ROLE OF THE INTERNET OF THINGS IN TUNNEL DESIGNING UNDER THE RANGE OF GEOLOGICAL CONDITIONS

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Abstract

Tunnel monitoring is one of the strategies to improve that must be carried out in order to guarantee the secure and trouble-free execution of the tunnel construction. Monitoring the development of tunnels using the Internet of Things (IoT) is being done due to the many benefits and functions it offers. During the last several years, optimizing the development of tunnels has emerged as a central focus of research and development efforts. This study investigated the uses of IoT technology in tunnel architecture. Global Positioning System (GPS), Radio Frequency Identification (RFID), Wi-Fi Position of fingerprint, and Ultra-Wideband (UWB) are only a few of the several methods that could be employed throughout the planning process of a tunnel to calculate the accuracy and frequency of the measurements. The GPS approach, which can anticipate high accuracy and frequency in the construction of tunnels, is suggested in this study. Finally, a comparative study indicates that the GPS technique outperforms other techniques by giving the greatest values of (25 meters and 1,575.42 megahertz) for both accuracy and frequency respectively. This reveals that these values are absolute, as the values for both accuracy and frequency must be the highest to demonstrate its increased reliability.

Keywords: Internet of things, Tunnel monitoring, Radio Frequency Identification, GPS, Ultra-Wideband, Wi-Fi Position of fingerprint, etc.

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1. Introduction

The design of tunnels is an area of study that is drawn from several disciplines, including seismic design, geological, geochemistry, and hydrogeology. The fundamental ideas of tunneling would be discussed in this study. Tunnels are becoming more prevalent as a result of newly available technology such as Tunnel Boring Machines (TBMs), roadway headers, reasonably safe blasting processes, and other similar things. The capacity of TBMs to dig tunnels at record rates has led to their widespread usage in modern construction. Tunnel design takes place in reservoirs or on subterranean roadways, although these kinds of constructions are not built as often as other kinds of buildings. A tunnel built for a roadway, for instance, would need to be able to withstand loads that come from the stone layer or any other excess material. On the other hand, tunnels that transport water will need to be able to withstand both exterior and eternal stresses. Figure 1 depicts the positions of the tunnel model's pressure point.

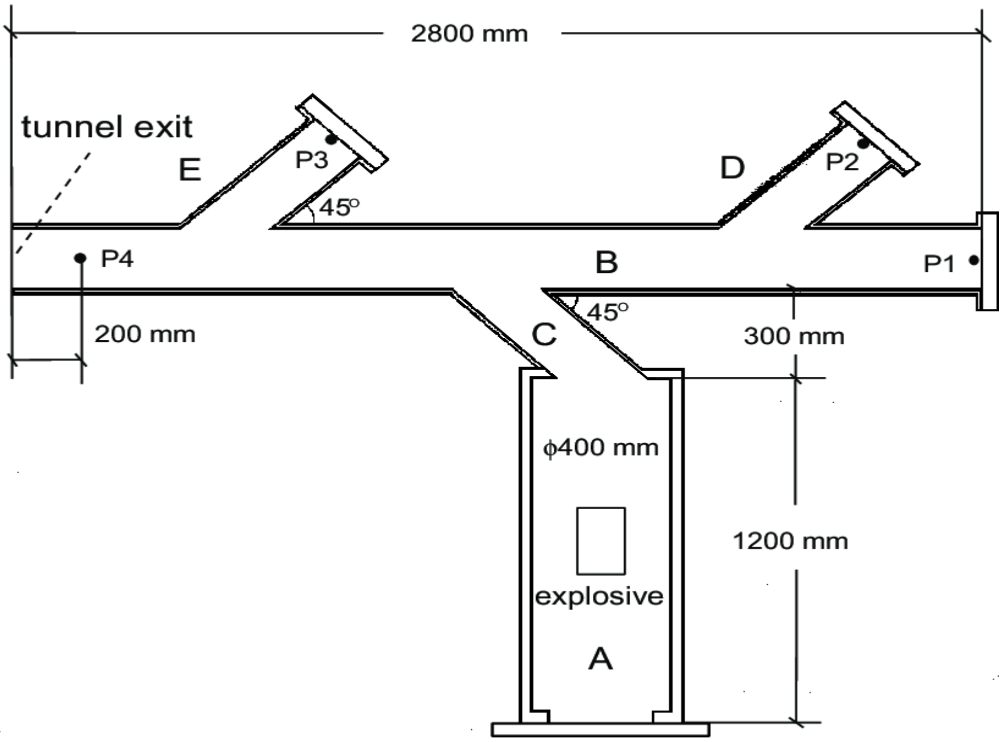

Figure 1: The tunnel model's pressure point positions [1]

