LONG RANGE AUTONOMOUS WEB-BASED TRACKING SYSTEM FOR MOVEMENT MONITORING USING INTEGRATED LORA-GPS DEVICES

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ABSTRACT

Remote tracking system in general is a device that provides user with location information of the tracked object or target. The tracking industries have become important today as the demand for tracking of many sorts have increased, either for livestock, ships, city busses or even for personal. There are various tracking methods, including Global Positioning System (GPS) integrated ones like Global System for Communication (GSM) trackers and non-GPS methods like VHF trackers. GPS integrated remote tracking system are most common and found to be more practical as the information provided to the end user is in the form of target display or GPS coordinates which is straight forward and convenient. However, these methods have their limitations and constrains especially concerning power consumption, cost, coverage, data security and self-dependability. There are few low power wireless technologies available today such as the Zigbee and Sigfox. In this thesis, a movement tracking system was developed based on the consolidation of the relatively new Long Range (LoRa) wireless technology and the GPS device integrated using Arduino board as the microprocessor especially due to its low power requirement and long range communication capability. The system was first designed, assembled and tested for its detectability in many parameters range, environment and movements settings, and also for its accuracy. The result for all the detection test reveals that despites the system's simple infrastructures, the system which was later introduced as the Find-X-Tech has an exceptional range of detection which is up to 5 kilometers radius as well as stable detection in many environment settings. At some points, observation unravel blind spots which is found to be due to geographical conditions. In terms of detectability in different movement settings, the test reveals that at straight road and sharp corners or U-turn, the detectability of Find-X-Tech are not affected. The accuracy test performed also found that the Find-X-Tech has an adequate accuracy range of 4.18 meters' radius. Through all the tests performed, it is concluded that the Find-X-Tech is not only usable but also a reliable form of GPS integrated based tracking method. In terms of cost, the development and operations of the Find-X-Tech system which includes independent infrastructures, are beyond doubt extremely lower compared to other GPS based movement tracking systems. The power consumption is also much lower as the Find-X-Tech system only powered using 5 volt direct current for both its transmitter and receiver. In terms of the physical portability, the signal receiving station can be effortlessly moved by users to cater to their specific coverage needs in different locations. The Find-X-Tech tracking system also ensures high level of data security through its direct point-to-point GPS data transition design. With no involvement of third parties, the system leaves no room for data exploitation by external parties, safeguarding the integrity and confidentiality of the information. The Find-X-Tech system has solved or at least greatly improved the constraints and limitations faced by the conventional GPS based tracking device.

ABSTRAK

SISTEM PENJEJAK JARAK JAUH BERAUTONOMI BERASASKAN WEB UNTUK PEMANTAUAN PERGERAKAN MENGUNAKAN INTEGRASI ALATAN JARAK JAUH (LoRa) - SISTEM KEDUDUKAN SEJAGAT (GPS)

