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LEO based Satellite Navigation and Anti-Theft Tracking System for Automobiles

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Abstract: GPS and Inertial Navigation Systems (INS) are used today in automobile navigation and tracking systems to locate themselves in Four Dimensions (latitude, longitude, altitude, time). However, GNSS or GPS still has its own bottleneck, such as the long initialization period of Precise Point Positioning (PPP) without dense reference network. For navigation, a number of selected LEO satellites can be equipped with a transmitter to transmit similar navigation signals to land users, so they can act like GNSS satellites but with much faster geometric change to enhance GNSS capability, which is named as LEO constellation enhanced GNSS (LeGNSS). This paper focuses on Low Earth Orbit navigation and anti-theft tracking system in automobiles that represents a framework which enables a navigating vehicle to aid its Inertial Navigation System when GNSS or GPS signal becomes unusable. Over the course of following years LEO satellite constellation will be available globally at ideal geometric locations. LEO Satellite aided Inertial navigation system with periodically transmitted satellite positions has the potential to achieve meter-level-accurate location.
Keywords: LEO constellation, LEO enhanced GNSS (LeGNSS), Precise Point Positioning (PPP), Inertial Navigation System (INS), Precise Orbit Determination (POD)

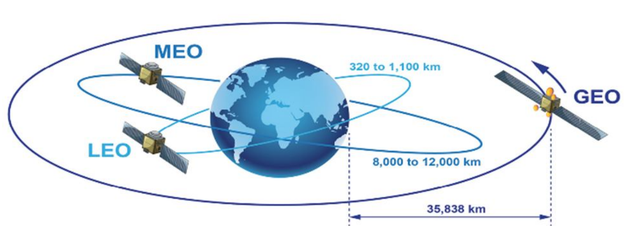
I. OBJECTIVE

The main objective of a LEO-based navigation and tracking system is to provide vehicle navigation services with precise point positioning and to implement anti-theft measures.

II. INTRODUCTION

The GNSS systems, mostly consisting of Medium Earth Orbit (MEO) satellites, have been providing accurate Positioning, Navigation and Timing (PNT) worldwide as a result of the modernization of GPS and GLONASS and the rapid development of Galileo and BDS. With the development of GNSS systems, GNSS positioning techniques have evolved continuously. Due to its superiority of standalone receivers, cost-efficiency, and accuracy satisfactory for most applications, Precise Point Positioning (PPP) has been proven to be very promising. PPP is limited in its wide applications because of its long initialization time. The long convergence time is largely due to the lack of precise atmospheric delay corrections. A dense network of reference stations is often required to obtain instantaneous positioning results with high precision, such as in Network Real Time Kinematics (NRTK), regional augmentation Precise Point Positioning (PPP) that is also named as PPP-RTK . It should be noted, however, that in case of unreliable GNSS signals (such as in deep urban canyons or near dense foliage), unreliable (such as due to intentional jamming or unintentional interference), or untrustworthy (such as attacks by malicious spoofers on systems), Navigation systems rely on unaided inertial measurement unit (IMU) data, in which case errors accumulate and eventually diverge, compromising the vehicle's efficiency and safety. GNSS-challenged environments could use signals of opportunity as PNT sources. Signals such as AM/FM radio, cellular and digital television are broadcast through low-Earth orbit (LEO) satellites. A meter-level accuracy solution based on signals of opportunity has been demonstrated on ground vehicles. LiDAR and INS have also been assisted by these signals.

INS systems operating in GNSS-challenged environments find that LEO satellites are particularly helpful aiding sources. First, because LEO satellites are 20 times closer to Earth than GNSS satellites in medium Earth orbit (MEO), their received signals are much stronger. Second, the orbital speed of LEO satellites is very fast compared to that of GNSS satellites, so their measurements of Doppler are very useful for LEO satellites.



Finally, the recent announcements by OneWeb, Boeing, SpaceX (Starlink), Samsung, Kepler, Telesat, and LeoSat concerning the provision of broadband internet via satellites will collectively lead to the launch of thousands of new LEO satellites, making their signals abundant and diverse in frequency and direction. Following is a list of existing and future LEO satellite constellations.

System	*Number of satellites*	*Frequency band*
Orbcomm	50	VHF
Globalstar	48	S and C
Iridium	66	L and Ka
OneWeb	648	ku and Ka
Boeing	2956	V and C
SpaceX	30000	Ku, Ka, and V
Samsung	4600	V

III. COMPONENTS OF LEO SATELLITE

Components of LEO satellites are (i) The LEO space segment (ii) the ground tracking network station (iii) LeGNSS positioning service principles.

