USING THE GPS FOR THE COMMAND OF THE MOBILE ROBOTS

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Abstract: The paper deals with the possibility of using a GPS receiver as position transducer for the navigation of vehicles (mobile robots). The properties of the position signal, transmitted by the GPS receivers, are investigated, along with the transfer protocols. The size and the dynamics of the position error, as well as the influence of the visibility are evaluated. The performance of a control loop, containing a mobile robot and the GPS, is verified experimentally.

1. INTRODUCTION

The Global Positioning System (GPS) is a navigation system, using artificial Earth satellites. It is designed to provide the position and the time, almost everywhere in the world, in any weather conditions, plus other information, originating from the above mentioned. This project, supported and controlled by the U.S. Department of Defence, is intended to serve equally military and public applications. The orientation systems for airplanes, ships, cars and missiles, the map builders and the land measurements are typical GPS applications. The system contains 24 artificial Earth satellites and fixed ground radio stations. The satellites orbit at a height of about 20.000 km, with a revolution period of 12 hours. The ground stations, distributed on the surface of the earth, track the satellites and continuously update the time and the position information. Every satellite periodically transmits data packs, containing the time (nanoseconds accuracy), its current position, the other satellites positions and other information. The GPS receiver obtains the position information from the radio transmissions of the satellites it can track. At least 3 satellites are necessary for computing the position on the earth. More satellites are necessary for additionally computing the altitude and the exact time. The error of the measurements depends on the positions of the visible satellites, the unmodelled deviations of the radio signals in the upper atmosphere, the reflections and the own noise of the receiver.

The purpose of this paper is to evaluate the possibility of using a GPS receiver as position transducer to control the trajectory of a mobile robot. This solution is already used as position transducer for military mobiles (missiles) or as help information for car drivers. Both applications are characterized by the long travel, where the position error becomes unimportant. On the contrary, the mobile robots may have different distances to travel, some of them acting in a narrow area. If the GPS satellites are not visible for the robots (for instance, inside the buildings), a special navigation system is used. This one may be made very accurate, but it is expensive. If the robots receive easily the signals from the satellites, they can use this inexpensive information for positioning. That is why the magnitude of the error, its dynamics and its effect on the position control system have to be studied. The final result is a conclusion about the class of applications where GPS is a good position transducer and about the limits of its precision. Supplementary, the transfer of the GPS data from the receiver to a computer is also an objective of this work. The presented study was carried out based on the information available on the web about the GPS and the user's manuals of some commercial receivers (Garmin).

2. THE GPS RECEIVER USED AS POSITION TRANSDUCER

The idea of using the GPS receiver for the control of the trajectory is not recent. It is already used on the ships, equally in automatic control or man controlled loops. The general structure of the automatic control loop contains the GPS receiver – as position transducer, the motor and the steering equipment – as position actuators and the controller. Usually, the controller is a program, executed by the robot processor. In robot positioning applications, the interesting aspects of the information acquisition from the GPS receiver are: visibility of the satellites, resolution of the data provided by the receiver, precision of the data and the data transfer protocol.

The number of the *transfer protocols* is limited. They influence the resolution of the acquired data, through the intermediate of the data format. In our experiments we used a Garmin12 receiver which supports the following two protocols: NMEA and Garmin.

The most common protocol, *NMEA*, that defines the interface between various pieces of marine electronic equipment and permits sending information to computers and to other marine equipment. The idea of NMEA is to send a line of data (characters followed by newline), called a sentence, which is totally self contained and independent from other sentences. There are standard sentences for each device category and there is also the ability to define proprietary sentences. All of the standard sentences begin with the '$' sign, followed by a two letter prefix, a three letter identifier and the body of the sentence. The prefix defines the device that uses that sentence type. (For GPS receivers the prefix is GP.) The three letter sequence defines the sentence contents. The body of the sentence contains data fields separated by commas. The sentence ends with a checksum and with a carriage return/line feed and can be no longer than 80 characters. This data is sent through a serial line at 4800 baud with 8 bits of data, no parity and one stop bit.

The following example presents the messages transmitted by a GPS receiver, in NMEA format, regarding hour, date, position (latitude, longitude, precision), speed and azimuth, altitude, number of visible satellites, along with other information about them (id, position, signal level etc.).

