

Indoor Positioning Methods – A Short Review and First Tests Using a Robotic Platform for Tunnel Monitoring

Alberico Sonnessa[1(✉)], Mirko Saponaro[1], Vincenzo Saverio Alfio[1], Alessandra Capolupo[1], Adriano Turso[2], and Eufemia Tarantino[1]

[1] Department of Civil, Environmental, Land, Construction and Chemistry (DICATECh), Politecnico di Bari, Via Orabona 4, 70125 Bari, Italy
{alberico.sonnessa, mirko.saponaro, vincenzosaverio.alfio, alessandra.capolupo, eufemia.tarantino}@poliba.it

[2] Sipal S.p.A. S.P. 83 c/o Aeroporto "Marcello Arlotta", 74023 Grottaglie, TA, Italy
turso.adriano@sipal.it

Abstract. The aim of this work is to provide a review of the main indoor positioning methodologies, in order to evidence their strengths and weaknesses, and explore the potential of the integration in an Unmanned Ground Vehicle built for tunnel monitoring purposes. A robotic platform, named Bulldog, has been designed and assembled by Sipal S.p.a., with the support of the research group Applied Geomatic laboratory (AGlab) of the Politecnico di Bari, in the definition of the data processing pipeline. Preliminary results show that the integration of indoor positioning techniques in the Bulldog platform represents an important advance for accurate monitoring and analysis of a tunnel during the construction stage, allowing a fast and reliable survey of the indoor environment and requiring, at this prototypal stage of development, only a remote supervision by the operator. Expected improvements will allow to carry out tunnel monitoring activities in a fully autonomous mode, bringing benefit for the safety of people involved in the construction works and the accuracy of the acquired dataset.

Keywords: Indoor positioning · Indoor mapping · IP for civil engineering · Tunnel monitoring · Unmanned Vehicles · SLAM

1 Research Aims

The aim of the research presented hereafter is to provide a short review of the main indoor positioning methods, by showing the preliminary results of an industrial application in the field of civil engineering, developed by Sipal S.p.a. and coordinated by the research group AGlab at the Politecnico di Bari, aimed at exploring the opportunity to deploy Unmanned Ground Vehicles for tunnel monitoring purposes.

To achieve this, a remote-controlled prototype robotic platform, equipped with sensors, has been designed and assembled. Field tests were carried out to assess the

© Springer Nature Switzerland AG 2020
O. Gervasi et al. (Eds.): ICCSA 2020, LNCS 12252, pp. 664–679, 2020.
https://doi.org/10.1007/978-3-030-58811-3_48

performance of the system and are still ongoing. The first results indicate that the integration of indoor positioning techniques in the inspection and monitoring activities can be a valid support in the tunnel construction stages.

2 Introduction

The accurate mapping of the environment in which we live, along with the precise positioning of people and objects in it, still represents one of the most challenging issues for the scientific community.

Nowadays, high-precision mapping techniques, that encompass satellite and ground-based sensors, allow to get very detailed 3D models of the territory and the built environment. Current positioning and navigation techniques, which mainly rely on geodetic GNSS (Global Navigation Satellite System) receivers, permit to estimate positions of a sensor with near-millimeter accuracy.

As for the consumer market, mobile phones made real-time positioning within everyone's reach. Thanks to increasingly more advanced sensors and algorithms embedded in our devices and the availability of web mapping/navigation services (e.g. Google Maps, Apple Maps), we can easily locate ourselves and navigate towards every destination. Outdoor real-time precise positioning needs a good visibility of the satellite constellations (open sky conditions) and a web access.

At indoors, the level of degradation of the satellite signals makes the civilian-graded accuracy of GNSS inadequate for many purposes [1]. However, the estimation of a sensor indoor position and/or motion finds application in different contexts, such as augmented/virtual reality, autonomous robot control [2] and civil engineering.

The improvements in the reliability of outdoor positioning methodologies, do not correspond to same advances in indoor positioning systems (IPS). Simultaneous Localization And Mapping (SLAM) problem for indoor locations, that is the simultaneous estimation of the state of a platform equipped with on-board sensors and the building of a model (map) describing what is observed by the sensors [3], is still an open issue.