A. The LEO Space Segment

LEO based global navigation system is a constellation that combines GNSS with a correct LEO constellation. Iridium is the largest LEO constellation operational today, consisting of 66 Low Earth Orbit polar satellites and providing voice and data services to satellite phones, pagers, and integrated transceivers throughout the entire globe. Our study uses the BDS, GPS, and Iridium satellites as the space segments of LeGNSS due to their stability and diversity of orbits. In its initial design, the GPS constellation had 24 satellites in six orbits with an inclination of 55°. In the Iridium constellation, there are 6 orbital planes spaced 30° apart and containing 11 satellites each. Its altitude and inclination is 780 km with an inclined angle of 86.4°. Near-polar circular orbits of the Iridium satellite can fully cover the entire Earth.

B. Ground Tracking Network Stations for Legnss

Inviting the GNSS ground tracking network, its aim is to rapidly achieve good geographic coverage for multi-GNSS data processing. In September 2013, the MGEX network had almost 90 stations, built from voluntary contributions by various national agencies, universities, and other institutions. All previous MGEX stations were integrated into the official IGS network in 2016. Let us assume that all these stations support the frequency bands of the LEO constellation. To make things easier, here we assume the same frequency range as GPS for the LEO constellation. They send back signals received from GNSS above and receive them from the satellites of LEO based global navigation system.

C. Legnss Positioning Service Principles

Signals are received by the LEO receivers from satellites above, such as GEO, IGSO, and MEO satellites. All satellite signals can be received at the ground stations. Ground station data can be streamed in real-time to a computation center in order to be processed. Different processing approaches are required for LEO data depending on which communication approach is used, such as centralized processing in a computation center or distributed processing at the individual LEO. Users will be able to view the generated products in real-time.

LeGNSS is likely to provide precise positioning based on its accuracy and time of convergence. With the recruitment of the fast-moving LEO constellation, the orbits of high Earth orbit satellites, especially the GEO satellites, are also believed to be improved.

IV. A REVIEW OF THE NAVIGATION AND TRACKING ERRORS IN LEO SYSTEMS

A discussion of LEO-based positioning errors is presented in this section: (i) satellite position and velocity errors, (ii) satellite and receiver clock errors, and (iii) ionospheric and tropospheric delay rate errors.

A. Errors in Position and Velocity

Navigating with LEO satellite signals requires consideration of the possibility of errors due to imperfect knowledge of the satellites' positions and speeds. The reasons for this are time-varying Keplerian elements caused by several perturbing accelerations that act on the satellite. File sets containing two-line elements (TLE) contain mean Keplerian elements and perturbing acceleration parameters. These files may provide input to the simplified general perturbations (SGP) model, which is specially designed to propagate the orbit of a LEO satellite. The speed of the SGP propagator is important in propagating a satellite position from one time to another (e.g., the SGP4) is improved by replacing complicated perturbing acceleration models with analytical expressions rather than numerical integrations. There is a tradeoff in satellite position accuracy caused by the SGP4 propagator's 3 km position error at epoch, and the propagated orbit will continue to deviate until the TLE files are updated the following day.

B. Clock Errors

LEO satellite clocks are not tightly synchronized and their clock errors (bias and drif) cannot be detected by their receiver, unlike GNSS. Additionally, LEO satellites usually do not have high-quality atomic clocks. The existing LEO constellations are equipped with oven-controlled crystal oscillators (OCXOs. In practice, the navigation receiver will be fitted with a low-quality oscillator, for instance, a temperature-compensated crystal oscillator (TCXO).

C. Ionospheric Delay Errors

Broadband constellations, on the other hand, are mostly located above the ionosphere, so their signals are delayed. Despite LEO satellite signals propagating through the troposphere, they have a lesser effect than ionosphere signals. There are two factors that determine the magnitude of the ionospheric delay rate: (i) the square of the carrier frequency and (ii) Time evolution of the satellite's elevation angle determines how the obliquity factor changes over time. TECV is the rate of change of the total electron content at zenith, which affects ionospheric delay rates as well. Due to the fact that TECV varies much slower than the satellite's elevation angle, its effect can be ignored. Signals sent by LEO satellites are significantly affected by ionospheric propagation since (i) their high-speed results in very rapid elevation angle changes (ii) Some LEO satellites transmit in the VHF band where signals experience very high delays.