TBMs are machines that are used to create tunnels that have circular cross-sections in a range of different types of geological environments. Due to the fact that it is highly effective, secure, and favorable to the environment, TBM is extensively employed in a variety of engineering projects, including the construction of hydraulic and hydroelectric systems, the building of transportation systems, and the development of municipal infrastructure. As a result of significant advancements in both the design and production processes of TBMs, recent years have seen an expansion of the uses of this mining method beyond soft rocks and into harder rock types. TBMs of today are capable of constantly and concurrently performing a variety of duties, including tunnel boring, scouring, and sustaining; a single operation could dig over 20 km of tunnel continuously. On the other hand, considering the high level of discipline and system coupling features, several obstacles need to be overcome in the design of the TBM. These obstacles include the following:

i. low efficiency in hard rock breaking.
ii. a rapid rate of tool wear.
iii. a high likelihood of becoming trapped.
iv. a lengthy period of excavating.
v. difficulties in precise control.
vi. a lack of flexibility to geological circumstances that are complicated.

1.1 Role Internet of things in tunnel designing

In all aspects of tunnel engineering, construction, and administration, the IoT is a frequent tool. This study makes use of the fundamental theory and technology of the IoT, conducts an analysis of the fit relationship between IoT technology and tunnel manufacturing, makes use of the extensive impression, synchronization, and the existing IoT system design equipped with intellectual auxiliary approaches, and it has effectively adapted this technique to tunnel engineering. Several project instances have shown that some methodologies, such as the RFID technique, wireless sensing networks, and the Zigbee transmission methodology, have high availability and are feasible. The construction monitoring system is able to realize the discovery of related environmental variables (including vulnerable harmful gases), as well as the traceability and placing of construction personnel, due to the ongoing advancement of the gathering automation of different multisensory data, the wireless internet transmitting, the security early detection, and the appropriate technical techniques of the building management system [2].

1.1.1 Railway Tunnel Construction

The building of a submarine tunnel almost invariably takes place in a very complicated setting. It is a well-known fact that high-pressure water would be present throughout the building of any metro connecting passageways [3]. It is of the utmost importance to gather data on stress-strain, displacement, and any other pertinent information in real time in order to minimize or do away with the possibility of a construction mishap. After then, the data that were obtained are instantly examined, and it is anticipated that the emergency measures will be immediately improvised in accordance with the circumstances at the construction site.

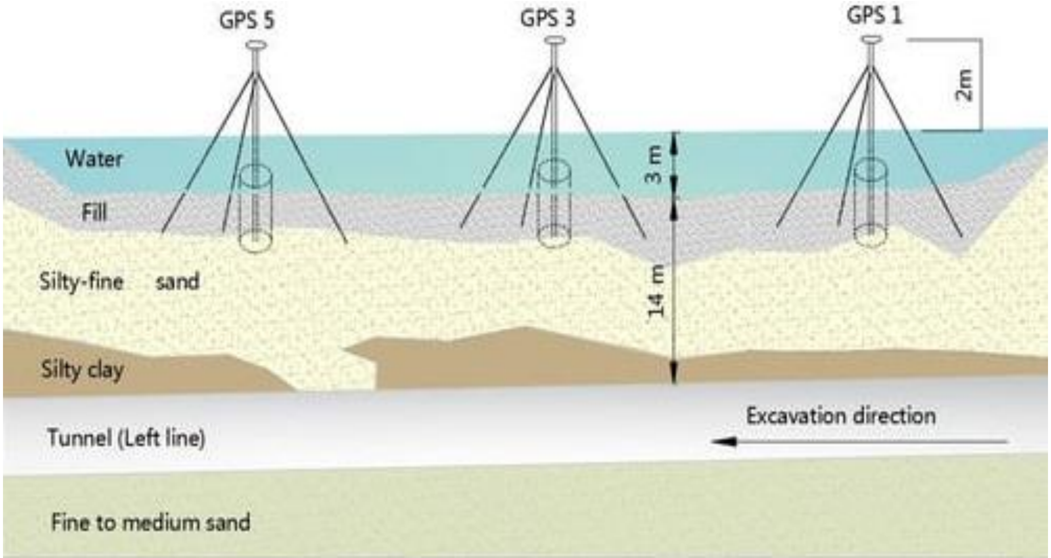

Figure 2: Architecture of tunnel engineering using IoT [4]