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$GPRMC,073012,A,4525.801,N,02802.132,E,005.4,304.7,200902,004.7,E*7D
$GPRMB,A,,,,,,,,,,,,V*71
$GPGGA,073012,4525.801,N,02802.131,E,1,09,2.0,63.0,M,34.5,M,,*7D
$GPGSV,3,1,11,01,81,326,51,02,13,113,38,04,34,307,45,07,04,256,00*7C
$PGRME,15.0,M,22.5,M,15.0,M*1B
$GPGLL,4525.802,N,02802.130,E ,073012,A*2B
$PGRMZ,207,f,3*1E
$PGRMM,WGS 84*06
$GPBOD,,T,,M,,*47
$GPRTE,1,1,c,0*07
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The advantage of NMEA protocol is that the sentences are easy to process and are sent automatically by the GPS receiver. The main disadvantage of NMEA is that due to the low baud rate, the GPS receiver will transmit one set of information only, every two seconds. Another disadvantage is that the *resolution* of the position information is dependent on the device used: our receiver allows only three digits after the decimal dot, i.e. a resolution of 1.8 meters latitude and 1.3 meters longitude (for the latitude of Romania).

The *Garmin protocol* specifies that data is sent through a serial line at 9600 baud with 8 bits of data, no parity, and one stop bit. All data is binary coded. The protocol is based on request-response messages, the GPS receiver playing the slave role. The position is returned by the GPS as 8 byte coded real numbers, the resolution being below one millimeter. As it will be proved further, this resolution is far too fine, in comparison with the precision of the feedback signal that can be obtained.

About the sampling period, it has to be noticed that the internal computing period is 1 second. If the user requests data at a higher rate, the receiver returns a measured position every second, intercalated with estimates of the position, based on the speed computed on the last few seconds. There is also a mode of asking the GPS to send asynchronous data periodically, without any request from the master computer (similar to NMEA), which we have not investigated yet.

In our experiment the Garmin protocol was used for data transfers. The effect on the position error is presented in Figure 1, which contains the position signal transmitted by the GPS, when it moves North, then Northwest (azimuth change of 45 degrees). The coordinates are the distances on the latitude and the longitude, expressed in meters (arbitrary origin). The sampling period was 0.1 seconds. Because the GPS receiver updates the position every second, only one sample in each series of 10 is a normal determined position. The other 9 samples are estimated by the receiver. The estimation error is obvious on the diagram. The same phenomenon is visible on the diagram presenting a 90 degrees azimuth change. Because of the presented contents of the transmitted data, the position signal we used for control was filtered by averaging on 1 second.

Concerning the *precision* of the information, it is more influenced by the visibility and less by the radio propagation conditions. The manufacturers consider that, in good reception conditions the upper limit of the error is no more than 15 meters.

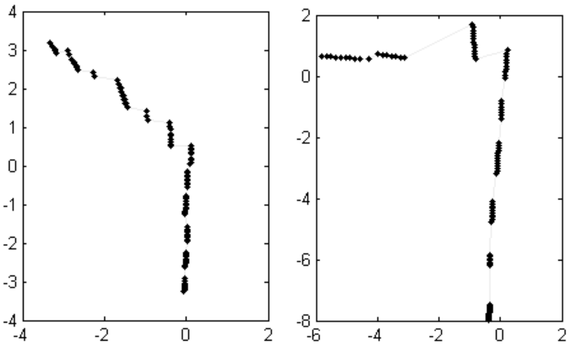

Figure 1: results of the high sampling frequency

The dynamics of the error is important, because the usual control methods consider the error as unknown, but having known statistic properties. In this respect, an experimental study was carried out. Figure 2 presents the wander of the position signal, in three different recordings standing still for 5 minutes, in the same point, having an average visibility (good visibility above, but horizon line obstructed by buildings, between 5 - 8 visible satellites). The graphic shows that in a timeframe of 5 minutes, having a normal visibility, the error can have a wander up to ten meters. In general, the changes in position are relatively slow, varying less than 0.5 metres per second. The dynamics of the error is influenced by the visibility variations, also. Figure 3 presents a test carried on for evaluating this influence. The GPS receiver is standing still and the position signal indicated by the GPS is recorded. The first part (dots) was recorded for 60 seconds, in poor visibility conditions (the antenna was shielded). The indicated position evolves to the South. The second part (circles) was recorded for the next 90 seconds, after having removed the shield. More satellites become visible and the indicated position moves North, correcting the previous error. The conclusion is that the previous error was about 10 meters (for the shielded antenna), and it was corrected slowly, after the visibility improved.