V. OPTIMAL SOLUTION TO OBTAIN HIGH PRECISION POSITIONING

The precise determination of satellite orbits and clocks can be performed by three types of observation resources, GNSS signals sent to LEO satellites (LEO onboard receivers), GNSS signals sent to ground tracking stations, and LEO satellite signals transmitted to ground tracking stations (ground receivers for LEO signals), respectively, are used to measure this. Ideally, we should process all observation data collected at all stations and by all satellites in a single robust estimation process. Sadly, the computation burden would make a real-time service of a large constellation of LEO satellites improbable. Two steps are necessary to schedule the task. In the first stage, we ignore LEO data in order to generate precise orbits and clocks of the GNSS satellites. In the second stage, fixed GNSS orbit and clock products are used to estimate LEO orbits and clocks. As a result of its computational efficiency, this processing can be carried out even onboard LEO satellites, but LEO's contribution to GNSS Precise Orbit Determination (POD), especially for GEO and IGSO satellites, has not been evaluated. By including a certain number of LEO satellites in the first step, processing can be improved. Additionally, a ground tracking network and observations from their onboard receivers can also be used to estimate LEO orbits and clocks, which may improve LEO products when compared with using only onboard data. By using data from a ground network to LEOs, it would be possible to calculate LEO orbits and time without a GNSS system, which would mean a navigation service based on the LEO constellation. Finally, users can obtain precise positioning results anywhere, anytime using the high-precision LeGNSS products broadcast via Internet.

VI. ANTI-THEFT TRACKING USING LEO SATELLITE FOR GROUND VEHICLE MODEL

An effective car anti-theft tracking system can be implemented using an in-vehicle system occupied with LEO satellite aided Inertial navigation system with periodically transmitted satellite positions. The user will be able to track the position of targeted vehicles even if the GPS signal is lost. The LEO satellite aided system will incorporate a module based system which will have LEO module, GEO based GPS system which are traditionally used and IMU with accelerometer and gyroscope. These modules will be embedded into the automobile and the user will have a state of the art user interface with all the information and data from these modules.

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VII. PUBLIC SURVEY

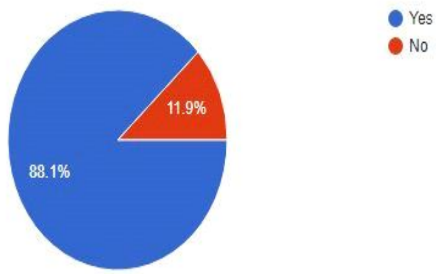
In order to test people's knowledge on current navigation and anti-theft tracking system, we used an online form and data collection services.

A. Questionnaire

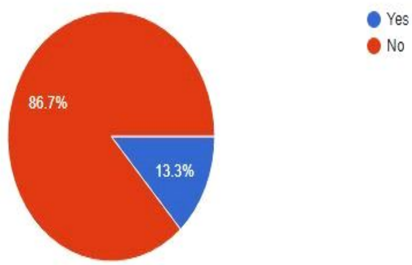
1) Do you use Navigation System?
2) Have you heard about LEO based navigation system?
3) Do you have pre-installed anti-theft tacking system in your vehicle?
4) Would you like to have LEO based anti-theft tracking system in your automobile as a security feature?
5) How likely are you willing to pay extra money to upgrade or install LEO based anti-theft tracking system in your vehicle?
6) Do you face any problem using current GPS navigation system?
7) How accurate do you think is the current GPS system used for navigation?

B. Result

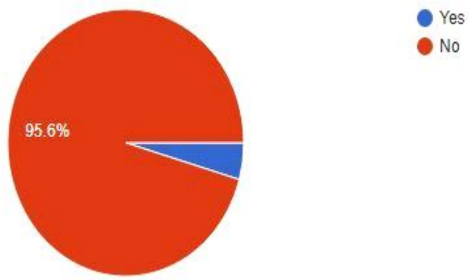
When people were asked whether they use navigation system, about 88.1% use navigation system and 11.9% don't use navigation system



When asked about the LEO-based navigation system, 86.7% were unaware of it, while 13.3% had heard of it.



When people were asked whether they have pre-installed anti-theft tracking system in their vehicle, only 4.4% had pre-installed tracking rest 95.6% don't have pre-installed tracking system in their vehicle.



