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Evaluation of GPS device properties for a possible use in future household travel surveys.

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TITLE: **Evaluation of GPS device properties for a possible use in future household travel surveys.**

ABSTRACT: This paper describes a series of tests undertaken to determine the potential usefulness of a specific passive, portable GPS device for use in household travel surveys. The tests were undertaken to provide a more complete understanding of the properties of the GPS device and to assess its suitability for replacing more conventional self-report diaries in a household travel survey. The tests were conducted first to ascertain the actual battery life of the devices, and then to test out the sensitivity and accuracy of the devices under a number of different conditions. This included tests by train, bus, and ferry in the Sydney area, and also by car and bicycle. The devices were also tested in various positions on the respondent's body and were also tested in urban canyon and tunnel situations. Two versions of the GPS-PPAL were tested, as a result of an updated version that became available during the testing work. The results show that the GPS-PPAL, especially in the latest modification, is well able to record travel very accurately in almost any situation.

KEY WORDS: ***Household travel survey; GPS; transport.***

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1. Introduction

GPS devices for potential use in transport applications continue to be improved. Their accuracy and availability have increased markedly in the past few years. However, transport planning has traditionally been based on self-report surveys, answered more or less precisely by people who often are not particularly interested in the survey. With increasing availability of the Internet, web surveys have been considered as an alternative to paper surveys. However, such surveys still rely on self-report.

As described in a few articles (Casas And Arce,1999; De And Mensonides, 2003 ; Draijer et al, 2000; Hawkins and Stopher, 2004; Kracht, 2006; Murakami and Wagner, 1999; Wolf, Guensler and Bachmann, 2001; Wolf, 2004; Yalamanchili, 1999), GPS devices have been developed well enough to be used for transport planning surveys. This paper reports on tests of a specific GPS device to see if it is good enough to be used in every situation for such surveys, to understand its capacities and limitations, and to determine the best way to use the devices to obtain the best results. The devices that are the subject of this research are BTT08 devices. There were two versions, an earlier model with an Atmel GPS chipset, and a more recent model, using the latest MTK chipset. The device is a custom-built device that weighs about 50 grams and is smaller in size than a typical mobile telephone. It has 8 Mb of storage, has voice recordings and flashing lights to indicate status of signal acquisition, has a rated sensitivity of -158 dbm, and a claimed accuracy of ±2.5 meters. For further details, the reader is referred to Stopher et al (2008).

The testing was done in and around Sydney, Australia (latitude about 34°S, longitude 151°E), which has a rolling to hilly topography, is located along the Pacific Ocean, and has a well-developed CBD, with urban canyons. There are also tunnels on a number of roadways, as well as an urban rail system that operates underground in the CBD, but at or above grade in most of the rest of the region. It is not expected that any of Sydney's features would make for unrepresentative conditions compared to other major cities around the world. The devices have been used recently in Cincinnati, Ohio where it appears that results are similar to those found and reported in this paper for Sydney.

The tests that were conducted were first of the battery life in continuous operation, mainly because experience has shown that respondents often "play" with the devices, exhausting the battery quite quickly, and also to ensure that there is sufficient battery life to record a full day of travel between charges. The second set of tests was of the accuracy of the device in public transport vehicles, where respondents may be sitting, standing, or, as occurs in Sydney, be on the lower deck of a double-deck train or inside a ferry vessel. The importance here is to determine if the devices can provide reasonably accurate traces of public transport trips. The third set of tests was of the use in a car or bicycle, with the devices carried in various different ways, such as on the floor of the car, in a backpack on a bicycle, etc. The fourth set of tests were of performance in an urban canyon situation, to determine mainly how quickly position would be found in such a situation. The final set of tests related to the speed with which the position was re-established after entering and then leaving a tunnel. This last is because the more rapidly position is found again after a tunnel, the less information is lost by the tunnel. The results are mostly descriptive, because statistical, numerical results are not considered appropriate for a general assessment of usability.

