + H_{zc}\sin\phi\cos\rho} \quad (11)$$

The only one condition is to know angles φ and ρ. 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 - it would require rotation of device in two surfaces. Value H_{zc} can be also evaluated from equation (10):

$$H_{zc} = \frac{H_z + H_{xc}\sin\phi - H_{yc}\cos\phi\sin\rho}{\cos\phi\cos\rho} \quad (12)$$

In the Figure 3 it also can be noticed that

$$H_z = H\sin\delta \quad (13)$$

where δ 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 δ) for various geographical coordinates.

If inclination is known, magnetometers provide values of H_{xc}, H_{yc}, and angles φ and ρ are known, azimuth can be evaluated from equations (13), (12) and (11).

E. Determining compass position

To determine angles φ and ρ, 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.

ADXL202E uses mass that can move in one axis, but is suspended elastically in center position. It is also one of the capacitor's plates. Other plate is immovable. If mass is moved by acceleration, distance between plates and capacity changes. Capacity, as electric dimension, can be converted to other electric dimension. Advantage of this method is small power consumption, disadvantage - oscillation of mass at rapid acceleration changes.

MXD7202 sensor uses convection phenomena. Sensor is a cube, with heater on the bottom. Heated air rises (precisely: moves in direction backward to acceleration) in the cube. It's side faces are four temperature sensors and each of them is more or less heated by air, depending how is it tilted. Temperature is converted into electrical signal and one cube measures acceleration in two axes at once. Disadvantage of sensor is power consumed by heater, but it was finally chosen to be applied in device because of no oscillations.

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. There it is represented by integer value, which has to be further processed.

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 φ and sin ρ). There is no need to calculate the angle itself, as it has large computational complexity.

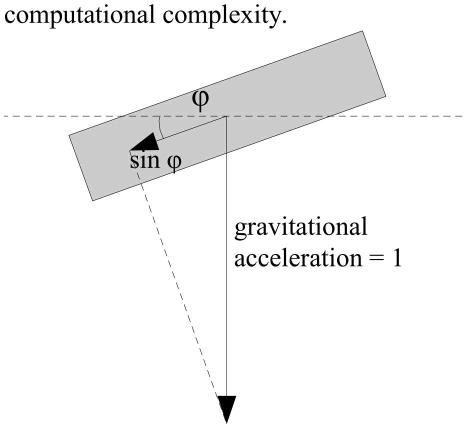

Fig.6 Tilted accelerometer

Cosine can be calculated from sine by using

$$\sin^2\phi + \cos^2\phi = 1 \tag{14}$$

To scale value from accelerometer to range <-1 ; 1>, sensor needs calibration. It is done by turning device vertically. In that position gravitational acceleration vector is parallel to X axis' sensor and digital value from this sensor matches 1g acceleration. This value is saved as X_{gmax}. In next step device is turned upside down and sensor is registering value that match -1g as X_{gmin}. These two values, X_{gmin} and X_{gmax} allows compass to calculate offset X_{0g} - value when no acceleration is acting on X axis' sensor (it is perpendicular to surface of Earth):

$$X_{0g} = \frac{X_{gmin} + X_{gmax}}{2} \tag{15}$$

Amplitude - relative value of gravitational acceleration (1g) as integer on scale of sensor - is also evaluated:

$$X_{1g} = \frac{X_{gmax} - X_{gmin}}{2} \tag{16}$$

Similarly values Y_{0g} and Y_{1g} are calculated from Y_{gmin} and Y_{gmax}. They are captured when device is laying on left and right side - with Y axis accelerometer along gravitational acceleration vector. To be sure that values X_{gmin}, Y_{gmin} are minimum and X_{gmax}, Y_{gmax} are maximum, during calibration device is displaying current and maximum/minimum registered value. It allows user who do calibration, to keep device in correct position. Disadvantage of this method is that all movements need to be done slowly. Only then movement accelerations will not affect calibrated parameters.

Evaluated values are stored in non-volatile Flash memory, similarly to parameters of magnetic field sensors. Acceleration sensors need to be calibrated only once, their characteristics do not change in time, for example, affected by temperature.

During normal operation sin φ is obtained from equation:

$$\sin\phi = \frac{X_{TC} - X_{0g}}{X_{1g}} \tag{17}$$

Where X_{TC} is current integer value from X-axis accelerometer.

Function arctan(x) must be implemented in microcontroller, to implement formulas (11), (12) and (14). Because of small computation capability of microcontrollers and small accuracy of magnetometers, the best solution is to calculate values of arctan before compilation and store them in program memory. Resolution 1° of pre-calculated values seems to be adequate.

Accuracy of azimuth obtained with the method described depends mostly on accuracy of magnetic field sensors and magnetic disturbance. Use of accelerometers and described above algorithm did not make results worse. The only problem appears when the device is in motion. A walking man is moving very irregularly and is causing many acceleration forces. They are detected by accelerometers and generate errors. If azimuth is displayed as an arrow pointing north, error is visible as flickering arrow at every step. This problem can be omitted, because natural reaction of user is to stop while looking at the display but it can be also solved by storing values obtained from accelerometers from few previous seconds. To calculate azimuth there are used averages of stored values. This solution seems to be adequate.

IV. Walking assistant for visually impaired persons

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 visually impaired 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 the white 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.

Destination of the 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].

