Map-Based Land Vehicle Navigation System with DGPS

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Abstract

Commercial automobile navigation systems currently employ a Global Positioning System (GPS) receiver coupled with a dead reckoning system and a map-matching algorithm. The dead reckoning system, which compensates for GPS inaccuracies and frequent GPS signal obstructions, employs an odometer, a directional sensor, and a backlight signal. The dead reckoning system along with a map-matching algorithm updates the position whenever the vehicle completes a sharp turn into a street whose position is distinguishable on the stored map. In this paper a positioning system is proposed, which employs only a DGPS or GPS receiver and a map-matching algorithm. The algorithm correlates the received power from different GPS satellite vehicles (SVs), leading to a specific signature, to a stored map with periodic time-varying estimates of SVs received powers. An experimental approach is presented to examine the feasibility of applying the proposed positioning system.

I. Introduction

Self-positioning systems can be divided into three location technologies [1][2]: stand-alone (e.g., dead reckoning), satellite-based (e.g., GPS), and terrestrial radio-based (e.g., LORAN-C or cellular networks). Another class of positioning systems is a hybrid system employing two or more of these technologies with possible addition to specific sensors and a map matching system. Map matching is applied to a wide variety of vehicular navigation. Marine vehicles determine the contour of the seafloor with sonar and compare the measured profile to stored bottom maps. Aircraft and cruise missiles measure the vertical profile of the terrain below the vehicle with respect to a certain reference and match it to a stored profile. Other military application employs gravity-gradient algorithms also based on map matching theory. For train-like applications, a map matching approach is proposed, which takes full advantage of the inherited one-dimensional train track [3]-[4]. For mobile robots and other land vehicle navigation, TV cameras have been employed to observe edges of recognizable objects for land navigation practice [5]-[8]. Another land navigation approach employs specific maps developed by an ultrasonic range sensor [9]. The most common application of map matching is employed for automobile navigation. The basic design used a measurement of the distance traveled along with the heading changes for dead reckoning [10]-[12], and other systems combine GPS with dead reckoning systems [13]-[19]. An update is achieved whenever the vehicle completes a sharp turn into a street whose position is distinguishable on the stored map. These systems typically use a fusion of sensors, in particular, GPS receiver, odometer, directional sensor (e.g., gyro), and digital-map database. The odometer and the directional sensor are used for dead reckoning. Even if differential GPS (DGPS) is employed, then dead reckoning and "generic" map matching should be implemented to compensate for DGPS "failures" (and GPS inaccuracies if GPS without differentiation is assumed). In this context, it is meant by a GPS failure the inability of a GPS receiver to estimate its position. In general, GPS failures occur whenever the signals sent by most of the GPS satellites are obstructed or when the dilution of precision factors are large – these phenomena are further discussed in Section II. However, based on the design of the GPS satellite layout, these failures do not take place in ideal opened space vicinity. Thus, the surroundings of a GPS receiver play in important character. In particular, if the vicinity of the GPS receiver does not obstruct the GPS satellite signals, then a dead reckoning system will not be needed. On the other hand, at a fixed time, the GPS receiver (or GPS antenna) vicinity may obstruct one or more satellite vehicles signals. Such obstructions depend on two variables: 1- the layout of the neighborhood, and 2- the time. Since the orbit of the GPS satellite vehicles (SVs) are periodic, then one can easily predict the locations of all SVs at all times – this phenomenon is thoroughly discussed in Section II. In addition, if the three-dimensional map of a *sufficiently* "small" area is available, then one can estimate all the SVs received powers at a certain point, leading to a unique signature consisting of all different SVs received power. Conversely, in theory, if the received powers of all accessible SVs are available, then the location of the receiver within a sufficiently small area can be recovered. The latter is the concept investigated in this paper. In order to assess the practicality of this notion from a theoretical approach, many variables need to be addressed, which may lead to rather complex analysis. Consequently, in this paper, experimental approach is selected to examine the feasibility of applying this novel idea.