2. Test results

2.1 Battery life testing

The goal of the first experiment was to find out the average time that the devices can be used continuously. The batteries were known to last for three or four days before charging them, but this included considerable time in sleep mode. The idle time was set to its maximum value of 15 minutes, meaning that the devices would need to be moved at least every 15 minutes, so that they would not go into sleep mode. To provide more accurate results, six devices were tested. Table 1 shows that the battery lasts for an average of almost 23 hours. The standard deviation of 1.7 hours is low, showing that the devices are very similar. After the first “Battery Low” message, the devices repeat this every 5 minutes until the battery is dead. This takes approximately 30 minutes which represents about 2% of battery life. Again, the standard deviation of 0.5% is very low.

GPS	Device 1	Device 2	Device 3	Device 4	Device 5	Device 6	Average	Standard deviation
Total time	20:30	21:01	21:39	23:07	24:34	25:44	22:46	1.70
Time before "battery Low"	20:05	20:31	21:10	22:30	24:19	25:08	22:17	
Time after "battery Low"	00:25	00:30	00:29	00:37	00:15	00:36	00:28:40	
"Battery Low time" percent	2.0%	2.4%	2.2%	2.7%	1.0%	2.3%	2.11%	0.52%

Table 1: Average battery life

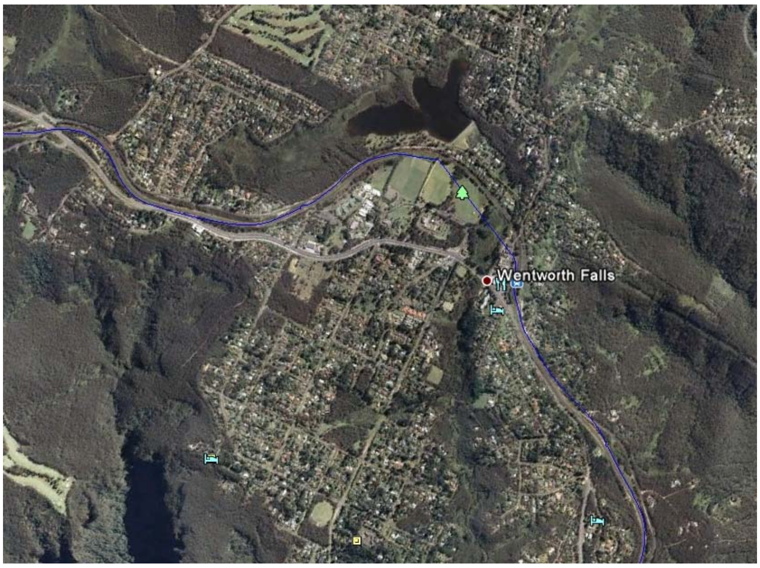
2.2 Public transport study

There were several goals to this part of the research. The main goal was to evaluate the quality of the data recorded by GPS devices during train, bus, or ferry trips. Secondarily, the experiment aimed at determining whether the quality and accuracy of the data depend on the location of the device on the person and on the location of the person in the vehicle. In each type of train, bus or ferry and in each location, e.g., sitting near the window or the aisle in a bus, in the upper or lower part of a double-decked train, or inside and outside on a ferry, long trips were recorded by eight devices: two devices hung on a belt, two devices in pockets, and two devices in the lower and two devices in the upper part of a backpack.

First, the Horizontal Dilution of Precision (HDOP) and number of satellites in view were checked: if HDOP was higher than 5 or number of satellites less than 4, the data were considered too inaccurate for further study, and the trip was repeated. Otherwise, the data were analysed using all the information available (longitude, latitude, speed, heading, number of satellites, HDOP, altitude, date, time, and distance) and a GoogleEarth map was produced to view the travel. Each point on the map where devices lost or regained signals was mapped, when it was possible to determine this from the record of the trace. The recording accuracy on each trip segment was evaluated and tabulated, so that the trips could be compared.

The most common errors are signal losses. The devices lose signal quite often and regain it a few seconds or minutes later. Straight lines are then seen on the map, linking the point where the position was lost to the point where the position was regained, making it relatively easy to find these errors on the map. In the example shown in Figure 1, the device lost contact near the tree symbol but did not take long to find it again, although the signal can sometimes be lost for much longer.