Consumer market solutions have been recently implemented by Apple in its high-end iPad tablet, that couple cameras and laser sensors. Interesting attempts aimed at freely making available indoor maps is the use of an Open Source platform to support indoor navigation, based on the OpenStreetMap tool, as showed in [4], and the opportunity provided by Google to its partners of integrating indoor maps in Google Maps.

3 Indoor Positioning Requirements in Underground Constructions

Many activities in the field of civil engineering requires reliable and robust IPS, as:

- Excavation and tunneling.
- Tunnel modelling and monitoring.

- Mining activities.
- Operation in dangerous environments.

With regards to the case study, in Table 1 are summarized the main positioning requirements in underground construction.

Table 1. Positioning requirements in underground construction according to [5]

Criteria	Criteria description	Value
Accuracy	For deformation analyses	1–5 mm
Accuracy	For monitoring purposes	1–5 mm
Accuracy	For machine control	1–5 cm
Range	Depending on the application	10–50 m
Positioning	Tasks requiring 3D-coordinates	Yes
Construction site-proof	Resistance against dust, emissions caused by construction machines, damages during construction works, vibrations and site deformations	Yes
Real-time availability	Survey tasks may need real-time measurements/outputs	80%
Usability	System should be operable by workers without surveying background	Yes
Costs	Cost must not exceed that of a surveying total station	5k–50k €
Operability under nonline of sight (NLoS) conditions	System should be operational under NLoS conditions; direct LoS between the reference sensors and the work site may be not available	Required

In accordance with the conditions indicated in the table it is therefore necessary to design an indoor system that guarantees the performance of the positioning. The position information of an Unmanned Vehicle can be provided by using various methodologies exploiting different sensors and technologies (or a combination of them). Main IP techniques will be shortly described in the following section along with main advantages and limitations.

4 Overview of the Main IP Techniques

IPS can be classified starting from the principles on which they are based, namely electromagnetic waves (visible, infrared, microwave and radio spectrum), mechanical waves (audible/ultra-sound) and inertial navigation (accelerometers and gyroscopes) [6]. Despite the difficulties of performing IP - especially where scenarios rapidly change for the presence of “moving things” (e.g. workers, construction machinery) – depending on possible Non-Line-of-Sight (NLoS) conditions, multipath from walls, ceilings and objects, signal attenuation/scattering - nevertheless, indoor locations can simplify navigation and positioning tasks, because of:

- Slow dynamics (with reference to the outdoor environment).
- Limited areas to be covered.
- Availability of facilities (electric power, web access, walls for target installation)
- Very limited weather effects.

Main IP techniques are listed in Table 2.

Table 2. Overview of indoor positioning methodologies by [6]

Technology	Accuracy	Coverage (m)	Measuring principle	Typical application
Cameras	0.1 mm-dm	1–10	Angle measurements from images	Automotive, metrology, robot navigation
Infrared	cm–m	1–5	Thermal imaging, active beacons	People detection and tracking
Polar Systems	μm-mm	3–4000	Time of Flight interferometry	Underground construction, automotive
Sound	cm	2–10	Distances using time of arrival	Hospitals, tracking
WLAN/WiFi	m	20–100	Fingerprinting	Pedestrian navigation
RFID	dm–m	1–50	Proximity detection, fingerprinting	Pedestrian navigation
Ultra-Wideband	cm–m	1–50	Body reflection, time of arrival	Resource management in construction projects - robotics, automation
High Sensitive GNSS	10 m	Global	Parallel correlation, assistant GPS	Navigation
Pseudolites	cm–dm	10–1000	Carrier phase ranging	GNSS challenged mines
Inertial Navigation	1%	10–100	Dead reckoning	Navigation

4.1 Cameras

Optical IP uses cameras as main sensor. With the improvement of their performances in terms of resolution of collected images/data and speed in their acquisition, the accuracy of this method has significantly improved in the last years.

