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Proposal of Pedestrian-Oriented Wearable GPS with the New Scalable Capability of Instantaneous Azimuth Limitation

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Abstract – A pedestrian would find it difficult to steadily acquire his bearings just using a Global Positioning System (GPS). This paper proposes a novel practical method for acquiring azimuth instantaneously with a new wearable GPS user segment that works even when the user is stationary. This is suitable for timely decision making out-of-doors. Possible systems are also proposed using this method. The device using this method can work both by itself and in combination; when multiple devices are connected, the azimuth limitation capability is improved. Improvements due to scalability are quantitatively confirmed with computer simulation.

Keywords : Global Positioning System, Azimuth, Elevation, Orientation, Guiding

1. Introduction

Generally speaking, low usability is responsible for the discrepancy between the contexts of use conceived of by the user and the designer [1]. In other words, human-centric design is not carried out. From this viewpoint, the low usability is discussed regarding current portable GPS units for pedestrians. The fundamental framework of the GPS user segment was initially designed for maritime and airborne vehicles. It would inevitably score low usability if it were simply used for pedestrians

To improve the low usability, we propose new requirements that reflect the context of use of a GPS unit for pedestrians as follows; (1) the same device should be able to provide azimuth information and location, rather than requiring multiple equipment (2) azimuth information should be given even in the user's stationary or rotating status, rather than only in walking status (3) azimuth information should be provided in the form of a sector of about 30 degrees with certainty, rather than a single value with limitless uncertainty (4) this azimuth acquisition functionality should have scalability. These design concepts are based one of the author's experience of mountaineering. (5) it should be wearable and hands free use. Based on the above considerations, we propose a new portable GPS unit, with instantaneous azimuth limitation ability and scalability.

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2. Conventional Approaches

Historically, GPS was designed as a maritime or airborne vehicle navigation system at the initial phase [2]. Therefore it is quite natural that the required accuracy is at a level suitable for marine or air vehicles. Such vehicles have room to install other equipment to compensate for deficits of GPS azimuth information.

However, GPS is now being used by pedestrians. As its conventional user segment for vehicles is simply appropriated for pedestrians who want azimuth information, this has led to usability problems. Unlike the maritime or airborne vehicles, pedestrians have the following special characteristics.

(1) Pedestrians are small, less than one-tenth of the location accuracy (2) They carry out frequent rotations around the vertical body axis (3) They cannot afford to have heavy or large equipment and find it difficult to give heed to repetitive calibrations (4) They sometimes walk in areas full of artificial and geological magnetism.

Due to (1), "GPS differentiation by setting two GPS units at a sufficient distance" is denied. This method was suitable for ships or airplanes.

Due to (2), "GPS location differentiation by trial walking" is denied. This method is very effective for vehicles that do not rotate around their vertical axes. However, a pedestrian may turn around the axis of the body, which invalidates azimuth by this method.

Due to (3), "rate gyro" [3] and "GPS carrier wave detection" are denied. Rate gyro requires frequent calibration. "GPS carrier wave detection" is extremely expensive.

Due to (4), "geomagnetism compass" is denied [3]. A pedestrian's environment is not free from artificial or geological magnetisms, which are practically unpredictable, being entirely different from the situation on the ocean or in the air. A geomagnetic compass may easily become unreliable in such an environment and should not be used when a critical decision must be made.

We have to make an invention of a device which keeps its usability even in the environment for pedestrians.

3. Human-Centric Design Process

ISO 13407 "Human-centered design processes for interactive systems" [4] defines the steps as follows: (1) understand and specify the context of use. (2) specify the user and organizational requirements. (3) produce designs and prototypes. (4) carry out user-based assessment.

First, we attempted to understand and specify the context of use. It includes a pedestrian's or party's acquiring reliable information on both the position and orientation quickly even when motionless in order to support timely decision making in critical situations such as on a mountain in bad weather conditions.

In the context of use, the most important requirements are considered to be as follows; (1) Azimuth and location information are simultaneously provided by the same low-cost device. (2) The acquisition requires no task such as user's walking, which may raise some risks including falling off a mountain ridge in bad weather conditions. (3) The azimuth information has to be suitable for timely decision making. The azimuth information should be presented not in a single value but in sector form. (4) The acquisition should be carried out both by a single device alone and by multiple devices connected, for individual and group (party) uses respectively. (5) The device should be wearable for hands-free use in bad weather conditions. In addition, it should be light-weight and low profile.