Figure 1: Short loss of signal



The other common errors are displacement, which means these errors depend on the accuracy of the signal: if the signal received by the device is not accurate enough or the HDOP is too high, paths can appear displaced. The data path can be perfectly parallel to the real path or can be completely wrong but in an area close to the real path. Figure 2 shows the real path in red and the path recorded by the device in blue. It can be seen that the real path goes through the train stations, whereas the blue path does not: the shape is displaced.

Figure 2: Difference between real (red) and recorded (blue) paths

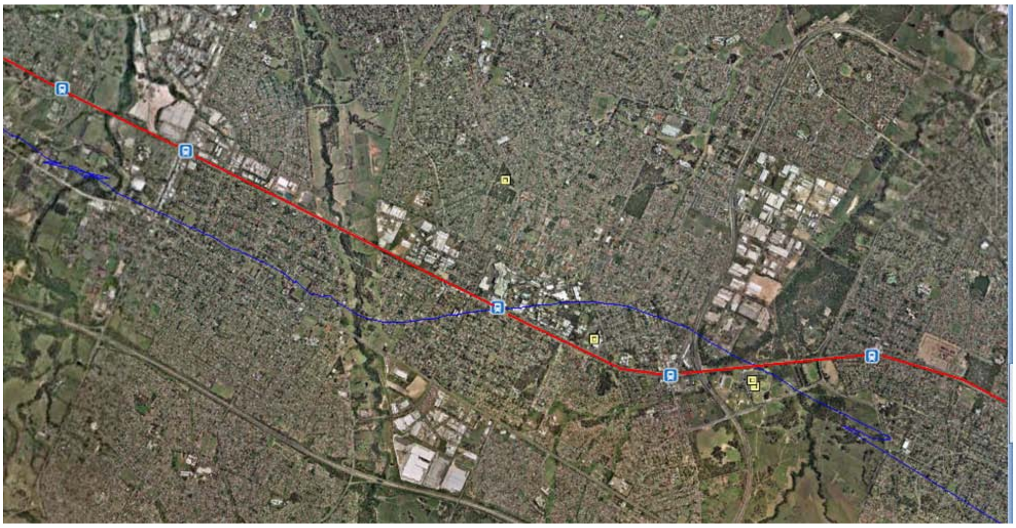


Figure 3 shows two paths that are parallel, but displaced. The HDOP number ranged between 1 and 3, and the number of satellites in view was six, so position should have been very accurate. Therefore, it is unclear why this error occurred.

Figure 3: Parallelism between the real and recorded tracks

Moreover, the device may position itself in a location totally different from its actual location, and then find the correct location again. Most of the time, the path does not make sense because it is very far from the previous position and it is impossible to travel such a distance in a few seconds, making it easy to find these errors. Very long straight lines appear on the map, linking the previous good position to the new wrong one. They can also be found in the data file as a very large speed and distance value. However, some errors of this type can be hard to find. A large number of wrong points can go unnoticed when they are close to each other and create a path that seems real, smooth and continuous.

2.3 Different means of transport studied and corresponding results

In terms of the trains, in Sydney, there are five types of trains that operate currently and each was used in the testing. Intercity trains and Oscars link the Sydney downtown to outlying urban areas, and the Millennium, Tangara and S Sets provide urban and suburban service within Sydney. To study the differences in the behaviour of the GPS devices on trains, each of these train types were tested, to check that there were no differences in interference with positioning. The approach was as follows: to simulate travel to the station and waiting for a train, eight old and eight new GPS devices were switched on at least 20 minutes prior to entering the train. Each trip was divided into several sections, and the data accuracy of each section was tabulated and, after analysing it, conclusions were drawn about the ability of the new and the old devices to gain and keep position in each location in each type of train.