Umumnya, sistem penjejak jarak jauh secara adalah alat yang memberikan pengguna maklumat kedudukan suatu objek yang sedang dipantau. Industri penjejak menjadi penting dengan permintaan yang pelbagai, tidak kira untuk ternakan, kapal laut, bas bandar atau kegunaan peribadi. Ada banyak kaedah penjejakan, termasuk penjejakan yang diintegrasi dengan Sistem Kedudukan Sejagat (GPS) seperti penjejak Sistem Global Untuk Komunikasi (GSM) dan ada yang tidak seperti penjejak Frekuensi Sangat Tinggi (VHF). Sistem penjejak jarak jauh yang diintegrasi dengan GPS adalah yang paling biasa digunakan dan didapati lebih praktikal kerana maklumat yang dibekalkan adalah dalam bentuk paparan koordinat di mana ia adalah jelas dan mudah. Walaubagaimanapun, kesemua kaedah ini mempunyai had dan kelemahan yang berkaitan dengan penggunaan tenaga, kos, liputan, keselamatan data dan keberdikarian. Terdapat beberapa teknologi kuasa rendah tanpa wayar yang wujud pada hari ini seperti Zigbee dan Sigfox. Dalam tesis ini, alat penjejak dibangunkan berpandukan penggabungan teknologi tanpa wayar yang relatifnya baharu iaitu Jarak Jauh (LoRa) dan alat GPS yang diintegrasi menggunakan papan Arduino sebagai mikropemproses terutamanya kerana penggunaan kuasanya yang rendah dan kebolehan komunikasi jarak jauhnya. Pada mulanya, sistem ini direkabentuk, dibina dan diuji untuk keupayaan pengesanan dalam banyak julat parameter, jenis persekitaran serta pergerakan, dan juga ketepatannya. Didapati bahawa walaupun dengan infrastruktur sistem yang mudah, sistem yang kemudiannya diperkenalkan sebagai Find-X-Tech ini mempunyai jarak pengesanan sehingga 5 kilometer radius dengan kebolehkesanan yang stabil dalam banyak jenis persekitaran. Pada suatu tahap semasa ujian, pemerhatian mendapati terdapat titik-titik buta yang disebabkan oleh keadaan geografi. Dari segi kebolehkesanan pada set pergerakan yang berbeza, keputusan ujian pada jalan lurus dan selekoh tajam atau pusingan-U menunjukan kebolehkesanan Find-X-Tech adalah tidak terjejas. Ujian kejituan yang dijalankan juga mendapati Find-X-Tech mempunyai julat ketepatan yang memuaskan iaitu pada julat 4.18 meter radius. Daripada semua ujian yang telah dijalankan, disimpulkan bahawa Find-X-Tech bukan sahaja boleh digunapakai tetapi juga adalah satu bentuk kaedah menjejak berasaskan integrasi GPS yang boleh dipercayai. Dari segi kos, pembangunan dan operasi sistem Find-X-Tech termasuk infrastruktur bebasnya tidak boleh disangkalkan jauh lebih rendah berbanding dengan sistem penjejak pergerakan berasaskan GPS yang lain. Penggunaan tenaga juga adalah lebih rendah di mana ia boleh dioperasikan hanya dengan 5 voltan arus terus untuk penghantar dan penerima. Dari segi kemudah-alihan fizikal, stesen penerima sistem boleh dipindahkan secara mudah oleh pengguna untuk memenuhi kawasan liputan spesifik mereka di kawasan-kawasan yang berbeza. Sistem pengesanan Find-X-Tech juga memastikan tahap keselamatan yang tinggi melalui reka bentuk transisi data GPS secara terus dari titik ke titik. Tanpa melibatkan pihak ketiga, sistem ini tidak memberi ruang untuk eksploitasi data oleh pihak luar, menjamin integriti dan kerahsiaan maklumat. Sistem Find-X-Tech telah menyelesaikan atau sekurang-kurangnya telah mengurangkan kelemahan dan limitasi sistem penjejak berasaskan GPS yang konvensional.

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LIST OF ABBREVIATION

GPS	-	Global Positioning System
LoRa	-	Low Power Long Range
GSM	-	Global System for Mobile Communications
VHF	-	Very High Frequency
IoT	-	Internet of Things
SMS	-	Short Message Service
GEO	-	Geostationary
MHz	-	Megahertz
ASM	-	Academy of Sciences Malaysia
GNSS	-	Global Navigation Satellite System
BDS	-	BeiDou Navigation Satellite System
GLONASS	-	Global Navigation Satellite System
GALILEO	-	Global Navigation Satellite System
ISM	-	Industrial, Scientific, and Medical
DBPSK	-	Differential Binary Phase-Shift Keying
GFSK	-	Gaussian Frequency Shift Keying
LPWAN	-	Low-Power Wide-Area Network
AES	-	Advanced Encryption Standard
IDE	-	Integrated Development Environment
GPIO	-	General Purpose Input Output
OS	-	Operating System
BTS	-	Base Transceiver Station
USB	-	Universal Serial Bus
HTTP	-	Hypertext Transfer Protocol
MySQL	-	Structured Query Language
IP	-	Internet Protocol
LAN	-	Local Area Network
POS	-	Position

RF	-	Radio Frequency
TDOA	-	Time Difference of Arrival
kHz	-	kilohertz
km	-	Kilometer
km/h	-	Kilometer per hour
m	-	Meter
V	-	Volt
SAR	-	Search and Rescue
UAV	-	Unmanned Aerial Vehicles