Although GPS differential signals are available almost all over the world (e.g., using geostationary satellite, radio broadcasting, Internet, etc.), it is worthwhile noting that the use of the differential mode of GPS is not required. However, the position errors, while "map-matching" cannot be exercised (e.g. open in open areas), will be as large as the corresponding GPS errors. With only additional signal processing and digital map storage and with no required additional sensors to GPS, the application associated with GPS can also be applied to the proposed methodology even for pedestrian navigation.

II. Proposed Methodology

The incentive and concepts that lead us to hypothesize that the GPS system could be considered as a reliable continuous standalone positioning system are established in this section. The hypothesis motivation to prove that one could rely "solely" on the GPS system as a reliable standalone positioning system will start from the fact that the orbital period of the GPS SV is 11 hours and 58 minutes. Consequently, the constellation of GPS SVs will maintain their previous locations (elevations and azimuths) after Δt, where Δt equals 23 hours and 26 minutes. The signal to noise ratio (SNR) received by the GPS receiver from each GPS SV depends directly on the background noise at the GPS receiver proximity environment as well as on the presence of nearby objects obstructing the LOSs between the GPS SVs and the GPS receiver. Accordingly, if a nearby object is present within the LOS between the GPS SV and the GPS receiver, the power of the signal received from that SV would drop significantly, thus lowering the SNR value. If the power received falls below a certain threshold value, the SNR value will be reported by the National Marine Electronics Association (NMEA) output message as a null string (value of zero). However, the SNR value depends, to a lesser extent, on the GPS SV elevation, since the power of the signal received from the GPS SVs will decrease as the SVs approach the horizon. A common problem of a GPS navigator is considered. Suppose that a GPS receiver is roving in a partial-dark (PD) region in which there is a sufficient number of GPS SVs in the sky for the GPS receiver to produce a Position, Velocity and Time (PVT) solution. Yet, the GPS receiver could not produce one because it could not use a sufficient number of SVs as a result of low SNR values. The same constellation of GPS SVs maintains (approximately) their current positions after Δt, and the SNR values depends directly on the proximity environment of the GPS receiver. It should be expected that if the GPS receiver returns to the same PD region after Δt, it should then encounter comparable SNRs. In other words, if the GPS receiver is roving in certain PD region at 01:00:00, for example, and then this GPS receiver returns to the same PD region at 00:56:00 the next day, then it would experience the same degree of darkness. In particular, the GPS receiver should report relatively the same SNR values for the available GPS SVs in both days provided that the GPS receiver would follow the "same" track in both days at a time offset (Δt). To further illustrate this notion, a specific pattern depicted in Figure 1 is considered. In this particular situation, there are five GPS SVs denoted as PRN 01, PRN 11, PRN 14, PRN 20, and PRN 25, where PRN refers to the psuedo-random noise generated by the GPS SV. Also, there is a GPS receiver mounted on a bus and roving between two buildings. It could be seen from the figure that there is a clear LOS between the GPS receiver and two of the GPS SVs, namely PRN 11 and PRN 20. However, the two buildings obstruct the LOSs between the GPS receiver and the three other GPS SVs, namely PRN 01, PRN 14, and PRN 25. The magnitude of the SNRs of PRN11 and PRN20 are much larger than the ones associated with PRN01 and PRN25, and the SNRs of PRN01 and PRN25 is much larger than the one of PRN14. However, if the bus were on the right or left of the two buildings of Figure 1, then the order of magnitude of these SNRs would be completely different. This fact results to different (SNR) signatures corresponding to different locations.

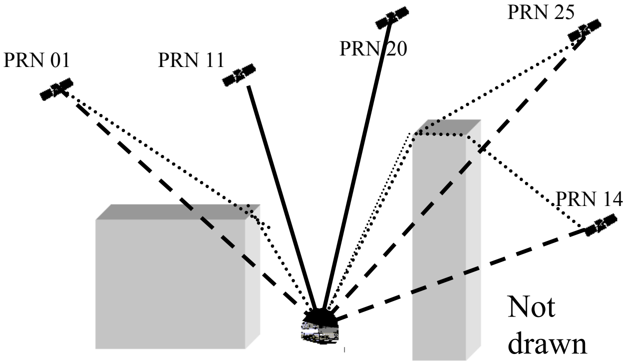

Figure 1. Buildings obstructing the LOSs between GPS SVs and a GPS receiver.