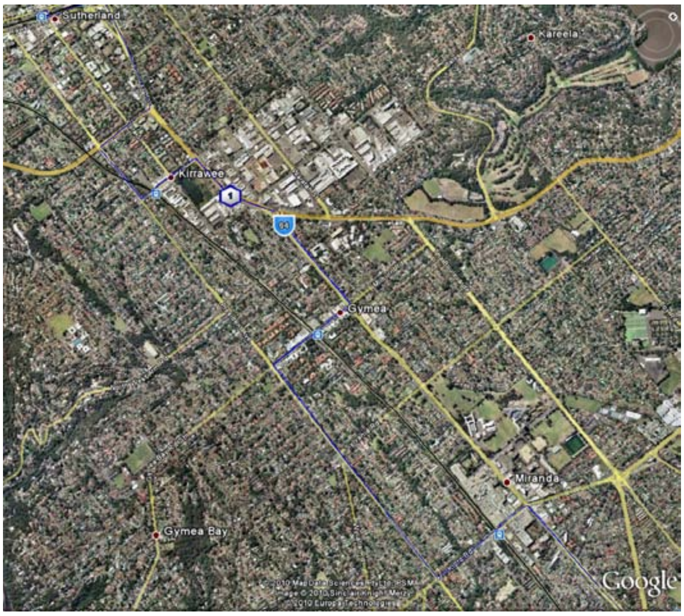
The results are summarized as follows. First, it was found that when the old devices gained position prior to entering the train, they kept position with good accuracy, regardless of the type of train. However, during every trip, in every type of train, at least one of the eight devices lost position, apparently at random. There is also no type of train that has more chances than others for position loss. It depends on the position of the satellites or on the outside environment much more than on the type of train or the location in the train. There is no difference between sitting near the window or near the aisle, and it is not possible to say that it happens more on the upper deck, on the lower deck, or in the vestibule. In summary, the location in the train has very little, if any, influence on the accuracy of the data. The data are accurate as long as the device does not lose the signal for some reason.

However, the older devices have difficulty in regaining position after losing it, if the train is moving; if they enter the train without position they will probably not record anything for the whole trip. If they go through a tunnel and lose position, they are unlikely to gain position again during the trip. The analysis of the data showed that the new devices hardly ever lost position during the trip if there is no major issue, e.g., a tunnel. Moreover, the recorded data quality was much better than for the old ones. Also, if they lost position during the trip, they had about a 50% chance of regaining it, unlike the older devices. Again, the new devices provide very good and accurate results, regardless of location or type of train. In conclusion, the location of the passenger in the train has no impact on the ability of the GPS device to maintain its position.

All the experiments were carried out with at least eight GPS devices (most of the time sixteen), so that at least two of them were in each location (belt, pocket, lower and upper backpack), so that differences in behaviour of the devices depending on where they were located could be identified. The public transport experiments, as well as the ‘CBD experiment’ that is dealt with later, showed that it was slightly easier for the device to gain and keep position if it was in the hand or hung on the belt, with a direct view of the sky and of the satellites. However, the difference was only slight. The ability to find the signal depended more on the time to find position than on the location of the device on the body. On the other hand, the devices showed the same ability to gain and keep position whether in a pocket, a plastic bag, or in a backpack. It is quite impossible to tell that one location is more effective, because of the random nature of the time to find position. In terms of the buses, identical tests were carried out on buses. They are similar but simpler since there is only one type of bus, with only one level. Nevertheless, this experiment aims at determining if there is a difference in behaviour depending on the position in the bus, i.e., close to the window or in the aisle, either sitting or standing. Again, eight old and eight new devices were switched on at least 20 minutes before entering the bus. Two experiments were carried out: the first one was a trip with the devices put on a seat next to the window, while, during the second one, they were in a bag in the aisle.