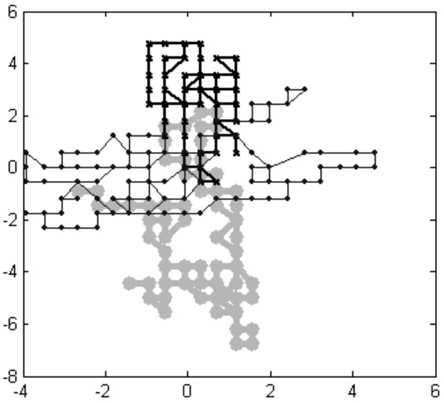

Figure 2: the wander of the position signal, for standing still receiver, normal visibility.

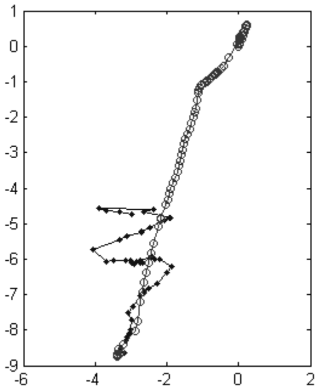

Figure 3: the wander of the position signal, during changes in visibility

The above mentioned properties of the GPS allow using it for position feedback, in a control loop of a vehicle (mobile robot), but suggest some limitations. Based on the evaluation of the size and the dynamics of the error, the following two hypotheses were verified:

- if the visibility of the satellites is poor, the applications where the robot travels on short distances or at low speed are affected by unacceptable errors;
- even when the visibility of the satellites is good, the behaviour of the robot becomes oscillatory if the dynamics of the actuator is too high – with respect to the dynamics of the feedback signal.

The first hypothesis is easy to explain: if the distance to travel is low, it becomes comparable with the average error. The second hypothesis takes into consideration the minimum sampling period for the position signal, which depends on the data transfer protocol. This period (one or two seconds) is equivalent to a dead time in the feedback loop, so the robot behaves similar to a low-order system, affected by a dead-time larger than the time constant. In these cases, the feedback loop affects the stability. The natural conclusion is that the dynamics of the actuator has to be slowed down, in order to maintain the stability.

Based on the above mentioned hypotheses, the conclusion is that the GPS receiver may be used as position feedback for the mobile robots in the following two distinct situations:

- when the robot travels on distances considerably larger than the average position error;
- when the visibility of the satellites is constantly very good, so that the precision of the measured position is better than the required accuracy of the positioning system.

Whatever the alternative, the dynamics of the actuator has to be adapted to the dynamics of the feedback signal, in order to avoid oscillations.

3. THE CLOSED LOOP EXPERIMENTAL RESULTS

The experimental device contains a mobile robot (only the propulsion and the steering are relevant for the experiment), a Garmin GPS (embarked on the robot), the data transmission part and a controller. The controller runs inside a computer, remotely linked with the robot. Identical results are obtained if the computer is embarked on the robot (for instance, a laptop). The computing complexity and the data transfer are very low, so the computer may even be replaced by a microcontroller, without affecting the results. The data transmission between GPS, computer and robot may be performed by wire or by radio (a pair of radio modems is linking the robot and the computer). This part is not important for the study, provided that the speed of the transfer (9600 bits/second) is higher than the dynamics of the position signal. The propulsion and the steering of the robot form the actuator of the positioning system. The speed of the propulsion is almost constant. The command for changing the direction of the robot may be continuous (as it is the case of the Pioneer2 robot) or discrete (in the case of simpler robots, as it is the case of the radio controlled 4 wheel vehicles). Even if the behaviours of the two types of steering are different, they do not influence the study about the GPS based position transducer. In the sequel, the results obtained with a discrete steering command are presented.