Based on the study learned from earlier GPS monitoring initiatives [4], a GPS monitoring network consisting of one access point (BASE) and six rover stations with the designations GPS1, GPS2, GPS3, GPS4, GPS5, and GPS6 was set up to collect data (Figure 2). The installation of the base station took place at the project's headquarters, which is about two kilometers distant from the river. The transmitter pole of a base station was constructed in the shape of an arch and mounted on a concrete block, which was then secured to the surface of a parking lot. Three solid steel bars provide an additional degree of stabilization to the antenna monument. In the immediate vicinity of the antenna are several huge trees, iron fences and roofs, and automobiles. It should come as no surprise that this location is not ideal for a reference station that is always operational Continuously Operating Reference Stations (CORS). Yet, it is a safe site and is capable of providing dependable current flows (AC) for power sources and a lightning-fast online connection for data exchange, both of which are very crucial for real-time monitoring (or monitoring that is nearly as accurate as real-time). In actuality, the choice of a point source must always include striking a compromise between a number of different factors, such as the distance to rovers, the impacts of multipath, the power supply, the data connection, and the site security.

1.1.2 Highway Tunnel Construction

The intelligence management system could perform monitoring at distant locations, data analysis, and planning instructions depending on the results of the investigation of the data that it has obtained. It was successful in implementing all-encompassing shows the amount, round-the-clock early warning, the deployment of all staff, and the inclusion into the building of the tunnel, both in terms of administration and control. The intelligent management system relies heavily on the use of many methods, such as strategies for detecting and transmitting data through networks, which are developed from the IoT. In the individual tracking system, the poisonous gas monitoring, and the distinct point architectural deformation monitoring system, the sensing techniques are used to collect information in order to accomplish their respective goals. This information is then sent to the tracking center terminal via the IoT. As a result of the somewhat confined nature of the building environment and the presence of specific hazards, the data collected throughout this project will be very helpful when selecting construction methods and performing subsequent maintenance. The accuracy of data gathering and the velocity at which it is sent through the IoT would determine to a large part whether or not the entire intelligence platform would be effective in the tunnel.

1.1.3 Geological Conditions

The preparation of geological forecasts before the construction of deep and lengthy tunnels is of the utmost importance for the protection of construction workers. The area of subsurface engineering has shown interest in this problem, but there has been no progress made toward a satisfactory solution. A geology forecast is a complete approach that is based on geological studies and by way of geophysics detection. This is because geophysical technologies have a degree of ambiguity and uncertainty associated with them. If this is not sufficient, it is to be augmented by transverse pre-trench and depth blast holes. During the building of deep and long tunnels, it is essential to adhere to the concept of timely sealing in conjunction with controlled drainage to properly seal the high-pressure and high-flow groundwater. Groundwater sealing relies on several factors, including real-time plugging, shoring equipment, shoring substance, shoring technique, shoring burden, and the sum of groundwater drainage. These factors, along with the sum of groundwater drainage, must be determined before construction by numerical computation and experiments. Using the traditional groundwater theory allowed for the development of the semi-analytical approach to the groundwater inflow problem. In contrast to the 2-D and 3-D analytical models, the calculation is straightforward and quick. The parameters that are necessary for the semi-analytical technique may be acquired with little difficulty. When a substantial deformation takes place or a steep tunnel passes through compressing fault zones, the surrounding rocks will display notable rheological tendencies. This is particularly true in situations when the pressure is tremendous, and the strengths-to-stress ratio is quite low. It is not possible to stop the deformation from steadily becoming worse by just raising the main support's rigidity. Tunnel deformation could be efficiently controlled by the main support that consists of two layers. Unfortunately, this would not be sufficient to stop any more tunnel deformation and will not maintain the rock mass in the surrounding area. Installing permanent lining promptly is an economical method that successfully restrains tunnel deformation and maintains the rock mass in the surrounding area in preparation for excavating in soft rock when the pore pressure is high. Figure 3 depicts the Topography of one tunnel.