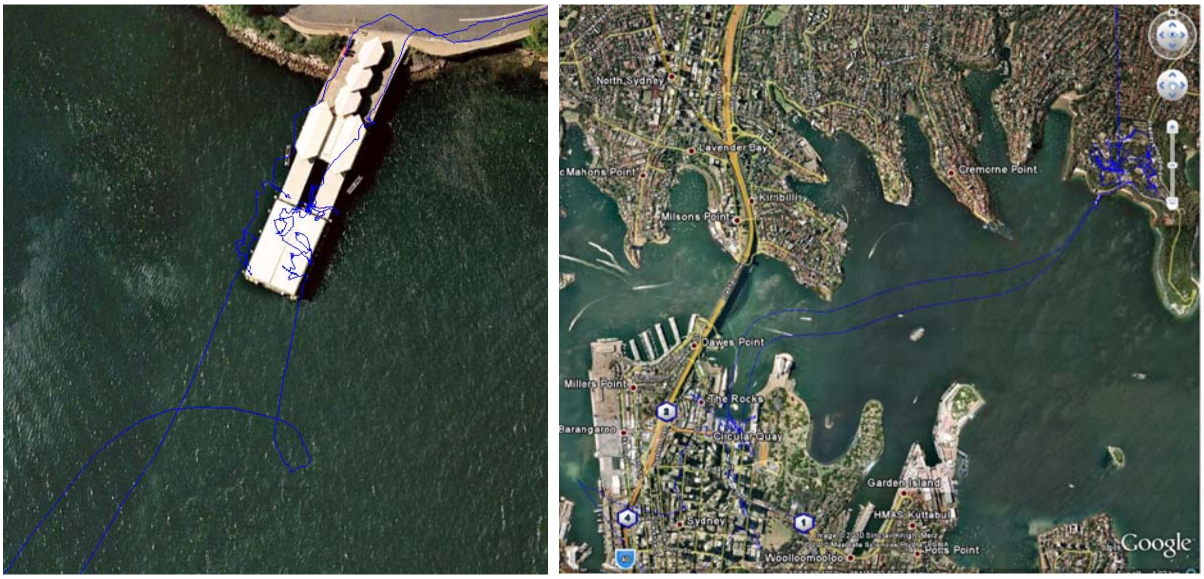
The results are summarized as follows. It appears that it is a slightly easier for the devices to keep position during the trip in a bus than in a train, because very few of them lost position and when it was lost, it was for a very short time. Moreover, both old and new devices provided ‘good’ results, although the new devices provided higher quality data: they lost the signal less often and were better able to regain it after a loss during the trip. The accuracy is clearly shown in Figure 4. Results on the buses were similar to the trains. The position in the bus showed no influence, as the two experiments gave exactly the same results, whether the GPS devices were located near the window or not. Provided the device is on when a respondent leaves home, it does not matter where the respondent travels in the bus.

Figure 4: Accuracy of bus data



In terms of ferries, because Sydney is on the ocean and has an estuary/harbor that divides the city, ferry use is quite widespread. Most ferry trips last about ten minutes, although waiting time and boarding and disembarking can increase this to about 30 minutes. The ferry study is similar to the previous studies. The aim was to determine if the devices are able to keep position during the trip irrespective of whether the passenger is inside or on the outside deck of the vessel. Again all devices, whether old or new, were turned on at least 20 minutes before the trip. Figure 5 shows, first, that the ferry makes a U-turn before arrival to let the passengers alight from the right side and, second, that the path seems to be very accurate. The path shows the high degree of accuracy recorded by the device. It was found to be easy for the devices to keep position on board the ferry provided they had position prior to departure.

Figure 5: Accurate data on the ferry



To conclude, good results were found with the use in a ferry. It is relatively easy for the devices to keep location during the trip. The recorded route seems to be more precise than those observed in buses and trains. This may be explained by the direct view of the satellites when on-board outside. As a result, the use of a ferry poses no problems for a household travel survey.

3. Private transport study

3.1 Private car

The same study was carried out with a private car. The trip completed was about 20 km long to the north of Sydney. Eight old and eight new devices were carried in the front pocket of a backpack. Each of the 16 devices provided an excellent result: they managed to keep position during the whole trip and provided the best accuracy so far. The path recorded by the device follows exactly the curve of the road, as shown in Figure 6, and the signal was never lost for more than one or two seconds. These tests are very encouraging because car travel accounts for most travel in Sydney.

Figure 6: Data from a car trip

3.2 Bicycles

Some data were collected with the GPS devices during trips by bicycle, because it seemed important to know if the devices were more likely to lose the signal by bicycle than on foot. The 16 devices were carried in a backpack during the whole trip and were switched on some time before. The results of the 16 GPS devices are similar, and of a high quality. The path is relatively precise (within less than two meters) and none of the devices lost signal for more than two minutes during the bicycle trip. Six breaks were taken during the whole trip, going just a little bit away from the main path. These can be seen clearly in Figure 7. Moreover, the path follows the real route exactly as shown further in Figure 8.