The retrieving of 3D information about the investigated environment is based on a photogrammetric approach. As discussed in [7], the scale of the photogrammetric model can be obtained integrating a Time Of Flight (ToF) range camera. Different references can be used to carry out the sensor positioning, according to [6], that is:

1. **Reference from 3D Building Models**, where the detected objects are compared with a database containing building interiors dataset.
2. **Reference from Projected Targets/patterns** when mounting of reference markers is not indicated or possible.
3. **Reference from Deployed Coded Targets** aimed at a) simplifying the automatic identification of corresponding points assigning a unique code to each marker, b) providing the system scale.
4. **Systems without Reference** that relies on the direct tracking of objects. Illuminated targets are often used to improve algorithmic robustness.

Cameras can be used to simultaneously map the surrounding environment and estimate motion, i.e. performing a Visual SLAM. According to [8], this solution can rely on geometry by getting geometric constraints from images for motion estimation, or, following the recent trends, using deep learning to autonomously reconstruct and navigate in an unknown location.

An innovative approach to implement Visual SLAM, based on the integration of standard and event cameras with IMU (Inertial Measurement Unit), has been presented in [2]. This method overcomes typical limitations affecting standard cameras, (motion blur and low dynamic range) integrating event cameras, where pixels operate autonomously, transmitting their changes of intensity/time they occur/pixel space-time coordinates. These sensors produce little amount of information when motion is limited.

The authors in [2] introduced a pipeline that combines events, standard frames, and inertial measurements to compute reliable and accurate state estimation, applied for onboard state estimation of an autonomous quadrotor.

This approach led to an accuracy enhancement of 130% if compared to the use of the event camera only, and 85% over standard-frames-only visual-inertial systems, although still being computationally manageable.

Main advantages and limitations of this technique are summarized in Table 3.

Table 3. Advantages and limitations IP camera-based technique

Advantages	Limitations
No infrastructure required (1,3,4)	Need for providing a constantly updated database (1)
Accuracy	Must be generally coupled with other sensor for SLAM purposes
Cost	

4.2 Infrared

Infrared (IR) light is characterized by a wavelength longer than those of visible light, thus making this technology less invasive with respect to the IP techniques based on visible light. According to [6], the main methods of using infrared signals are: a) artificial light sources b) infrared imaging based on thermal radiation c) use of active beacons.

1. **Artificial Infrared Light sources** using active infrared sources and infrared sensitive cameras. An application in the gaming field is the Kinect (V1) embedded in the Xbox console, where the 3D shape is retrieved from the distortion of a pseudo random pattern of structured IR light dots captured with the infrared camera.

Though developed in the video gaming world, Kinect has been wide spreadly used in the SLAM field thanks to the KinectFusion and Kintinuos algorithms [9–11].

2. **Imaging using Natural Infrared Radiation,** namely passive IR localization methods. Sensors operational in the thermography region are capable to acquire a passive image of the environment using natural thermal emissions.
3. **Active Beacons** based on infrared receivers located at known positions and mobile beacons whose positions are not known. A sub-meter precision can be reached when several receivers are employed in each room.

Main advantages and limitations of this technique are listed in Table 4.

Table 4. Advantages and limitations IP IR-based technique

Advantages	Limitations
Low cost	Limited coverage range and accuracy
No infrastructure required (1,2)	NLoS problems between sender and receiver
	Interference of IR waves with fluorescent light/sunlight

4.3 Sound

The sound wave is a particular wave in which the perturbation is the pressure variation induced by a vibrating body in the surrounding medium (usually air or building material). The use of sound waves for IP purposes is based on locating mobile nodes through multilateration and TOA (Time of Arrival)/TDOA (Time Difference of Arrival) that is the multiple distance measurements to static nodes mounted permanently in a given environment.

Most widely known techniques are [12]:

– **Active Bat**
  A network of receivers with a centralized control unit are used to process the transmitters signal (ultrasound) and estimate their position.
– **Cricket System**
  A number of active devices (beacons, emitting ultrasound)), called 'Cricket nodes' [13], establish the positioning network and are used by the target (listener) for position determination.
– **Dolphin System**
  Mixed ultrasound-RF system, where a number of reference nodes emit in series RF and ultrasound signal, used by other nodes to compute distance to reference node.