Based on these requirements, the new design was produced. In the process, many inventions were made and registered for patents in the United States, Great Britain, Australia, Germany, and France as well as in Japan.

After that, we carried out semi user-based assessment on the performance of the proposed design by simulations.

4. GPS: Global Positioning System

GPS (Global Positioning System) consists of space, management and user segments. [2]. The space segment of GPS includes the GPS satellites that fly in circular orbits at an altitude of 20,200 km and with a period of 12 hours. The orbits are tilted to the Earth's equator by 55 degrees to ensure coverage of the Polar Regions. Each of the 24 satellites, positioned in 6 orbital planes, circles the Earth twice a day. These orbital planes are illustrated in Figure 1. As of September 2007, there are 31 actively broadcasting satellites in the GPS constellation. Additional satellites improve the precision of the GPS receiver calculations by providing redundant measurements.

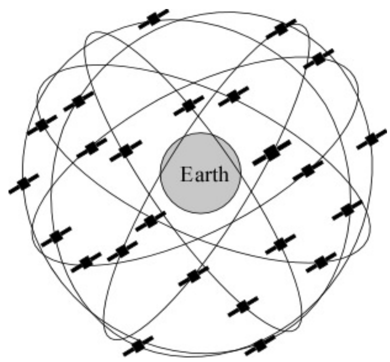

Fig. 1 GPS satellites orbits

The exterior of a GPS satellite has a variety of antennas. The signals generated by the radio transmitter are sent to GPS receivers via L-band antennas. Another component is the radio transmitter, which generates the signal. Each of the 24 satellites transmits its own unique code in the signal.

The Control Segment of GPS consists of the Master Control Station, Six Monitor Stations. The master control station is responsible for overall management of the remote monitoring and transmission sites. Each of the monitor stations checks the exact altitude, position, speed, and overall health of the orbiting satellites. The control segment uses the measurements collected by the monitor stations to predict the behavior of each satellite's orbit and clock. Noted variations, such as those caused by the gravity of the Moon, Sun and the pressure of solar radiation, are passed along to the master control station.

At the position calculation phase, 4 times and locations (x_1, y_1, z_1), (x_2, y_2, z_2), (x_3, y_3, z_3), (x_4, y_4, z_4) at 4 navigational messages from 4 satellites and light speed c are used known values, to build as 4 elements simultaneous equations. 4 unknown values are the current position and time of the user $(x, y, z), t$. Solving the 4 elements simultaneous equations, the current position of the user and the time can be specified.

$$(t - t_1)c = \sqrt{(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2}$$
$$(t - t_2)c = \sqrt{(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2}$$
$$(t - t_3)c = \sqrt{(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2}$$
$$(t - t_4)c = \sqrt{(x - x_4)^2 + (y - y_4)^2 + (z - z_4)^2}$$

Besides the current position and the time, all satellite azimuths are acquired. This is because the almanac data can be extracted from any one navigational message. Thus, at the same time as the position calculation, all the satellite azimuths are to be known. This is exploited by the proposed GPS unit for pedestrians in this paper.

5. New Proposed GPS Unit to Provide Both Azimuth and Location

The principle of the azimuth limitation of the present invention is explained with reference to Figure 2. Near the middle of Figure 2 are disposed a first planar patch antenna 1a and a second planar patch antenna 1b. The first planar patch antenna 1a and second planar patch antenna 1b are disposed back-to-back and parallel with each other. Both antennas are perpendicular to the ground. The direction in which an observer faces when standing on the ground and looking down on the antennas arranged with the first planar patch antenna 1a on the left and the second planar patch antenna 1b on the right is defined as measurement direction 5.

The first and second patch antennas 1a, 1b are provided with hemispherical beam patterns with respect to the Right Hand Circularly Polarized (RHCP) L-band signal known as L1 at 1575.42 MHz used by the standard positioning service of the GPS satellite system.

When two such planar patch antennas are disposed back-to-back in parallel with both standing perpendicular to the ground, the coverage area to which the antenna sensitivity of each (i.e., the first planar patch antenna 1a or the second planar patch antenna 1b) extends coincides with half of the sky divided in two by a great circle 7, as shown in Figure 2. This great circle 7 forms the boundary between the coverage area 6a of the first planar patch antenna 1a and the coverage area 6b of the second planar patch antenna 1b. In other words, the coverage area 6a of the first planar patch antenna 1a is the sky quarter-sphere in which the GPS satellite A is present and the coverage area 6b of the second planar patch antenna 1b is the sky quarter-sphere in which the GPS satellite B is present.