CHAPTER 1

INTRODUCTION

1.1 Background

A remote tracking device is a device that provides the end users with a timely ordered sequence of location data that leads the end users to the subject's physical location. Location data from a tracking device for example vehicle tracking device is typically presented in the form of coordinates or widely known as GPS data (D.E. Struble & J.D Struble, 2020). The GPS data consist of latitude and longitude coordinates that are sourced from the GPS module inside the transmitter of the tracking device. The GPS data is then transmitted to end users through diverse wireless methods, each of which possesses unique advantages and disadvantages (Rekha et al., 2020). Such common type of remote tracking device which utilize the GPS module for its coordinates is known as the GPS based integrated tracking device in this thesis.

Movement monitoring of certain objects or targets is important to some researches, biologists, companies, authorities and even personal (Dempsey & Forst, 2016). It has been an important part in many sectors and have been essentials in many industries. It allows end users to monitor the movement of their precious assets or test subjects for many reasons including safety, time management or data analysis. Movements are hard to be monitor trough visual especially when it comes to long range movements, or movement on poor visibility areas, for example to track an animal (Jachmann, 2001), which is hard to be constantly viewed or monitored especially if the animal is not under captivity. Logically, subject which needs to be constantly monitored especially those with wide range movements are not practical to be wired. Due to the matter, wireless technology which uses radio frequency is often been used as a medium between the subject and the end-users. It is use to convey information such as the GPS data to the end user.

Existing and commonly used non-GPS based tracker for example the Very High Frequency tracker or known as the VHF tracker and the GPS based tracking device such as the GSM-GPS integrated tracker and Satellite–GPS based tracker are all using wireless radio-frequency to transmit information to the end user or base station. Similar to the basics of the mentioned existing tracking systems, a form of wireless technology called LoRa is futher explored in this thesis. Despite being invented over a decade ago (Slats, 2020), the integration of LoRa wireless technology with GPS has resulted in a unique tracking system, which is still considered a new form of technological advancement in today's world. This combined system offers distinctive capabilities that make it stand out in the field of tracking and monitoring.

The LoRa technology ultra-long range signal reachability on low power helps the LoRa–GPS integrated tracking system to be independent to reach great distances, unlike other wireless GPS based tracking system which needs the affiliation with third party wireless signal provider to achieve such coverage. The integration of LoRa wireless capability with GPS functionality has also garnered attention among researchers. Notably, Calabrò, A., & Giuliano, R. (2021) introduced an innovative concept involving a GPS integrated LoRa tracker device designed for localizing individuals or victims in Search and Rescue (SAR) operations. Their proposed solution incorporates an integrated Wi-Fi sensor strategically positioned on top of Unmanned Aerial Vehicles (UAVs) or drones, enhancing the effectiveness of SAR missions.

The user of the fully develop LoRa-GPS based integrated tracking system has full control of the system operation parameters, especially the location of the receiver. The location of the receiver setup is important in any telecommunication system as it may affect the coverage (Penttinen, 2015). Most signal provider focused on common area which resides by most of its users, setting aside specific areas that needed by some specific tracking operations. With the LoRa – GPS based integrated tracking system, the location of the receiver can be change to suits the coverage locality required by the user.

1.2 Problem Statement

In the previous sections, we have discussed limitations, especially those related to GPS-based integrated tracking systems. This section elaborates on these limitations and constraints. In GSM-GPS integrated tracking, GPS data is generated by the tracker's module, which sends latitude and longitude coordinates as text via SMS. This SMS traverses multiple terminals, including SMS centers and telecom towers, before reaching the end user (Daniel, 2017). Using a web platform for GSM-GPS tracking, these GPS coordinates are transmitted via SMS to a web server managed by the host, allowing users restricted web access to view the transmitter's location. Globally, GSM bands are limited, with Asia Pacific predominantly utilizing GSM Band 8 (900 MHz) and GSM Band 3 (1800 MHz) as per ITU-R M.2070-0 (2015). Figure 1.1 shows example of existing GSM-GPS based integrated tracking device transmitter.