– **Audible Sound Positioning System**
  A mobile device (transmitter) emits sound detected by acoustic receivers equipped with a CPU and a wireless network interface capable to send data to a central server, that estimates the range transmitter-receiver and send the estimated coordinates to the transmitter.
  Main advantages and limitations of this technique are evidenced in Table 5.

Table 5. Advantages and limitations IP sound-based technique

Advantages	Limitations
Low cost (at room scale)	Expensive for large environments
Accuracy (few centimeters) [14]	Variable accuracy as sound speed depends on temperature and humidity

4.4 WLAN/Wi-Fi

Due to its wide deployment in many indoor environments, WLAN (Wireless Local Area Networks), known as Wi-Fi, is employed to estimate the position of a mobile device in a range up to about 100 m.

To date, empirical models for WLAN-based indoor positioning are preferred [15], such as fingerprinting (FP) [16, 17] hereafter described.

As first step, signals are collected offline in order to build a database of discrete grid of locations, or reference point (RP), namely the radio-map. A signature is generated from the collected RF signals. The next stage, that is the online phase, make use of the radio-map for navigation via classification algorithms, or novel methodologies based on machine learning [18], and deep learning [19–22].

The accuracy of FP is strictly related to the number of calibration points, ranging from one to tens of meters.

Main FP-based IPS are:

– **FP-Based IPS Based on RSS**
  This method employs received signal strength (RSS) measurements as fingerprints for radio-map creation and online navigation.
– **FP-Based IPS Based on CSI**
  This approach is based on the channel estimate, which defines an indoor location using multipath attenuation and further physical phenomena such as refractions and reflections, characterizing this environment with detailed information [18, 19, 22]. The channel state information (CSI) can be used as FP.
– **FP-Based IPS Using FFNN**
  This innovative combined approach is proposed in [15], using WLAN signals such as CSI and RSS for fingerprint and state-of-the-art feed-forward neural network (FFNN) model for the evaluation of the IPS.
  The proposed FFNN model achieved a 1.3 m mean accuracy in an indoor setting, with 0.8 m of std. dev.
  Main advantages and limitations of this technique are shown in Table 6.

Table 6. Advantages and limitations IP WLAN-based technique

Advantages	Limitations
Low cost (use existing infrastructure)	Signal power loss due to reflection, absorption, refraction, scattering, interference, and multipath
Accuracy (around meter)	

4.5 Radio Frequency Identification

RFID (Radio Frequency IDentification) IP methods relies on a reader, capable of obtaining through RF the data from active, passive or semi-passive electronic tags storing an ID, used to locate the RFID tag. A standard application able to manage a large number of tags is in the product tracking aimed at avoiding stealing in stores, with readers at known locations and tags on the product to be monitored. The accuracy and the range in RFID may vary significantly, depending on whether they are active or passive and the density of devices, with some researches achieving around-centimeters accuracies [23].

The typical case of RFID positioning using ToA, is based on measurements from a single tag; positioning is obtained combining the Angle of Arrival (AoA) measurements from that tag [1].

Main advantages and limitations of this technique are shown in Table 7.

Table 7. Advantages and limitations IP RFID-based technique

Advantages	Limitations
Accuracy (decimeter-meter)	Signal power loss due to reflection, absorption, refraction, scattering, interference, and multipath
	Privacy concern
Unique ID can be used for security purposes	Data management and configuration when a large number of devices is deployed

4.6 Ultra-Wide Band

A review of the state of the art in Ultra-Wide Band (UWB) positioning has been recently performed in [24].

UWB is defined as a RF signal characterized by a bandwidth greater than 500 MHz, usually operated in the 3.1–10.6 GHz range.

According to [25], UWB positioning methods can be grouped into two main classes, i.e. FP-based and geometric methods. Geometric methods are hereafter described, because comprehensive FP database are difficult to build.