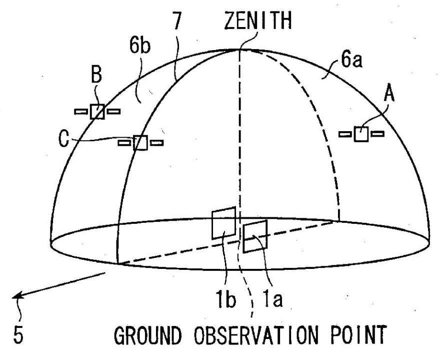

Fig. 2 Configuration of the antennas and the sky hemisphere

The signal of standard positioning services transmitted by a GPS satellite has a microwave band frequency of 1575.42 MHz and, therefore, exhibits excellent linear propagation property like light. When observed by the first planar patch antenna 1a, a distinct difference arises between the receiving status for the signal from the GPS satellite A in the coverage area 6a and the receiving status for the signal from the GPS satellite B not in the coverage area 6a.

As shown in Figure 3, the first planar patch antenna 1a is connected to the first GPS receiver 2a and the second planar patch antenna 1b is connected to the second GPS receiver 2b.

Considering Figure 2 and Figure 3 together, the signal from the GPS satellite C in Figure 2 can be received by the first GPS receiver 2a and the second GPS receiver 2b in Figure 3.

In the present invention, when signals are received simultaneously by both GPS receivers in this manner, it becomes possible to discriminate the direction of the GPS satellite C as the measurement direction 5 or as the direction opposite the measurement direction, and, by using the satellite azimuth of GPS satellite C and the aforesaid satellite azimuth information of the GPS satellite A or the GPS satellite B and the result of the area discrimination, to determine the azimuth of the measurement direction 5.

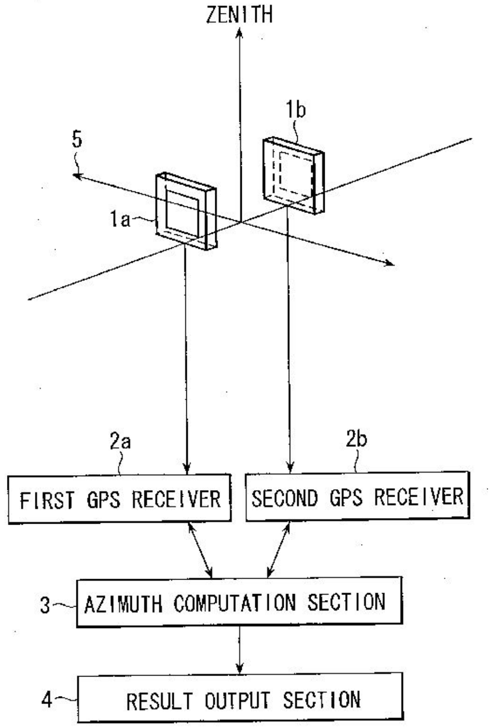

Fig. 3 Block diagram of the azimuth acquisition device

The easiest way to create hemispherical beam pattern planar patch antenna is to block the extra sensitivity of a planar patch antenna having a wider beam pattern than the hemisphere using shield material. In the actual fabrication of a planar patch antenna, the completed antenna may have a solid angle slightly broader than the hemisphere of the width theoretically calculated at the time of design. This occurs because the result of the design assuming an infinite ground plate in the theoretical calculation differs from the actual situation [5]. A typical GPS antenna beam pattern of the plane patch antenna is illustrated for example in [6]. Using electro-magnetic wave absorption and shield sheet in the back of the antenna, the hemispherical antenna pattern is easily created [7]. The technique for correcting such beam shape deviation by slightly modifying the substrate size, patch size or the like to obtain the desired antenna pattern is known as antenna pattern shaping [5].

In this invention, however, even when a beam of solid angle shape comes out somewhat broader than desired, the antenna can still be used as it is. In this case, the great circle in Figure 2 is not a line but is a band of small width (small visual angle as seen by an observer). The slight spread imparts a small width to the measurement direction 5 and the direction opposite the measurement direction and increases the probability of catching a satellite with these directions by chance, which enables azimuth determination immediately fortuitously even when intending azimuth limitation.

The first GPS receiver 2a and second GPS receiver 2b shown in Figure 3 can have the same functional features and specifications as the GPS receivers included in widely-used compact mobile positioning devices employing L1 signals. This makes it possible to take advantage of technologies developed for the production of small, lightweight civilian GPS positioning devices, most notably size reduction and ease of volume production. Thanks to the size and weight reduction achieved in civilian GPS positioning devices, GPS receivers are abundantly available in sizes commensurate with planar patch antennas. They are also easy to manufacture. Moreover, these GPS receivers have planar patch antennas formed integrally with the receiver case, and inexpensive palm-sized models are already available.