On the other hand, if the bus would return to the same location after Δt, the five GPS SVs should maintain their "current" locations, and the receiver should report relatively the "same" SNR values for the five available SVs. With the aid of this information the GPS receiver would be capable of identifying its location as it enters this PD region based *solely* on the GPS system and without needing to refer to any external positioning systems. However, a singularity arises if the GPS receiver would report the same SNR values for *all* the SVs in "nearby" PD regions. This would cause confusion about the *true* position in which the GPS receiver is roving. On the contrary, it would cause no confusion if the SNR values for *all* the SVs available at a certain time happen to be "relatively" identical in more than one *far apart* PD regions, since map-matching techniques could resolve this dilemma. Map matching is based on a premise that the vehicle could be nowhere but on a road. The vehicle's *most* recent route history, together with the *latest* estimates of position and velocity from the positioning system, could be used by the map matching algorithm to find the likeliest road segment from its stored database and places the vehicle on the "correct" road segment. It is unlikely that the GPS receiver would loose lock for a very long time. Therefore, as soon as the GPS receiver would loose lock, it would use its most recent route history together with the latest PVT solution to zoom on the region in which it is roving [1]. Since the SNR values depend directly upon the proximity environment in which the GPS receiver is roving, it should be expected that the SNR values reported by the GPS receiver to be "relatively" identical if it happens that there exist identical regions in terms of geometry, provided that the power level of the background noise in those regions is almost the same. Fortunately, this is not the case in urban areas due to the *irregular* and *asymmetrical* building distribution. Even in the case of parallel streets, where identical geometry might exist within the same proximity, the GPS receiver can not move from one street to another by jumping around, and it is forced to turn. Fortunately, turning left or right would change the geometry of the surrounding environment, thus changing the SNR values. Hence, enabling the GPS receiver to identify its position. Another class of singularities is when the GPS receiver is within total-dark (TD) region (e.g., inside a tunnel). In this case, the system would only report the position to be somewhere inside this specific TD. However, a probabilistic technique, based on an open-loop approach, may be implemented for a class of TD (e.g., inside a tunnel). If the speed estimate of the GPS receiver is available before entering this TD region, then this speed can be assumed constant and integrated to give an estimate of the distance traveled within this region. Unfortunately, the model for the associated error would possess random walk characteristics.

III. Experimental Work

In this section we present the experiments conducted in order to examine the validity of the proposed methodology. The objective of the experiments is twofold. First, they should show that there is some form of *consistent* SNR values if the GPS receiver would return to the same PD region after Δt. Second, they should show *different* SNR values in different nearby PD regions. In other words, they should show that each road segment within the zoomed PD region has it unique consistent signature (SNR value). The experiments were conducted in the streets of a neighborhood of Byblos city (Figure 2). With the help of the Almanac data, a time slot in which the minimum number of GPS SVs above Byblos city was selected. The advantage of conducting the experiments at such a time was that the number of SVs would be critical, thus being unable to use one or more SV would cause the GPS receiver to be roving in a PD or a TD region. The best time slot was found to fall between 23:00:00 and 00:00:00 (local time), since at this time slot the number of GPS SVs above the city of Byblos ranged between four and five. Finding the region in which the experiments was going to take place was the toughest part of all. It was desired to conduct the experiments in a region where there is an intersection of different streets, and where each street including the node of intersection falls in a PD region. This would make it almost impossible for the GPS receiver *alone* to predict in which road segment it is roving, even when map matching algorithms are applied. After conducting extensive trial experiments in the chosen section of Byblos city at the chosen time slot, an "ideal" region was found. Figure 2 zooms on the chosen region from the original map. In this particular region, it was found that node N and its proximity constitute a PD region. It was necessary to rove far away from node N in order to enter a clear (CR) region again. After finding the right time slot to conduct the experiments at, and after deciding on the region at which the experiments would take place, two sets of experiments over two consecutive days were conducted. The experiments were aiming to show that each road segment within the zoomed PD region has its unique consistent signature (SNR values). The experiments took place on February 20, 2001 and February 21, 2001. The roving car started on February 20, 2001 at 21:24:02 at point A shown in Figure 3. Then, the car moved directly to point B, where it stopped and moved backwards to C. It stopped again and moved forward to point D. At point D, the car vehicle stopped again and moved backwards to node N, where it was turned such that its front was pointing towards point E. Finally, the car moved forward to point E, where the first experiment ended. On February 21, 2002, at 21:20:02 the "same" route was followed by starting at point A and ending at point E, while preserving the order of the intermediate points B, C, and D. The points that were collected throughout the experiments were stored with the aid of a Trimble Navigation TSC1 Asset Surveyor. On the other hand, the NMEA output messages were read by connecting the PRO XRS Trimble Navigation GPS receiver to the COM1 port of a laptop PC and were stored with the aid of a Hyper Terminal private edition software Version 6.1. After conducting the experiments over the two days, the points were transferred to the PC, and with the aid of the Lebanese American University Trimble Navigation Base Station, the data was differentially corrected through post-processing. Then, using the Trimble Navigation Pathfinder Office Version 2.11