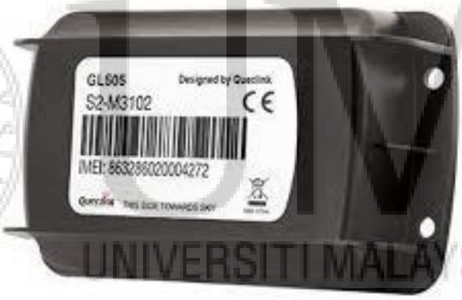

Figure 1.1 : Example of GSM-GPS tracking device
Source : Queclink Wireless Solution Co., Ltd.

GSM-GPS tracking has a long history of use in diverse industries and is considered highly practical. Nevertheless, it has inherent limitations and constraints that require addressing. The GSM–GPS based integrated tracking system operations rely solely on the availability of the GSM provider signal (Ifeoluwa, A. & Francis, I., 2023), the coverage is also more limited than the satellite-based tracker (Silvy, 2012). GSM-GPS integrated tracking devices require active GSM signal coverage to transmit GPS data to end users or the tracking system provider's webserver, making them non-functional in areas without GSM signal coverage. GSM infrastructure is primarily designed for wireless voice traffic (König-Ries et al., 2002), posing challenges for users such as researchers who require tracking in remote areas like deep forests or deserts with no GSM provider signal are available. GSM–GPS based integrated tracking devices operation is also costly, as it may involves sending hundreds of SMS during the tracking session. Cost also incurred when the GSM line need to be maintained by paying the subscription fees even when not in use (Nemati, 2008). GSM devices, including older cellphones without power-hungry processors or bright displays, are still significant power consumers, especially during calls or SMS transmissions. (Sauter, 2011). Such situation causes problem for GSM based transmitter with small battery capacity.

In Satellite-GPS integrated tracking systems, GPS data from the transmitter device is transmitted to the tracking service provider via satellite data services. For example, In Iridium's Satellite-GPS integrated tracking system, GPS data from the ground transmitter is relayed to Iridium satellites in space. It is then relayed from one satellite to another and then to the ground station (Ilčev, 2020) for further distribution to reach end users. In this case, GPS data collected by satellites is transmitted to the ground station, typically a webserver accessible to end users for viewing transmitter location and information. Satellite data service frequencies vary by provider; for instance, Iridium satellites use frequencies between 1616 MHz and 1625 MHz for ground communication. (Pandya, 2000). The Figure 1.2 shows some examples of existing satellite data-based tracking device transmitter.

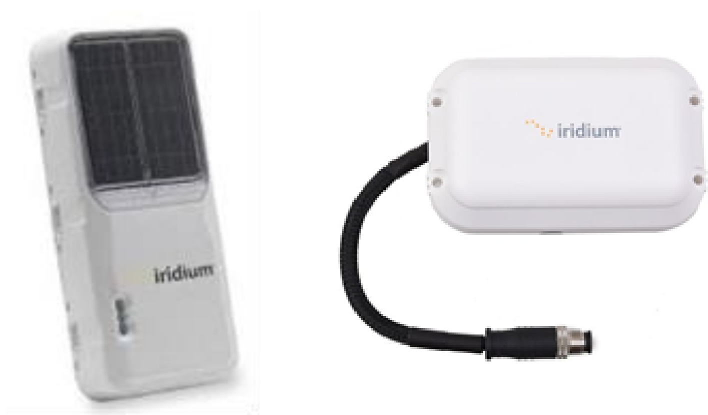

Figure 1.2 : Example of Satellite-GPS tracking devices

Source : Iridium Communications Inc.

Satellite-GPS integrated tracking methods, like GSM-GPS ones, have been widely used for decades, proving effective. However, it's essential to recognize their limitations and constraints. For example, Satellite-GPS integrated tracking devices use satellite data services, like GEO satellites, to relay GPS data, which can be costly to operate. (Jiang & Luo, 2022). The option of the transmitter hardware is also limited as it is usually provided by the satellite data service provider via direct purchase or rental. Similar to the GSM-GPS tracker, the device operation dependability relies solely on the satellite data provider coverage availability.