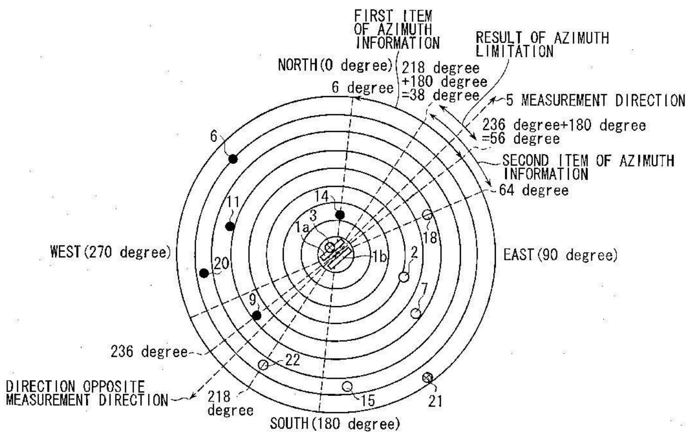

Fig. 4 Satellites and the antennas in azimuth limitation

The first GPS receiver 2a attempts to synchronize with and decode satellite signals through the first planar patch antenna 1a and to determine the position. Similarly, the second GPS receiver 2b attempts to synchronize with and decode satellite signals through the second planar patch antenna 1b and to determine the position. In other words, the first GPS receiver 2a and the second GPS receiver 2b conduct a search for the signals from all GPS satellites expected to be present in the sky, just as does the GPS receiver of an ordinary mobile satellite positioning device, in exactly the same way as if connected with antennas whose coverage areas are the sky hemisphere.

The only difference at this point, between the GPS receivers in an embodiment of the device for acquiring azimuth information according to this invention and the GPS receiver of an ordinary mobile satellite positioning device, is the fact that the GPS receiver 1a cannot synchronize with the signals from GPS satellites not being in the coverage area in the sky 6a and the GPS receiver 1b cannot synchronize with the signals from GPS satellites not being in the coverage area in the sky 6b while the GPS receiver of an ordinary mobile satellite positioning device placed horizontally can synchronize with the signals from all GPS satellite in the sky.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Satellite ID	Satellite azimuth (deg)	Satellite elevation (deg)	Channel Status in first GPS receiver	Channel Status in second GPS receiver	Exclusion decision	Region discrimina tion
14	6	68	Sync.	-	-	1
18	64	32	-	Sync.	-	2
2	110	49	-	Sync.	-	2
7	128	31	-	Sync.	-	2
15	177	15	-	Sync.	-	2
22	218	13	-	Sync.	-	2
9	236	32	Sync.	-	-	1
20	262	12	Sync.	-	-	1
11	285	28	Sync.	-	-	1
6	313	9	Sync.	-	-	1
3	340	86	Sync.	-	High elevation angle exclusion	
21	144	4	-	-	Ground feature blocking exclusion	

Fig. 5 An example of the data table in azimuth limitation

The signal transmitted from every GPS satellite contains information on the orbits of all GPS satellites (almanac data). Every satellite transmits this data. Therefore, in the case of a satellite present in the sky at an angle of elevation of greater than 0 degrees viewed from the current location but whose signal is blocked by a building or the topography, or of a satellite not in the antenna coverage area whose signal is not synchronized with, i.e., in the case of a GPS satellite in a state preventing reception of its radio wave, the angle of elevation and azimuth of the satellite concerned can be computed and output by a simple calculation from data received from another GPS satellite. Equipment that outputs such information already exists.

Although all GPS satellites transmit signals at exactly the same frequency, owing to the utilization of a technology called the spread spectrum communication system made possible by Pseudo Random Noise coding, signal interference does not occur even when using the same frequency. Each GPS satellite is assigned a unique Pseudo Random Noise code, which is a different digital signal sequence wherein 0 and 1 appear to alternate irregularly. This enables the signals from the satellites to be distinguished and separately received. In other words, the principle of Pseudo Random Noise coding makes it easy to discriminate the signal from each GPS satellite present at an angle of elevation of greater than 0 degrees as viewed from the current location.