Figure 7: The whole bicycle trip with the six visible breaks

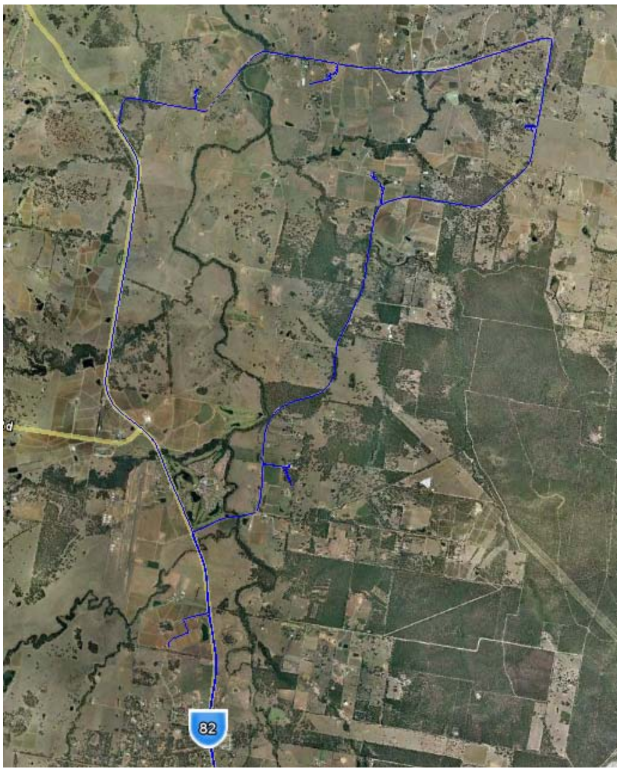


Figure 8: Details of the bicycle trip

The left part of Figure 8 clearly shows that the bike was on the left of the road before moving away to the top of the picture. After coming back from the break, it was on the left again. The right part of Figure 8 shows that, coming from the right, the bike stopped to let a car pass, and after that turned right. In the same manner, at the return, the cyclist travelled along the right verge, and stopped before crossing the road because there were some cars coming towards the cyclist. In conclusion, the bicycle trip shows the high degree of accuracy of the new GPS devices and the ability of both types of devices to keep the signal. The use of the bicycle does not affect the quality of the signal which is as precise as by foot.

4. GPS device properties in the CBD

The goal of the next experiment was to evaluate if the GPS devices can be used in household travel surveys in the city centre. The devices should be able to record the whole trip without losing position for a long time. If the devices lose position in an urban canyon, it is necessary that they should be able to regain it quickly and accurately. In tunnels, no signal will be obtained, but it is important to identify when the respondent enters and exits the tunnel. Two experiments were conducted. The first one aimed to evaluate the time the devices needed to gain position after losing it in an urban canyon in the CBD. The second one was to determine if the devices can record entry and exit of a tunnel trip with enough accuracy to be usable.

4.1 Finding position in an urban canyon

For this experiment, the devices were switched on prior to leaving, with enough time to gain position because the trip included ten minutes walk, then 15 minutes bus, after which the devices entered the CBD, so each of them found position at least ten minutes before entering the CBD. It is known that the devices can lose position or be in sleep mode up to 30 minutes without erasing the initial position in their memories. Thus, if it sleeps or loses position for less than 30 minutes, it uses the initial position to find the new one faster. The devices have the same behavior patterns whether they lose position or they switch to sleep mode, therefore the time they need to gain the position back is the same after sleeping or losing position. The experiment aimed at comparing and analysing the time both old and new devices needed to regain position, whether they had slept for 20 or 40 minutes. The results are summarized in Table 2.