- **TOA and TDOA-Based Methods**
  The TOA method is based on computing of the range transmitter - receiver by estimating of the Time Of Arrival of signals, thus requiring the precise synchronizations between the transmitter and receiver. The TDOA method locates the receiver using the Time Difference Of Arrival computed between the receiver and multiple transmitters, not necessitating their synchronization [26].
- **AOA-Based Methods**
  The AOA-based approaches first make use of the angle of the signal received from the transmitter, and then estimate the receiver location by using the intersection of the angle line from the transmitters [25]. Such approaches don't require clock synchronization and use a small number of anchors nodes, nevertheless necessitating the coupling of nodes with an antenna array.
- **RSSI-Based Methods**
  Geometric-RSSI (Received Signal Strength Indicator) methods relies on the measurement of the strength of the signal acquired by the receiver and transform it into a range observation between the transmitter and receiver. The performance of RSS methods is usually low if compared to TOA and TDOA approaches [27], but they are relatively low cost, and can deploy a large number of nodes.
  Main advantages and limitations of this technique are summarized in Table 8.

Table 8. Advantages and limitations IP UWB-based technique

Advantages	Limitations
High data rate acquisition, multipath resolution capabilities, low energy consumption/interference with other systems	Signal power loss due to reflection, absorption, refraction, scattering, interference, and multipath
Accuracy (centimeter-meter)	
Penetration of obstacles	

4.7 High-Sensitive GNSS/Assisted GNSS

GNSS receivers hardly track signals in challenging settings such as urban canyons or at indoors, where signal fades [28]. This has boosted the research in the field of so-called highly sensitive and assisted GNSS (HSGNSS-AGNSS) receivers.

AGNSS receivers use an additional data link (e.g. internet connection) for providing information about satellite ephemeris, almanac, differential corrections and timing information, usually directly acquired from the GNSS constellations.

High-Sensitive GNSS (HSGNSS) receivers deploy further methods, not deepened here, aimed at increasing the signal reception in indoor environments.

However, performance of indoor GNSS technologies are not yet comparable to the level of accuracy reachable in outdoor settings. Even if indoor GNSS do not provide the needed accuracy for pedestrian navigation in a closed environment, this sensor can be integrated in an IPS with an inertial platform, in order to supply sparse coordinate updates.

Main advantages and limitations of this technique are showed in Table 9.

Table 9. Advantages and limitations HS-GNSS -based technique

Advantages	Limitations
Availability of an already existing infrastructures (satellite network)	Expensive
	Low accuracy

4.8 Pseudolites

The pseudolite system represents a powerful indoor positioning system, due to the capability of covering large areas and provide accurate positioning solution [29].

Pseudolites (pseudo-satellites) are basically ground-based beacons capable to generate pseudo-codes analogous to GNSS codes. This solution also embeds mobile rovers whose positions are estimated by measuring the distance between rovers and pseudolite beacons, generally positioned at known locations [6].

Pseudolites can cover wide areas (tens of kilometers); the main restriction in the yr usability is related to NLoS conditions between pseudolites and rovers. The use of a combined pseudolite receiver enables the acquiring and tracking of both GNSS and pseudolite signals, thus permitting a seamless transition from outdoor to indoor settings.

Main advantages and limitations of this technique are listed in Table 10.

Table 10. Advantages and limitations of IP pseudolites-based technique

Advantages	Limitations
Large coverage area	Multipath
	Time synchronization in deep indoor settings due to the unavailability of atomic clocks
Accuracy (centimeter-decimeter)	No easy solution for ambiguity resolution

4.9 Dead Reckoning Positioning Based on Inertial Navigation Systems

Dead Reckoning (DR) relies on the estimation of the current location of a target, computed from an already known position (fix), and taking advantages on the measurements of physical quantities used for defining its movement, (e.g. path and speed) [1].

The DR technique based on Inertial Navigation Systems (INS) encompass the integration of an Inertial Measurement Unit (IMU) with a computational platform.

An INS estimates the position, velocity and orientation quantities from the IMU, which embeds gyroscopes, accelerometers, and/or a magnetometer aimed at measuring the direction and strength of the magnetic field.

Due to significant drift problems, INS is commonly integrated with additional sensors which provide information on the system position.

Main advantages and limitations of this technique are evidenced in Table 11.