Figure 4 is an example of satellite constellation where the azimuth limitation function is available. Figure 5 is an example of the data table that the azimuth limitation module creates from the received signals. Figure 6 is an example of the azimuth extraction from Figure 5.

Region discrimination	Finite sequences	Satellite azimuth (deg)	Case ID/ State ID	Available function in this case	Result
1	S1	6	6/A	Azimuth limitation	38<z<56 clockwise
2		64			
2		110			
2	S2	128			
2		177			
2		218			
1		236			
1		262			
1	S1	285			
1		313			

Fig. 6 An example of the azimuth extraction from the data table in azimuth limitation

The configuration of the 2 planer patch antenna has already been discussed. However, a single antenna type device is also configurable. Takahashi [8] discuss it in detail. The configuration illustrated in Figure 7 illustrates the concept. In this case, one antenna is both location device and azimuth device; in the latter case, the single unit serves as if there were two units.

6. Usability Discussion

In the previous section, a new GPS user segment that provides both location and azimuth is proposed

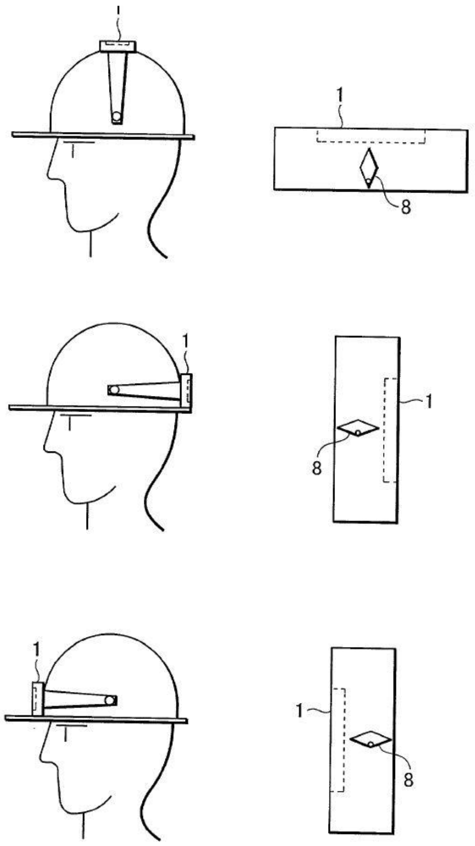

Fig. 7 Proposed GPS unit deployment on a helmet or cap (Single antenna unit type)

in a cost-effective fashion. When placed horizontal as usual, it works as a standard GPS user segment. When placed vertical, it works as a completely new GPS user segment with azimuth limitation ability. In this section, usability is discussed in more detail.

6.1 Basic and Simple Functions: Azimuth and Location Only

As seen so far, this proposed device has double functionality both of location and azimuth. None of the conventional low-cost devices are able to achieve this feature alone. (The carrier wave detection method of GPS can achieve this, but it is extremely expensive and is a combination of GPS units itself.)

6.2 Quickness to Find Azimuth with No Task

This proposed device can immediately provide azimuth information on its power-on. The user is not required to walk or to suppress turning around the body axis. This proposed method is superior to the conventional GPS location differentiation method in this point.

Figure 8 and 9 show that the expected value of azimuth limitation depends on the time, i.e. the satellite constellation. This proposed system takes full advantage of the plurality of GPS satellites. The transformation of latent capability in the existing infrastructure to a new form close to the new user context is a usability improvement.

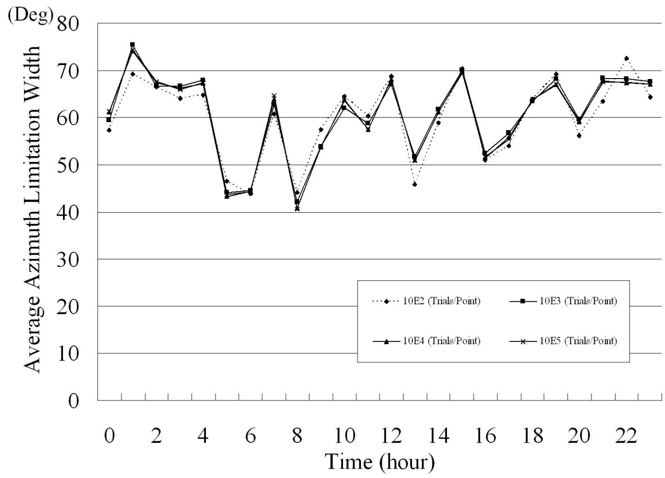

Fig. 8 Azimuth limitation width dependency on GPS constellation (Single unit)