Device	Time of sleep (minutes)	Time to pick up (minutes)
NEW 1	20	1
NEW 2	20	2
NEW 3	20	1
NEW 4	20	1
NEW 5	40	1
NEW 6	40	1
NEW 7	40	1
NEW 8	40	1
OLD 1	20	6
OLD 2	20	2
OLD 3	20	17
OLD 4	20	5
OLD 5	40	24
OLD 6	40	28

Table 2: Time required to gain position for each device after sleeping

The new devices show an impressive ability to regain position in an urban canyon, where very little sky was available. The devices seem to be able to pick up the signal in any location in the CBD very quickly, whether they have lost it for a long time or not. In contrast, the old devices need much more time to gain position. The results also show as expected that the old devices take much longer to regain position after being off for 40 minutes, rather than 20. However, even after 20 minutes, a loss of position for 6 to17 minutes creates an important lack of data. In conclusion, the old devices are inappropriate for a household survey because of the too long time they need to regain position in an urban canyon. In contrast, the new devices are appropriate.

4.2 Finding position after a tunnel

This experiment aims at determining if the devices can locate exit from a tunnel rapidly enough to fix the position of emergence. The approach was to record a trip for a normal user going to work in the CBD and taking the train to go there. Eight old and eight new devices were used. The trip included a short walk, then a bus ride, and then the user entered the CBD before by taking a train in a CBD tunnel, and then went back on the bus. The goal was to see if it is possible with both types of devices to detect all stages of the trip, and see that the user took the train in the tunnel segment, although the path between the two stations is underground.

The results show again a sharp difference between the two types of device. Only one out of eight old devices shows that the user took the train from the correct station and got out at the correct station. Three devices show the trip to the correct station but never regained position after entering the tunnel. Four devices lost position when entering the CBD, having only three of four satellites in view and a HDOP number up to 20. Only one of the eight new devices did not show the two stations, because it lost position when entering the CBD (four satellites in view and HDOP around ten). Six out of eight showed the walk and the bus trip with good accuracy, lost the signal at the entry station and gained position at the exit station in a few seconds, after ten minute in the tunnel.

In conclusion, the old devices should not be used to record a city centre trip in an urban canyon or tunnels. New ones can on the contrary be used because they are still quite accurate and manage to keep the signal in every position, even after going through a tunnel, in which case they regain position very quickly.

5. Conclusions

In terms of performance on different public transport modes, cars, and bicycles, the following conclusions can be drawn: First, the position of the devices on the person carrying out the test has little influence. It seems to be slightly easier to gain position when the device is held in the hand or hung at a belt, with a direct view of the satellites, but the differences are small. There is also no significant difference in performance according to the position of the device on the person, i.e., in a trouser pocket, in the front pocket of a bag, or in the bottom of a backpack. Second, the study has shown that the behavior of the devices was similar, regardless of whether they were placed at the upper or the lower level of the train, at the window or aisle of the bus, or inside or outside on board a ferry. Third, the old devices have shown a good ability to gain and keep position, although they can sometimes lose it for several reasons, e.g., in an urban canyon or through a tunnel. If they lose position, it is very hard to regain it during the trip in trains and buses. Fourth, the new devices are much better than the old ones. They rarely lose position and, when they do, they usually regain position quickly. Moreover, they are more accurate than the old ones. Fifth, trips by bicycles and by private cars are recorded very precisely. The signal is rarely lost and the quality of the positioning is very good. Sixth, while the old devices lose position too often or could not gain an accurate position when they were in urban canyons, the new devices are much better able to keep position. They can gain position everywhere, keep it most of the time in all types of transport means with a good accuracy, and even if they lose the signal they regain it very quickly. The CBD and tunnel experiments, added to the public transport ones, highlight the fact that they can record a whole trip and be accurate enough to be understood and analyzed for a survey.

Overall, it can be concluded that GPS devices, such as the ones tested in this research, are now accurate enough to be useful as a substitute for self-report surveys. Most situations in which GPS recording has been compromised in the past are now no longer an issue, as shown by the newest devices tested, and only loss of signal in tunnels remains as an issue. Even here, with accurate identification of the entry and exit points and times for a tunnel, the loss of data will be small, except in large cities with extensive and complex underground transport systems, such as London, Paris, or New York.

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