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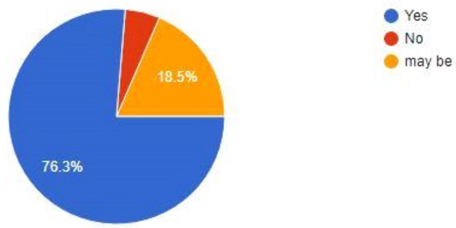
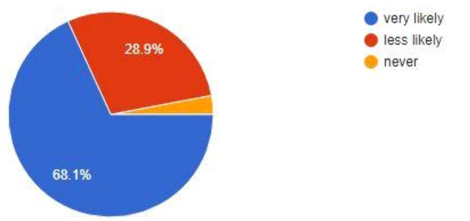
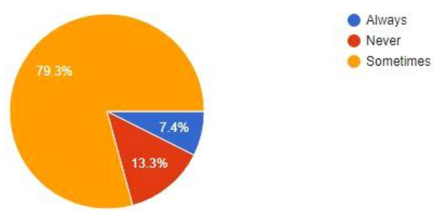
When people were asked whether they would like to have LEO based anti-theft tracking system in your automobile as a security feature, 76.3% were interested, 18.5% were uncertain or neutral and rest 5.2% were not interested.



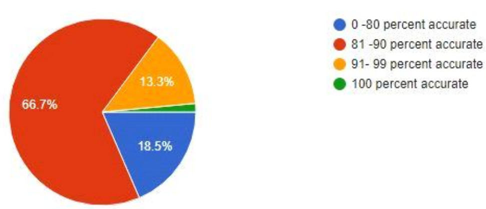
When people were asked whether they are willing to pay extra money to upgrade or install LEO based anti-theft tracking system in your vehicle, 68.1% were willing to pay, 28.9% were uncertain and 3% were not willing to pay.



When people were asked whether they face any problem using current GPS navigation system, 79.3% experienced problems sometimes, 13.3% never encountered any problems, and 7.4% experienced problems constantly.



When people were asked about the accuracy of current GPS system used for navigation, only 1.5% agreed to 100 percent accuracy, 18.5% agreed to 0-80 percent accuracy, 66.7% agreed to 81-90 percent accuracy and 13.3% agreed to 91-99 percent accuracy.



VIII. HYPOTHESIS TESTING

In hypothesis testing, one analyzes data from a sample to make inferences about a population parameter or distribution of probabilities. The first step is to formulate a hypothesis regarding the parameter or distribution. This is known as the null hypothesis, abbreviated as H0. Following this, an alternative hypothesis (denoted Ha) is defined, which is the polar opposite of the null hypothesis. Hypothesis-testing determines whether or not H0 can be rejected based on sample data. When H0 is rejected, the alternative hypothesis Ha is true.

For this paper,
Null hypothesis (H0): LEO based navigation/tracking system is more accurate than current navigation system.
Alternative hypothesis (Ha): LEO based navigation/tracking system is not accurate than current navigation system.

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A. *Test (Statistics)*

There are 3 tests available to determine if the null hypothesis is to be rejected or not. They are:

1) Chi-squared test
2) T-student test (T-test)
3) Fisher's Z test.

In this paper,
We will be using a two-tailed T-student test.
When two groups are related in some way, a t-test determines whether there is a significant difference between their means.

B. *Level of Significance*

The significance level (also known as alpha or α) is the probability of rejecting the null hypothesis when it is true. There is a 5% possibility of finding a difference if there isn't one at a significance level of 0.05, for instance. A lower significance level indicates that more evidence is needed to reject the null hypothesis.

C. *Level of Confidence*

The confidence level indicates how likely it is that the location of a statistical parameter measured in a sample survey will be accurate for the entire population.

Sr no.	Data
1	88.1
2	13.3
3	4.4
4	76.3
5	68.1
6	86.7
7	85.5
Mean (x)	60.342857142857
Standard Deviation (s)	35.952461999278

Level of significance = 0.05 i.e. 5%
Level of confidence = 95%
A t-score (t-value) is the number of standard deviations away from the t-mean Distribution's.

The formula to find t-score is:
$t = (x-\mu) / (s/\sqrt{n})$
Where x is the sample mean,
μ is the hypothesized mean,
s is the sample standard deviation, and n is the sample size.
P-value, or probability value, indicates how likely your data is if the null hypothesis is true. We can calculate the p-value once we know the value of 't'. In the case where the p-value is less than the alpha level, then the null hypothesis can be rejected, and we can conclude that LEO based tracking and navigation is not as accurate as the existing system.

<u>Calculating t-value</u>:

Step 1: Determine what the null and alternative hypotheses are.
Null hypothesis (H0): LEO based navigation/tracking system is more accurate than current navigation system.
Alternative hypothesis (Ha): LEO based navigation/tracking system is not accurate than current navigation system.