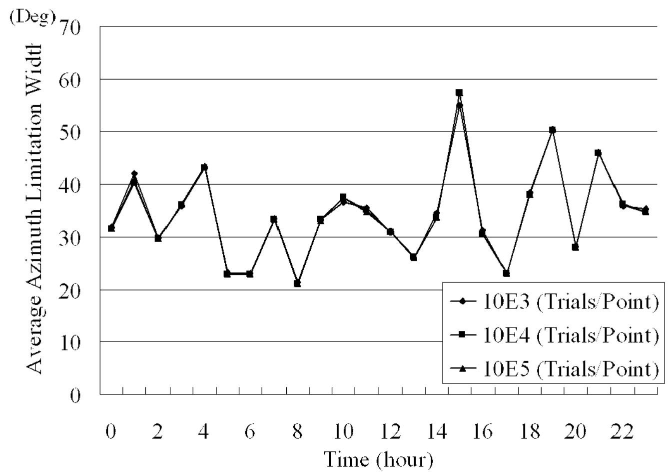

Fig. 9 Azimuth limitation width dependency on GPS constellation (Double units parallel deployment)

6.3 Azimuth Provision in Sector Form Suitable for Critical Decisions

The conventional low-cost azimuth presentation method is subject to erroneous features; a geomagnetism compass is subject to other magnetisms, rate-gyro is subject to errors accompanied with rate detection accumulation. The range is indicated by two azimuths. These azimuths are quite certain as endorsed by a high self-correlation feature at synchronization and matching between original and replica 1024 C/A chip code. The true azimuth value is always between the two in a clockwise manner. This capability is specific to the proposed device.

6.4 Azimuth Acquisition by Units with Scalability

The explanation is based on the configuration of back-to-back 2 GPS units and a single GPS unit described so far. However, any number of GPS units work when placed at the sides of a polygon. Figure 10 shows examples of how such GPS units can be placed on the sides of regular polygons; triangles, squares, pentagons, hexagons, heptagons and octagons. For multiple units to function together, it is sufficient that an angle detector of the adjacent unit is provided.

Figure 11 shows the simulation results of the expected azimuth limitation width. The date and time is selected at 24 timings, 1 hour interval, from 0:00 to 23:00 of February 20th, 2000. 10,000 trials at 24 discrete timings were carried out. In total, 240,000 data were obtained to draw a point on the graph. The location selected was Hibiya Park, Chiyoda-ward, Tokyo.

Using a normal GPS unit, a user cannot detect any azimuth information without walking, which is associated with high cost and risk. However, according to the graph, if a user has even one GPS unit, he/she can immediately acquire azimuth information about 60 degrees. If a mountaineering party has two GPS units, they can immediately acquire azimuth information about 30 degrees. With more of the proposed GPS units, a narrower (better) azimuth limitation width is acquired.

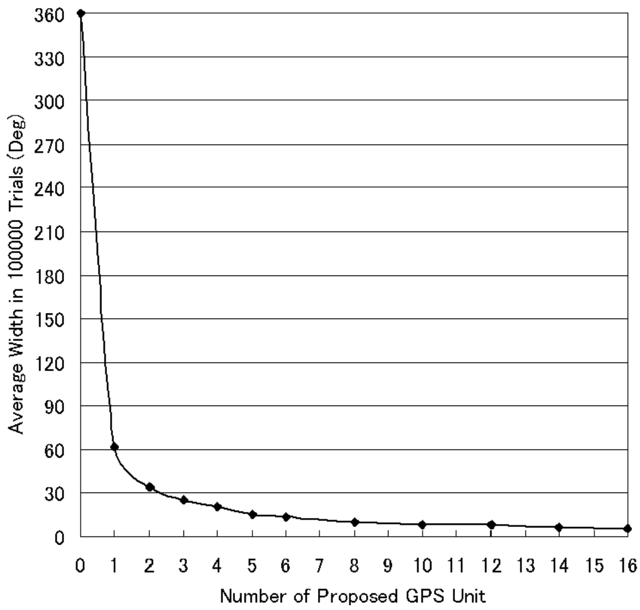

Fig. 11 GPS scalability: azimuth limitation width and number of proposed GPS units

For practical purposes, two or three units might be sufficient to acquire meaningful results outdoors. Interestingly, even with only one proposed GPS unit, it can be used as if it were two, as shown in Figure 7. It is important for portable devices for use in outdoor activities to be light weight and small volume; scalability is also preferable and contributes to high usability.