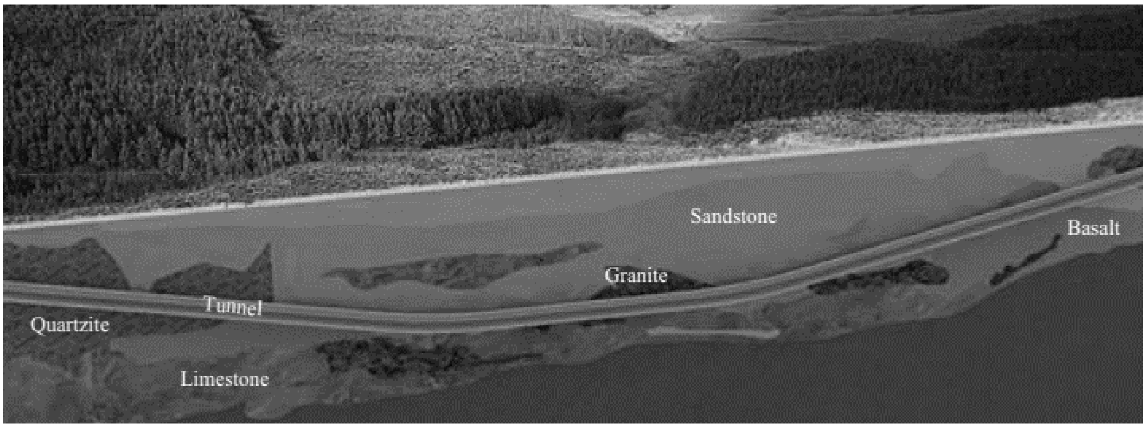

Figure 3: Topography of one tunnel [5]

2. Literature of review

This section highlights the work of a variety of authors who contributed to the relevant topic presented in this study.

Zhang et al., (2014) [6] analyzed that the excavations of deep and lengthy tunnels present various unique obstacles, including the presence of unknown geological features, groundwater recharge pressure, and significant in situ stress. This is in comparison to the excavation of ordinary tunnels. The very lengthy and deep Taining tunnel could have been found through extremely difficult geological terrain. This tunnel needed to go through a number of different fault zones as well as very jointed areas. Throughout the excavation process, it was common to run across large deformations as well as groundwater with high pressure. A complete strategy was established in order to forecast the possible harmful geological formations. This method included tunnel acoustic predictions and ground-penetrating radar detection in addition to horizontal drilling. Both of these techniques were used. In order to exert control over the high-pressure groundwater, many strategies, including radial grouting, pre-excavation curtain grouting, timely sealing, and efficiency release and pressure reduction, were used. Despite the peak in situ stress, the implementation of defensive measures such as the increase of assist stiffness, the utilization of double-layered main support and pre-support, the emergence of predetermined deformation, lipolytic reinforcement, and the additional mechanism of permanent lining was necessary to guarantee the safety of the remodeling in the nearby mountain masses.

Calautit et al., (2014) [7] proposed Computational Fluid Dynamics (CFD) model. This analytical model, which was used to forecast pressure losses, used input boundary conditions that were orientated in that direction as their point of origin. Instead of using the traditional technique, which involves simulating flow solely in the test part of the wind tunnel, a comprehensive replica of the complete wind tunnel was examined. Because of this, it modified not just the flow quality in the test portion but also the dissipation across the whole of the circuit. According to the results of the evaluation of the branching channel configurations, the flow quality of the test section was much more influenced by the flow patterns in upstream parts than in downstream sections. As a result, the design of the diffuser at upstream curves, especially those that are in alignment with the test section, requires more care and consideration. As shown by the verification of the test rig via the use of the block model, CFD was able to replicate the wind tunnel data in terms of speed, friction factor, and stress coefficients with just an inaccuracy of less than 10%.