Not to forget the security and privacy issues arises as the satellite data are exposed to the satellite data provider system before to the end user (Prasad, et al., 2011), which could be harmful if the data are exploited. Such security issues also applied to the GSM–GPS based integrated tracking system. Another limitation shared by both tracking methods is users have no control over the receiver system, including antenna location, type, sensitivity, and more. User especially of the GSM-GPS based integrated tracking system have to accept the flaw of the coverage provided by the GSM signal provider as it is. These limitations and constraints have placed a burden on users, underscoring the need for the development of new GPS-based tracking systems to create a more user-friendly tracking environment.

1.3 Research Objectives

The objectives of this research are:

i. To design and to develop a complete and reliable long range autonomous web-based tracking system for movement monitoring using integrated LoRa-GPS devices.

ii. To evaluate the performance of the developed long-range autonomous web-based tracking system in various scenarios, including different speeds, U-turn maneuvers, and diverse environments such as hilly terrain, winding roads, flyovers, dense housing areas, shop lots areas, normal housing areas, and highways

iii. To assess the positioning accuracy of the developed movement tracking system.

1.4 Contribution of The Thesis

Conventional types of GPS based locating device have been used for the past years for wide range tracking activities (Vignudelli et al., 2011). These activities may include animal, vehicle, fleet or personal tracking or any type of tracking that involves long range and wide area movement that ranges to few or even tens of kilometers away. As discussed earlier, these conventional types of tracking device have their constraints or limitations. However, most users accept these limitations as it is, as if it is a package that comes together with the system and devices and nothing much can be done to solve or even to improve the matters. Through the development of the web-based tracking system for movement monitoring using integrated LoRa-GPS devices, this thesis aims to develop a much improved and ideal version of GPS based tracking device compared the conventional.

In General, there are three main contributions presented by this thesis. The first contribution is the development of a wide range tracking device that the overall cost to obtain and operate is lower. Expensive tracking devices as currently available in the market today, together with the operation and maintenance cost incurred restrict the usage of tracking device in certain field where budget is limited. With low obtaining and operation cost, more fields and sectors can benefit from the tracking device proposed in this thesis. Second contribution of this thesis is that the developed tracking system giving the user the ability to control the tracking coverage, as the proposed tracking system design is a standalone system which includes the user to handle and set up not only the tracker transmitter system, but also the receiver system, hence controlling the tracking coverage area to match their areas of interest. The conventional tracking device especially the GSM-GPS tracking device, the coverage of tracker as discussed are solely depends on the GSM provider signal availability, and there is nothing much can be done if the area is not covered.

The third contribution of this thesis is the increased level of security in GPS data handling. The LoRa-GPS tracking system is a standalone tracking system with no third-party involvement. The GPS location data that is transmitted from the transmitter is directly received by the system receiver without any intermediaries. This eliminates the possibility of data exploitation by external parties.

1.5 Thesis Arrangement

It is important to note that this thesis is primarily based on the outcomes of two previously published papers in the ASM Science Journal (Puvok & Dayou, 2019) and Transactions on Science and Technology (Puvok & Dayou, 2022). Additionally, it also includes findings from a forthcoming paper currently in draft form for future publication. These three papers have been structured into chapters 4, 5, and 6, which follow a sequential arrangement. Each chapter comprises a concise literature review, methodology, results, discussions, and conclusions specific to the investigated topics.

Overall, this thesis is structured into seven chapters. The first chapter which provides an introduction to the tracking system, giving a general background. It also touches upon existing GPS-based tracking systems, highlighting the challenges and issues they often face. Additionally, the thesis highlights the contributions and presents a brief outline of the subsequent chapters.

Chapter 2 is the literature review that discusses the brief history of the of tracking methods which goes back to the primitive era until the development and the early beginning of the GPS system. This chapter also discusses other means of movement tracking technology which are available today. Specifications of the NEO-6M GPS module which were used in the development of the LoRa-GPS tracking system was also highlighted. This chapter also touched on others low power and long-range wireless technology together with variety of microprocessors available today which are possible for integration. This chapter is concluded with a summary of the literature review. Overall, the Chapter 2 provides deeper literature review contents and wider overview of the tracking system technology that provides overall view compared to the brief literature given in Chapter 4, 5 and 6.