A computer simulation was conducted to determine what level of azimuth limitation values can be acquired in the case of on-the-spot azimuth limitation using the device for acquiring azimuth information in an embodiment of the method for acquiring azimuth information of the present invention. The results are as follows.

The computer simulation was conducted using real-time GPS satellite orbital parameters of actually operating GPS satellites on February 17, 2000 in the sky over the center (latitude N35 40' 14.9", longitude E139 45' 33.4") of Hibiya Park in Tokyo (located in a middle latitude area in the northern hemisphere). Evaluation was conducted with respect to fixed time points between midnight (0) and 23 (0, 1, 2, ... 22, 23) o'clock, i.e. with respect to 24 separate fixed time points spaced at regular time intervals. The

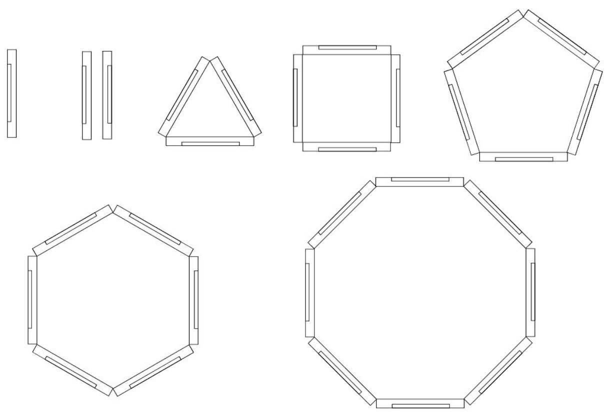

Fig. 10 Alignment Example of Multiple use by proposed GPS unit(s)

evaluation was conducted at different time points in order to accurately reflect the fact that the number of available satellites and the satellite constellation in the sky hemisphere vary depending on the time of day.

In order to obtain realistic results, the angle of elevation region of 5 degrees and lower, which is affected by ground feature signal blocking, was defined as being unavailable, and control was effected to exclude high elevation satellites (85 degrees and higher satellites) from azimuth computation due to the possibility of such high elevation satellites contaminating the azimuth limitation result by the possible existence of the unit's slant in real use of context. Figure 11 can be interpreted as the expected azimuth limitation width at one of the least obstacle environments of sufficient reality.

The spread spectrum communication method is resistant to affects of multipath or fading effects by nature, compared to other communication methods such as time division multiple access for the following two reasons; (1) When a long delay multipath is considered where the delay time is longer than the chip width (about 300 meters or 1 micro second at C/A code), the self-correlation function of Gold code invalidates its effect [9]. (2) When a short delay multipath is considered where the delay time is shorter than the chip width, the multipath effect on the azimuth is so small (about 10^{-3}) that it is negligible. Assuming the multipath whose amplitude is weakened by 12 dB compared to the direct wave, the length measurement error would be about 35 meters [10] or 4 meters [11] when a correlator width of 1.0 or 0.1 is taken advantage of respectively. The effects on the azimuth limitation affected by these length measurement errors are to be found 2.0×10^{-3} or 1.6×10^{-3} degrees at most respectively, and are negligible [12].

The arbitrary (random) setting of the measurement direction 5 in actual use was emulated by making random numbers (0-359) to select the measurement direction 5 on every trial in the whole simulation.

One-hundred-thousand random trials were conducted at each time point to enhance the evaluation results and enable consistent assessment.

As 100,000 random simulations were conducted at each of the 24 time points, the total number of trials was 2,400,000.

A maximum of 12 directions at intervals of 30 degrees are commonly used in human daily activities: north, north-northeast, east-northeast, east, east-southeast, south-southeast, south, south-southwest, west-southwest, west, west-northwest and north-northwest. The method of this invention enables azimuth limitation of this level even by random measurement with no rotation. This demonstrates that the invention provides a simple azimuth information acquisition method with great practical utility.

The number of available GPS satellites in the sky hemisphere viewed from a middle latitude area is usually as many as 9 to 12. This largeness of the number of available satellites in the sky hemisphere is believed to be the main factor for the high efficiency of the device for acquiring azimuth information, which is an embodiment of the method for acquiring azimuth information of the present invention. In the proposed framework, the greater the number of synchronized satellite signals, the narrower the azimuth limitation width. It, however, is notable that, even when only 6 to 8 satellite signals can be received on a forested mountain, the azimuth limitation ability still remains. If a simple situation is considered where signals from only 6 satellites evenly scattered in the sky hemisphere are available, the expected azimuth limitation width is to be 60 degrees or the like. This kind of simple thought experiment makes clear the potential validity of the proposed method in the variety of different situations that pedestrians encounter outdoors.