software, the points recorded in the two experiments were plotted separately, while setting the map of that specific region of Byblos city as a background (see Figure 3). It was noticed that the PD and CR regions were almost identical over the two days of the experiment. This means that the GPS receiver lost lock from the GPS SVs and gained it again at almost the same locations. This observation proves that there exists some form of "consistent" signatures of PD and CR regions when the same locations are revisited after Δt.

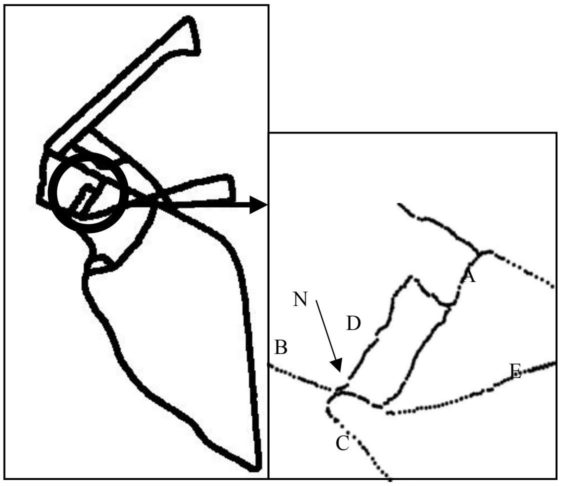

Figure 2. Map of a District in Byblos City and a Zoom on the Location where the Experiments were Conducted

Afterwards, a MATLAB code was written in order to extract the parameters of interest from the ASCII NMEA output messages. The data extracted was then tabulated and analyzed. Some samples of the data collected are presented next. It was mentioned earlier that the aim of the experimental work conducted is to prove that there exists some form of unique consistent signatures of nearby PD regions. Succeeding to do so will enable the GPS receiver to identify its position within PD regions based solely on the GPS data, thus eliminating the need to refer to external positioning systems. The parameters under consideration here will be the GPS SV positions as well as the SNR values of each GPS SV available. The GPS SVs positions were taken care of by conducting the experiments at the same location with a time offset of Δt between the two consecutive days. By extracting the GPS SV positions (elevations and azimuths) from the GPGSV NMEA output message, it was noticed that all the SVs maintained their locations at $\{t + \Delta t\}$ throughout the two days. The SNR values of all the available GPS SVs were tabulated and analyzed separately. Table 1 and Table 2 show the SNR values, the elevations (E), and the azimuths (A) of all the available GPS SVs in the PD region between points u and v (see Figure 3). The elevations and azimuths of all the GPS SVs are reported for one second only, and they are the same throughout the subsequent seconds. It should be noted that the intention of this particular experiment is to demonstrate that there exists some form of consistent signature for the same PD region evaluated at two different time instants with a difference of Δt. The following conclusions could be drawn from the tables. First, the time fix indicates that on February 20, 2001 at 21:24:21 the GPS receiver was roving inside the PD region between points u and v, whereas it was roving within the same PD region on February 21, 2001 at 21:20:21 (i.e. after Δt). Second, the GPS SVs maintained their previous locations (elevations and azimuths) after Δt. Third, almost all of the SNR values match among the two days of the experiments. The "major" mismatches are highlighted with a black cell. Here, a mismatch is referred to when the values of two SNRs of interest differ by more than 10 dBs. Now, to explain these two mismatches, it should be recalled that the experiments were conducted while mounting the GPS receive on a roving car. Thus, even though the experiments were synchronized in time over the two days to have a time offset of Δt, it was extremely difficult to synchronize the experiments in space over the two days, i.e. to be "exactly" at the same position over the two days at $\{t + \Delta t\}$. This explanation is strengthened by noting that the SNR values recorded at the seconds adjacent to the mismatches are identical. Thus, it seems that the car was displaced in position by few meters over the two days. In conclusion, out of the five SVs, four SV SNRs are completely matched and the fifth is 75% matched.