Table 11. Advantages and limitations IP INS-based technique

Advantages	Limitations
High accuracy if positions are estimated with high rate	Costs (for high precision IMUs)
No need for external reference	Drift that can lead to cumulative error

4.10 Polar Systems

Polar systems measure distance and angles, retrieving the position of a target object using the three-dimension vector between sensor and objects.

Most widely known polar systems are Total Stations (TS) and Laser Scanners (LS). Basically, TS and LS rely on the same measuring principles, where angles are measured by means of digital bar-codes embedded in the sensor, and an Electronic Distance Meter (EDM) measures the distance from the instrument to a target (typically a retroreflective prism) or a surface by timing the round-trip of a pulse of light. The signal reflected by the surface is detected by a sensor connected with the emitter. The instrument automatically scans the surfaces in its field of view and is capable to acquire millions of point per second [30].

These instruments mainly differ in terms of accuracy (TS can reach an accuracy of few millimeters) speed of acquisition and number of acquired point per seconds (LS can acquire up to one million of point/sec).

IP Polar systems-based tools, relying on high-precision rugged sensors/instruments developed for working in severe conditions, are particularly suited for civil engineering applications.

Main advantages and limitations of this technique are showed in Table 12.

Table 12. Advantages and limitations IP Polar system-based technique

Advantages	Limitations
Accuracy (around mm)	Cost
	Must be coupled with other sensors for navigation purposes
	Computational problems due to the amount of data (LS)

5 Case Study – IP for Civil Engineering Applications

An experience of IP for civil engineering applications is being jointly conducted by Sipal S.p.a, and the research group Applied Geomatic laboratory (AGlab) of the Politecnico di Bari in the frame of the innovative project "Technological Construction Site for Military and Civil Infrastructures/Cantiere Tecnologico per Infrastrutture Militari e Civili." (Unmanned Vehicles and Virtual Facilities).

The project is co-funded by the European Union-European Regional Development Fund POR Puglia 2014/2020 and the Puglia Region. A section of the project involves the development of hardware and software tools to be installed on board aerial and ground UVs, aimed at integrating or replacing traditional survey techniques used for collecting and analyzing key data in the different stages of a construction site.

Within this activity, it is being implementing a platform named Bulldog to be used for tunnel monitoring purposes [31], that is:

- The estimation of the over/under-excavated sections of the tunnel with respect to the type section.
- The survey of the excavation head, during the tunneling works, for controlling its stability and identifying the most suitable consolidation systems.
- The automatic identification of under-excavated areas that requires further work to reach the minimum theoretical tunnel section.

5.1 The Bulldog Platform

The Bulldog platform (Fig. 1) exploits IP Polar system-based techniques.

The hardware of the platform consists of:

- A remotely controllable Unmanned Ground Vehicle (UGV), (max speed: 30 km/h, max payload: 130 kg) equipped with two Optic cameras and two IR cameras.
- A Trimble SX10 scanning station, that integrates the features of a TS (angular accuracy: 1", distance accuracy: 1 mm + 1.5 ppm) and LS (3D point position accuracy @100 m: 2.5 mm).
- A GEO-Laser AD-12 automatic tripod, for automatic levelling of the surveying instrument.

At this stage of its development, Bulldog must be remotely driven towards the target area inside the tunnel. As first step, the platform carries out high-precision localization operations computing its position by mean of the TS. The sensor position is obtained by measuring some retro-reflective prisms of known location installed in the tunnel. After the preliminary IP operations, Bulldog is able to perform a scan of the target area in LS mode, providing a point cloud with an average centimeter spacing.

The acquired data are processed and analyzed using specific tools developed on purpose in Python language, able to extract cross-sections of the tunnel and related construction characteristics and to estimate the over/under-excavated sections of the tunnel with respect to the typical section (Fig. 2).