6.5 Fitness to Wear with Minimized Load

The exemplified configuration, i.e., the headband configuration, can be embodied in various similar configurations, such as headphone-like (illustrated in Figure 12) and hat-like configurations, having the following advantages: (1) The measurement direction 5 of the device always coincides with the direction in which the user faces, which is very convenient because it provides the user with a direct operation to point the measurement direction to the orientation in which the user is interested and an intuitive understanding of how to utilize the numerical values representing the result of the acquired azimuth information. (2) Wearing the device for acquiring azimuth information on the head maximizes the vertical projection distance between it and the ground and, as such, minimizes the effect of signal blockage by ground and topographical features. (3) The user is likely to feel at ease about the appearance of the device when worn because wearing of headbands, other ornaments, headphones, earmuffs and other functional devices on the head is commonplace.

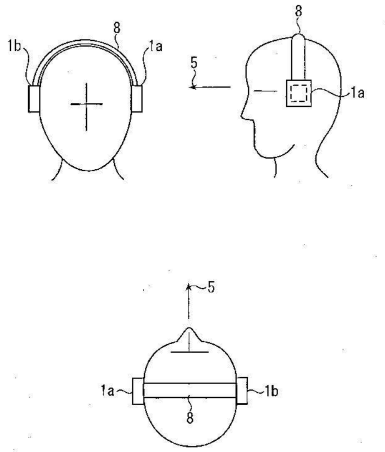

Fig. 12 An example of the wearable application on the head (Double unit type)

(4) The user is likely to feel at ease about how he or she looks when turning in order to carry out azimuth determination because the action can be performed naturally in the manner of looking at something in the distance without any specific behavior that would appear strange to other people in daily life situations . This is an important point for vision-impaired persons in using this device.

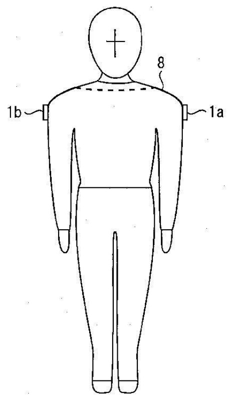

Fig. 13 Example of the wearable application on the body (Double unit type)

It is also possible to attach the planar patch antennas on the outer sides of the shoulders or limbs as illustrated in Figure 13 as well as on the chest and back in parallel, back-to-back orientation.

Such ideas are expected to make GPS user segments more familiar to pedestrians, including mountaineers, and to contribute to making pedestrians' outdoor activities safer and more secure. A prototype is currently being developed, the details of which are to be reported as well in the future.

7. Conclusion

In this paper, we discuss the low usability of conventional azimuth acquisition devices, especially the GPS differentiation method for pedestrians.

We made a new design step-by-step according to ISO 13407 in 1999, Human-centered design processes for interactive systems. As a result, the most important requirements are considered to be as follows;

(1) Functionalities should be limited to basic and simple ones. (2) Important information should be acquired quickly, with no task required (3) The important information should be useful for user's timely decision making. In order to be so, the information should be presented not in a single value, which the user cannot easily tell how far the true value possibly locates, but in sector form, which the user can have confidence to make a decision based on the fact that at least it is true as a sector. (4) Outdoors, scalability is desirable so that both group activities and individual activities can be supported by the same devices. (5) It should be wearable for hands-free use

There are many studies on interaction systems for indoor use. However, there are few studies on systems for outdoor use. This study is an important case study of an electric device for outdoor use, including a significant new invention, which is registered for patent in many countries.

We carried out a semi user-based assessment on the performance of the proposed design by simulations. Firstly, we made it clear that the average value of azimuth limitation width is about 34 degrees, for the back-to-back 2 unit configuration. Secondly, we found that the average value varies from about 22 degrees to 58 degrees, depending not on the number of trials but on the GPS satellites constellation at the time. Finally, we quantitatively evaluated the scalability of the proposed method. Even a single unit can ease a situation of orientation loss as it can easily limit an orientation up to about 60 degrees on average. With only two or three units, the averages of azimuth limitation widths are dramatically improved up to about 34 degrees and 25 degrees respectively.

As this device satisfies the requirements for pedestrians on land simultaneously, it should help prevent people from becoming lost in mountain areas even under bad weather conditions, support learners in outdoor education as a wearable e-learning device [12], and assist visually-impaired people to walk.

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