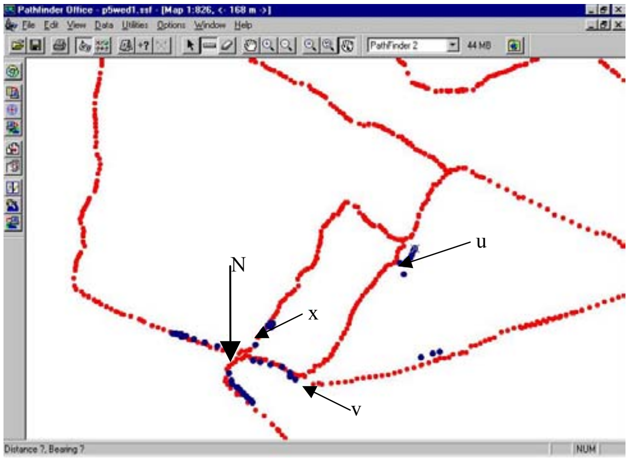

Figure 3. Route of February 20 and 21, 2001

After comparing all the SNR values between the two tables, we can conclude that there exists some form of consistent SNR values within the same PD region. In other words, the PD region under consideration has its consistent signature.

Table 1 SNR Values, Elevations, and Azimuths in PD Region between Points u and v in Day1

Time Fix	# of SVs	PRN	SNR	PRN	SNR	PRN	SNR	PRN	SNR	PRN	SNR
212420	5	1	29	11	49	20	0	25	47	13	0
212421	5	1	30	11	45	20	0	25	46	13	0
212422	5	1	0	11	47	20	0	25	42	13	0
212423	5	1	0	11	47	20	0	25	45	13	0
212424	5	1	0	11	48	20	0	25	40	13	0
212425	5	1	47	11	47	20	0	25	41	13	0
212426	5	1	46	11	46	20	0	25	38	13	0
212427	5	1	47	11	47	20	0	25	43	13	0

Time Fix	PRN	E	A	PRN	E	A	PRN	E	A	PRN	E	A	PRN	E	A
212420	1	47	250	11	66	190	20	52	324	25	42	66	13	18	242

Table 2 SNR Values, Elevations, and Azimuths in PD Region between Points u and v in Day2

Time Fix	# of SVs	PRN	SNR	PRN	SNR	PRN	SNR	PRN	SNR	PRN	SNR
212020	5	1	26	11	45	20	0	25	46	13	0
212021	5	1	0	11	48	20	0	25	42	13	0
212022	5	1	0	11	46	20	0	25	45	13	0
212023	5	1	0	11	48	20	0	25	39	13	0
212024	5	1	46	11	48	20	0	25	41	13	0
212025	5	1	48	11	46	20	0	25	41	13	0
212026	5	1	43	11	46	20	0	25	45	13	0
212027	5	1	38	11	48	20	0	25	40	13	0

Time Fix	PRN	E	A	PRN	E	A	PRN	E	A	PRN	E	A	PRN	E	A
212020	1	47	250	11	66	190	20	52	324	25	42	66	13	18	242

Table 3 SNR Values, Elevations, and Azimuths in PD Region between Points u and v in Day1