It is easy to notice the elements that influence the behaviour of the robot: the position transducer and the controller. The GPS receiver and the transfer protocols were already described. The controller is a simple one, deciding if a command for changing the direction has to be issued. This controller is appropriate to the steering subsystem that accepts only the discrete commands: straight, left or right. The reference signal is the direction to be followed to the target. The feedback is the present direction of the robot (computed from the GPS signal, during the last two sampling periods). The error signal of the controller is the difference between the two directions. Because of the discrete nature of the command (tripositional command), the controller contains a dead-zone of 15 degrees, but no hystherezis.

In the previous paragraph, it was shown that the Garmin12 GPS provides real measured positions every 1 second, the rest of data containing estimates (see figure 1). Because we used a sampling rate of 0.1 seconds, the position signal fed to the controller is obtained by averaging on 1 second. Figure 4 shows the effect of averaging on this signal.

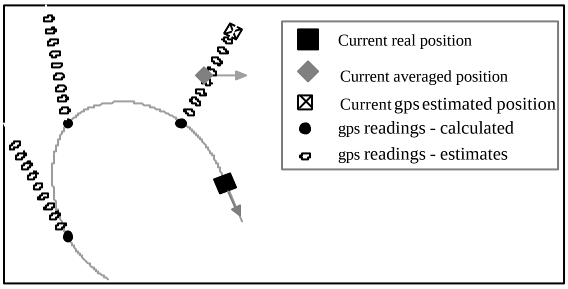

Figure 4: The calculated position and the computed heading differ significantly from the real ones especially when the robot takes a curve.

The behaviour of the controlled robot was tested on straight and rectangular reference trajectories. Figure 5a presents the results obtained when the robot followed a straight line reference, going South, and the actuator (the command for the steering) was slow. Slowing the speed of the actuator was actually obtained inside the controller, by modulating the width of the command. The oscillating tendency is not important, because the dynamics of the actuator is comparable with that of the transducer. The deviations from the straight line (not necessarily superposed with the reference!) are limited to 2.5 meters and are the combined result of the GPS error (poor visibility) and control loop oscillations. Better results are obtained when the visibility is good.

Figure 5b shows the results obtained when the visibility is improved, on a rectangular reference trajectory, but the actuator is too fast. The oscillations are caused by its fast dynamics, compared to the slow dynamics of the position feedback. The failure in reaching the corners is not a bad result, because of the GPS error and the dead-zone of the position controller. This result confirms the above mentioned hypothesis that fast actuators are not suitable when the feedback signal is slow (dead time of 1 second).

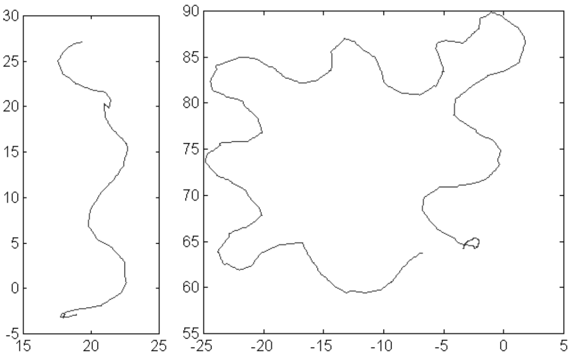

Figure 5
a. results obtained on a North-South reference;
b. the trajectory recorded for a square reference and fast actuator

4. CONCLUSIONS

The presented control structure is mainly based on using the GPS receiver as position transducer, in order to avoid the effect of internal cumulative position errors. The controller runs inside the computer and has a simple structure.

The experiments proved that the visibility of the satellites and the sampling period of the GPS receiver influence the quality of the trajectory tracking. The main conclusions are:

- GPS is not suitable for travelling on small distances or when the visibility of the satellites is poor;
- a simple controller provides acceptable results;
- in order to avoid oscillations, the steering command has to possess low dynamics, comparable to that of the GPS (general automatic control property).

Further work will be carried on for improving the results by using two GPS receivers, in a differential configuration (one mounted on the vehicle and the other one placed in a fixed position); the maximum error is expected to be reduced significantly.

REFERENCES

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