The device is intended 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 in which a user is moving more precisely than navigation satellite system. It can also fix 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 [5]. Maps - if not updated frequently by publisher - may also become obsolete and user cannot update them by himself. 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.

A. Functionalities

The primary functionality of the device 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 make 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, visually impaired 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.

B.Hardware selection

Many GPS solutions for visually impaired people uses PDAs and smartphones as hardware. Their greatest advantage is ease of creating software - programmer can use operational system, with all it's libraries and API. Hardware is accessible by special functions, on higher abstraction level. Also many devices are connected to the Internet. Disadvantage is that these are universal devices, not designed only for navigation and not designed for blind people. Devices do not contain magnetic compass, some of them require external bluetooth GPS receiver [5]. Blind people must install Braille keyboards and screen reader software. Also installation of software is reported as difficult for users [7]. Device described in this paper has hardware and software designed for easiest and most accurate navigation of blind people.

C. 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.

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.

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 usage by visually impaired persons so all information is also displayed on the screen.

D. 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.

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.

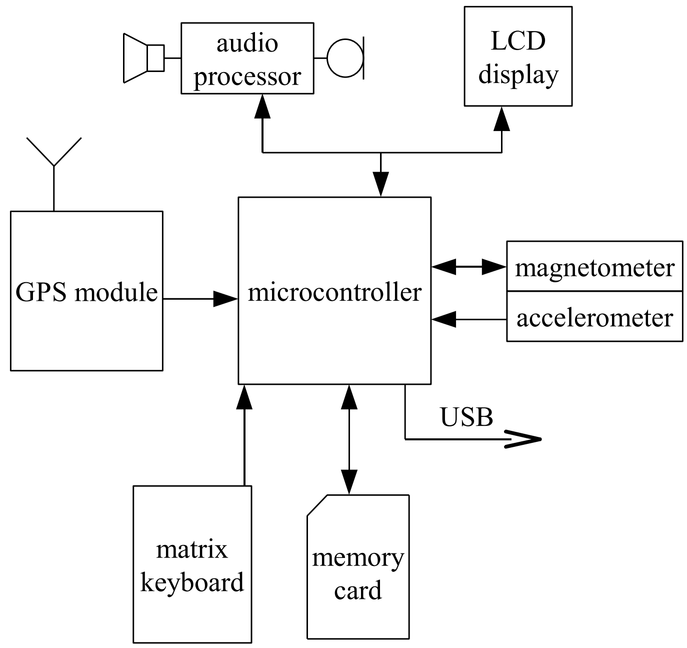

Fig.7 Device architecture

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-ADCPI 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.

E. 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.

Device uses USB Framework provided by Atmel for it's microcontroller. This software uses built-in USB controller and supports most popular device classes, including Mass Storage Device Class. User application must only provide and register callback functions which reads and writes blocks of data. Block size can be defined and in device it is set to 512 bytes. Callback functions writes and reads blocks directly to SD/MMC card. It simplifies software and puts all responsibility of operating filesystem to the PC computer. It allows computer to access filesystem in advanced way, for example format or repair. In other hand, filesystem cannot be used by computer and device simultaneously, because of possible collisions. That is why when USB is in use, all device's functionalities are disabled. Also USB transmission consumes a lot of microcontroller's resources - mainly RAM memory, and it cannot realize navigation in the same time. Device enters USB mode when connected cable is detected. After this processor is reseted, USB sign is displayed on LCD, clock speed is turned to 48MHz and USB Framework is entered.

USB port is also used to charge battery - directly from computer or universal charger.

F.Software

Device's firmware is written in C, because this language provides easy access to hardware layer and programs written in it are fast. Writing software like this in low level language was impossible because of it's complexity. As compiler was used GNU C compiler (gcc) for ARM processors.

1)Software modules

Software is splitted into modules, each module responsible of servicing peripherals or providing functionalities. Modules are:

- configuration of microcontroller: it's clock, IO ports, interfaces, timers/counters, stack initialization,
- compass callibration and direction determination,
- memory card reading, writing and use of filesystem,
- service and initialization of audio processor,
- displaying text and graphics on LCD,
- doing navigational calculation,
- USB communication,
- graphic user interface,
- voice user's interface,
- reading and writing non-volatile memory (preserving configuration and updating firmware),
- battery level control, powering on and off device.

To use filesystem, device use external library - Embedded Filesystem Library (efsl). This library supports FAT16 and FAT32 filesystems for reading and writing.

2)Optimization

Microcontroller used in device contains only 32 KB of RAM memory. Major part of it is used by various buffers - filesystem cache, audio stream buffers, display memory and USB queue, however device contains flash memory card. Because of that data (cities, points, routes, system messages) are stored on card in structures, that allows software to load as little as possible into memory at once. It also easies using other languages, to communicate with user - all voice records, texts and LCD bitmaps are stored as files on card.

The device is powered by lithium-polymer battery with capacity of 1500mAh. The power consumption has been optimized for long operation. The battery 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.

V. Summary

During tests in urban environment the accuracy of fixed position was mainly between 3 and 10 meters. Unfortunately in Poland, where tests took place, GPS module was unable to receive EGNOS correction. ESA satellites that transmit correction signal, are geostationary, so they are placed over equator. At areas with greater longitudes, such as Poland, satellites are visible too low over horizon and communication with satellite navigation is impossible.

Accuracy of GPS module 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.

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