Time Fix	# of SVs	PRN	SNR	PRN	SNR	PRN	SNR	PRN	SNR	PRN	SNR
212015	5	1	0	11	45	20	30	25	45	13	0
212016	5	1	0	11	44	20	28	25	45	13	0
212017	5	1	0	11	44	20	0	25	45	13	0
212018	5	1	0	11	47	20	0	25	45	13	0
212019	5	1	0	11	49	20	0	25	45	13	0

Time Fix	PRN	E	A	PRN	E	A	PRN	E	A	PRN	E	A	PRN	E	A
212015	1	47	250	11	67	190	20	53	324	25	42	66	13	18	242

Table 4 SNR Values, Elevations, and Azimuths in PD Region between Point x and Node N in Day2

Time Fix	# of SVs	PRN	SNR	PRN	SNR	PRN	SNR	PRN	SNR	PRN	SNR
212120	5	1	42	11	43	20	49	25	0	13	0
212121	5	1	40	11	45	20	50	25	0	13	0
212122	5	1	29	11	47	20	45	25	0	13	0
212123	5	1	35	11	51	20	42	25	0	13	0
212124	5	1	38	11	52	20	39	25	0	13	0

Time Fix	PRN	E	A	PRN	E	A	PRN	E	A	PRN	E	A	PRN	E	A
212120	1	47	250	11	66	189	20	53	324	25	42	66	13	19	242

In order to check for the uniqueness of the signature of two different PD regions, another set of experiments should be conducted and analyzed. The experiments should simply compare the SNR values between two different PD regions, while maintaining the GPS SV positions at the same locations. Table 3 and Table 4 show the SNR values, the elevations, and the azimuths of all the available GPS SVs in two different PD regions within the same day (February 21, 2001). Table 3 shows the data recorded in the PD region between points u and v, whereas Table 4 shows the data recorded in the PD region between point x and node N. Again, the elevations and azimuths are reported for one second only since they are the same for the subsequent seconds in the tables. By analyzing Table 3 and Table 4, we could conclude that there exist more mismatches (identified by black cells) among the SNR values between the two PD regions. Three of the SV SNRs completely disagree between the two locations. Thus, it could be concluded that each PD region has its unique signature. Many other similar experiments were conducted, which are not reported in this paper, resulted in similar conclusions.

Remark. Up to the knowledge of the authors, electric interference from ordinary electrical apparatuses, climatic conditions, and different time terms were never considered a critical factor affecting the precision of DGPS PVT solution. In fact, many experiments were conducted in different climatic conditions (rainy and clear days) and different durations (day and night).

IV. Conclusion

In this paper, it is shown that a GPS receiver, without the integration of any other external sensor, can be used for a positioning system. Two different experiments were presented supporting consistency and uniqueness of signatures. In particular, it was shown that when the GPS receiver returns to a certain PD region after Δt, which is twice the orbital period of the constellation of the GPS SVs, the GPS receiver experienced the same conditions of darkness. That is, when the same track was followed throughout two consecutive days having a time offset of *Δt*, the SNR values reported for all the available GPS SVs were almost identical. Nevertheless, these values were unique in different road segments emanating from the same node (within the same proximity) due to the different geometrical distribution of the surrounding terrains and buildings. This has led us to conclude that each PD region within the same proximity has its unique consistent signature. If such a signature could be revealed while the GPS receiver roves into a certain PD region, then it could be relied on the GPS data and map-matching algorithms *solely* to identify one's location. The advantages of applying this method for position determination are twofold. First, using the GPS data alone along with map matching techniques would eliminate the need to couple the GPS receiver with external positioning systems. Thus, the GPS receiver, a map, and appropriate map matching algorithms would be sufficient and reliable enough for position determination. Second, this new proposed system would prove to be useful whenever it is applied for personnel navigation, since it would not be practical to install additional sensors on pedestrian personnel. Employing the proposed method would require further research. Basically, development of two algorithms: 1- development of an automatic algorithm that estimates the SNRs of the visible GPS SVs *in real time* for the specific region of interest would be desired. This algorithm would require a digital 3-D map of the terrains and buildings for the urban areas of interest. Such 3-D maps could be constructed and frequently updated with the aid of aerial images. 2- development of another algorithm that correlates the estimated SNRs to the SNRs measured by the GPS receiver would also be required.

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