Sharifzadeh et al., (2012) [8] proposed the Sequential Excavation Method (SEM), and its supportive structure in rocks that have become worn, and incompetent is the fundamental obstacle in tunneling. The Single entity tunnels that are currently being built as part of the Zanjan– Tabriz motorway are situated 25 kilometers away from Tabriz and have a combined length of 4533 meters (the north tunnel is 2244 meters long and the south tunnel is 2289 meters long), a width of 14 meters, and a height of 11 meters. Due to the fact that three collapses took place throughout the first 800-meter length of the southern tunnel, either the supportive system or the excavation sequences needed to be modified. The only reason why modifying the digging sequences was ever considered for this study was that the substantial expenses associated with changing the support system were taken into account. The technique of top heading and benching was first suggested since it was based on the size of the tunnel's span as well as the ratio of the tunnel's Uniaxial Compressive Strength (UCS) to its vertical in situ stress. After that, the digging sequences were evaluated, and a detailed design was developed for them. The use of the back analysis approach on the three collapsed zones stated above led to the discovery of the rock layer's shear strength values that are most likely to be applicable. The findings that were obtained from this study found that the displacement values in the crown portion of the collapsed zones were in a range that was somewhere between 70 and 75 millimeters. Therefore, based on the least effective strength measurements derived from back analysis, three distinct patterns of digging were suggested and submitted to finite difference numerical modelling, which was accompanied by an effectual SEM design with a safety factor of 2. This design lowered the deformations after digging the upper edge sailing the entire tunnel segment in the crumbled areas with less than 45 mm and 70 mm respectively. After that, the updated SEM design was successfully utilized during the excavation of the remaining length of the Shibli tunnels, and there were no other collapses that occurred as a result of its use.

Borrmann et al., (2015) [9] proposed Building Information Modeling (BIM) and Geospatial Information Systems (GIS) have been suggested as possible solutions to the necessary problems of analysis, modelling, and visualization. On the reverse hand, it is necessary to have a solid basis for managing representations at several scales. In the realm of geographic information systems (GIS), multi-scale modelling has already been an accepted practise, but within the realm of infrastructure building information modelling (BIM), there have been no such methodologies developed as of yet. Yet, multi-scale ideas are also very important in the BIM environment, since the planning process often offers only data in the initial stages and progressively precise and fine-grained information in the latter stages. This study proposed a complete idea for merging non-linear and non-depictions with creating data models, with a specific emphasis on the geometric-semantic modelling of shield tunnels, to satisfy this need. Specifically, the study examines the modelling of shield tunnels. This study discussed potential extensions to the BIM dataset Industry Foundation Classes (IFC) to integrate non-linear and non-representations of shield tunnels. These potential extensions are based on an in-depth analysis of the data modelling methods that are used in CityGML as well as the requirements that are present in the context of projects that are aimed at infrastructure planning. The provision of tools for maintaining the integrity of the depiction across the various Levels-of-Detail (LoD), while also taking into consideration semantics and geometry, is given a lot of attention in this project. This study also suggested using a generative geometry description to develop consistency preservation methods. This kind of geometry description makes it feasible to express explicit relationships between geometric entities that exist on multiple levels of detail (LoDs). When one item on a higher level is updated, all of the dependent objects on lower levels also get an automatic refresh as a consequence of the change. The last part of this study will go through the process of converting the IFC-based multi-scale tunnel design into a CityGML-compliant tunnel representation.

Zhen et al., (2019) [10] proposed an Ultra-Wideband (UWB) in autonomous navigation technology, particularly those pertaining to robot localization methods which could be employed in locations where GPS is not available, the use of robots for inspection work has been rapidly expanding in recent years. Even though a great number of strategies have been developed to localize a robot using onboard sensors like cameras and LiDARs, the challenge of attaining reliable localization in geometrically degraded situations, such as tunnels, continues to be difficult to solve. In this study, the robust localization challenge brought by such circumstances serves as the primary emphasis. The localizability at a specific place in the preceding map is estimated using a brand-new degeneration characterization model that is described here. In addition, the study of the localizability of a LiDAR and range radio is carried out. In addition, a probabilistic sensor fusion approach that combines Inertial Measurement Unit (IMU), Light Detection and Ranging (LiDAR), and the UWB is created. The findings of the experiment indicate that using this approach enables reliable localization inside a long tunnel that is in a straight line.

Jian et al., (2004) [11] proposed a model based on GPS/GIS/GSM to fulfill modern faraway monitoring and maintenance of long and wide (LW) highway tunnels in China in hopes of enhancing the management and operation of long and wide (LW) highway tunnel in China. This is done by analyzing the operational features of the LW highway tunnel and tracing the most recent GPS/GIS/GSM technology. This study provided a comprehensive illustration of the workings and framework of two primary systems of highway tunnel management and operation system based on GPS/GIS/GSM. These two systems are passageway structural maintenance systems that rely on GIS and automobile shipment based on GPS/GIS/GSM. These two systems have also undergone the methodical analysis and design processes that are characteristic of the software system design technique. In conclusion, the enterprise cost accounting approach was used to do an economic study on this model. Moreover, an evaluation of the practicability of this system based on GPS/GIS/GSM was also carried out.