Step 2: Find the test statistic.
In this case, the hypothesized mean value is considered 0.
$t = (x-\mu) / (s/\sqrt{n}) = (60.342 - 0) / (35.952 / \sqrt{7})$
$= 4.441$
Calculating p-value:

Step 3: Calculate the test statistic's p- value.
To calculate the p-value, we use the t-Distribution table with n-1 degrees of freedom. In this case, the sample size is 7, so n-1 = 6.
In this case, the calculator provides a p-value of 0.0043728, which is less than the alpha level we selected, and consequently the null hypothesis can be rejected.

IX. CONCLUSION

Although LEO based navigation and tracking system might not be as accurate as current navigation system, there is still room for improvement, which leads us to LEO based navigation and tracking system. In the future, more research will be done on LEO, making it a safer and more effective option. In addition to being more accurate than the traditional navigation system, LEOs assist in tracking and anti-theft measures will make our automobiles safer and less vulnerable to theft.

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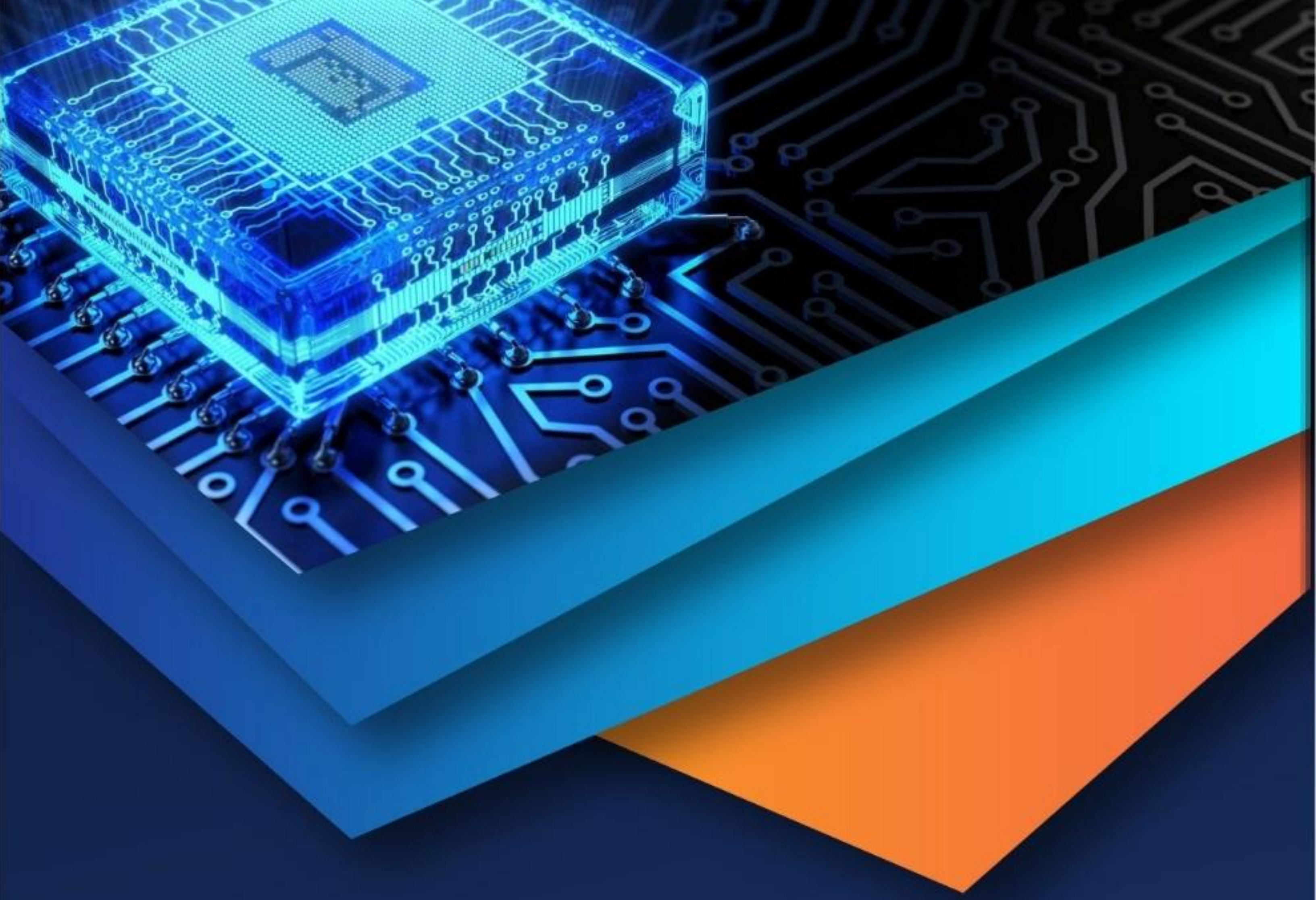

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