Chen et al., (2017) [12] analyzed that the vast amount of study that has been conducted in this area, there is still a pressing need for the development of a localization algorithm that is time-effective, highly accurate, simple to implement, and resilient. The algorithm required just a marginal amount of involvement from humans. This provided an improved positioning technique for Wi-Fi-capable devices that is based on the Received Signal Strength Indicator (RSSI). The approach is named Dynamic Weighted Evolution for Position Tracking (DWELT). RSSI data exhibit oscillations as a result of the myriad of processes that influence the dispersion of radio signals. These fluctuations prevented the employment of easy placement mechanisms derived from commonly known propagation loss models. In its place, DWELT makes advantage of data processing on basic RSSI values and implemented a balanced posterior-probabilistic evolution in order to achieve rapid convergence in localization and tracking. This study is the first version of DWELT, which is designed for one-dimensional location (i.e., it may be used in passageways or corridors), and it is also the first stage towards a more general implementation. In more than 81 percent of the circumstances, simulations and tests demonstrate an accuracy of one meter, and in 95 percent of the cases, the accuracy is less than two meters.

Su et al., (2016) [13] observed that the Global Positioning System, or GPS, did not function properly inside buildings, and the precision of other localization methods generally requires the use of infrastructure upgrades or cumbersome war-driving, the problem of indoor localization utilizing smartphones and other mobile devices continues to be a challenging one. In these types of situations, this study presented a localization method that makes use of motion information obtained from the altimeter, tachometer, and gyroscope sensors included inside a smartphone in order to estimate changes in direction and identify steps taken. At the same time, this study also used the fingerprinting approach that is based on Wi-Fi in order to independently estimate positions. A Bayesian filter is used to integrate these data with an internal picture of the environment before concluding. This study will be able to reduce the quantity of training that is necessary and function in areas with limited Wi-Fi connectivity thanks to this technology. This study demonstrated the advantages of using user movement for indoor localization by testing the technique in two situations that are representative of the real world.

Paraskevopoulou et al., (2018) [14] presented the Convergence-Confinement Method (CCM), which could be performed mathematically (using closed-form solutions) or by making use of Linear Displacement Profiles. Since this procedure overlooked the influence of time dependency, the delayed deformation that resulted could manifest even minutes or hours after the excavation was finished. This study failed to account for the additional deformations during the prototype development, which could have resulted in an inaccurate shortlisting of the present time of configuration and the establishment of a support system, which could have resulted in safety concerns for the organization's workers, which may have resulted in huge costs and complications with the completion of the project. This study failed to account for the additional deformations during the preliminary design. With the use of isotropic axisymmetric variational modelling, the primary objectives of this study were to investigate and analyze the total deformations that occurred around a round tunnel in a viscoelastic kind of medium. The authors behind this study also suggested a fresh method that is straightforward to use, and which accounts for the passage of time.

Amato et al., (2018) [15] proposed that backscatter transmission in Radio Frequency Identification (RFID) bands could link billions of gadgets of the future to the IoT. Conventional passive RFID systems suffer from power limits, which restrict RFID tag transmission to close ranges. Nevertheless, these limitations could be circumvented by using reflection amplifiers in conjunction with the system. This study demonstrated that negative temperature coefficient impedance circuits, such as tube diodes, are superior to province reflection amplifiers in terms of both gain and power consumption by a margin of 27 dB and 10 dB, respectively. Reflection increases of 40 dB and 29 dB have been shown by two prototypes operating at 5.8 GHz that use commercially available tunnel diodes. These gains have been achieved with a total biassing energy usage of 45 W and 39 W, accordingly, at infringing RF levels of power as low as -84 dBm. Transmitting just -14 dBm of actual anisotropy radiation intensity (EIRP) from a transceiver with a sensitivity of -90 dBm allowed for the establishment of a 5.8 GHz RFID connection that had a range of 23 meters.

3. Comparative analysis

This section offers a comparative analysis of various techniques used for tunnel designing with the proposed technique. In this study, the comparison of various tunnel designing methods is done based on two parameters i.e., Accuracy and Parameters. Accuracy is used to check measurement with an accepted standard while frequency is the rate at which something occurs over a particular period or in a given sample. The higher rate of accuracy, as well as frequency, indicates the best fit.

It could be observed from the graph given in figure 4 that the proposed technique has the highest value of 25m and 1,575.42MHz for both accuracy and frequency respectively while techniques such as (RFID), Wi-Fi Location of fingerprint, and UWB have a low value of (4m and 433MHz/2.4 GHz), (less than 4m and 2.4GHz) and (0.3m and 3.1~10.3GHz) for both accuracy and frequency respectively. This indicates that the proposed technique, i.e., GPS has the highest accuracy and frequency for the best technique to be obtained. There is a wide range of authors who used various techniques and their respective accuracy and frequency which are presented in Table 1.

Table 1. Comparative analysis of literature review

Authors	Technique	Parameters	
		Accuracy	**Frequency**
Jian et al., (2004) [5]	GPS	5~50m,50% of possibility reaches 25m	1,575.42MHz
Amato et al., (2018) [10]	RFID	3~5m, 50% of possibility within 4m	433MHz/2.4 GHz
Su et al., (2016) [8]	Wi-Fi Location of fingerprint	3~5m, 50% of possibility less than 4m	2.4GHz
Zhen et al., (2019) [6]	UWB	0.3m	3.1~10.3GHz

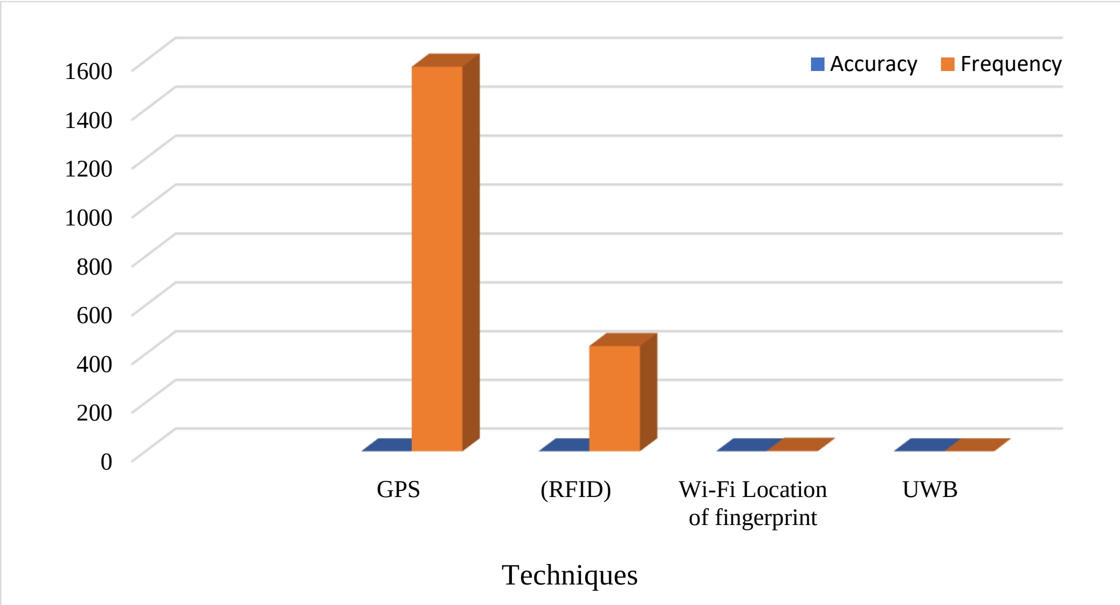

Figure 4: Graphical representation of Parameters

4. Conclusion and future scope

This study provided a concise introduction to the idea, the structure features, and key methods of the IoT to provide technical assistance for tunnel design. Additionally, this study shows the project consultant of its use in different industries, particularly in tunnel engineering. The next sections focused on particular examples of how the IoT could be used in various aspects of tunnel construction. The GPS methodology, which can construct tunnels with high precision and frequency, is presented and analyzed in this work. Also, this GPS technique is contrasted with other methods for constructing tunnels. With the use of GPS technology, construction businesses can monitor and pinpoint the location of their industrial machinery in real-time. Moreover, when linked to cloud services, GPS devices can collect and analyze crucial data on the location of an industry's heavy equipment. Based on the preceding comparison analysis, it could be concluded that the proposed technique, namely GPS, outperforms all other methods by providing the highest values of (25 meters and 1,575.42 megahertz) for both accuracy and frequency respectively. This indicates that these values are absolute for both accuracy and frequency values, which must be the highest to show their highest reliability.

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