Fig. 1. The Bulldog platform

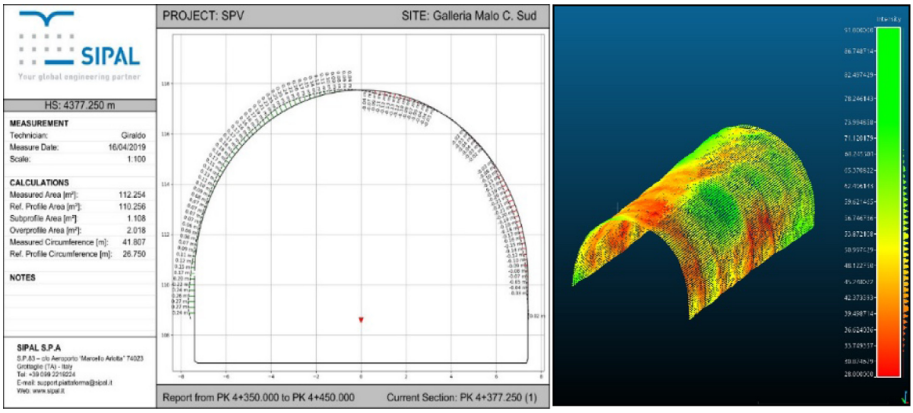

Fig. 2. Analysis tool user interface

Bulldog has been designed considering the requirements in terms of needed accuracy for the UGV positioning and reconstruction of the 3D model (some millimeters) of the surveyed area, and the possibility of easily upgrading the system by replacing or adding new SW features and/or sensors.

5.2 Expected Developments

Next steps expect the implementation of SLAM algorithms in the system, in order to make Bulldog capable of autonomously detect obstacles and move inside the construction area from its initial position, simply providing to the system the coordinates of an end point. To this aim, a Velodyne VLP-16 LS and an IMU will be integrated in the platform.

While not as accurate as SX10, Velodyne LS can be used for navigation, being able to quickly acquire a reliable (about 3 cm of accuracy) point cloud, useful for a fast and continuous mapping of the indoor environment. Therefore, the lack of efficient real-time 3D model generation methods of as-built 3D indoor environment is still an open issue.

An IMU will be also integrated to better reconstruct the Bulldog trajectories.

In this prototyping stage, SLAM algorithms are verified using ROS (Robot Operating System), a set of open source software libraries and tools for building robot applications [32], installed on TurtleBot, a low-cost robot kit with open-source software, equipped with a 2D or 3D distance sensor, a simplified IMU and microcomputer [33].

ROS+TurtleBot enable the testing and improvement of new features, allowing the speeding up of the system development.

6 Conclusive Remarks

Positioning and mapping activities in an indoor environment represent, in some cases, very difficult tasks. Nevertheless, high-accuracy IPSs have become in high demands in recent years, due to the increasing need for precise indoor localization in many sectors, ranging from the assistance for aged people to pedestrian navigation in large public buildings, to autonomous driving.

In the field of civil engineering, accurate IP and SLAM are required especially in potentially dangerous environments, as construction sites, where traditional measurement techniques could be replaced by fully automated procedures, avoiding possible injuries to operators.

In this work, different IP methodologies have been described in order to provide an overview of the main advantages and limitation of each technique, and an application of IP polar system-based method to an integrated robotic platform for monitoring tunnels has been presented.

As discussed above, the integration of IP techniques in the Bulldog platform represents an important advance for accurate monitoring and analysis of a tunnel during the construction works, allowing a fast and reliable survey of indoor environments and requiring, at this stage of development, only a remote supervision by the operator.

Expected improvements will allow to carry out monitoring activities without the need of a surveyor, bringing benefit for the safety of the construction area and accuracy of the acquired dataset by reducing possible errors due to the human factor.

Acknowledgements. This research is funded by the project "Technological Construction Site for Military and Civil Infrastructures/Cantiere Tecnologico per Infrastrutture Militari e Civili." (Unmanned Vehicles and Virtual Facilities), co-financed by the European Union-European Regional Development Fund POR Puglia 2014/2020 and Puglia Region.

References

1. Mendoza Silva, G., Torres-Sospedra, J., Huerta, J.: A Meta-Review of Indoor Positioning Systems. Sensors **19**(20), 4507 (2019)
2. Rosinol Vidal, A., Rebecq, H., Horstschaefer, T., Scaramuzza, D.: Ultimate SLAM? combining events, images, and IMU for robust visual SLAM in HDR and high-speed scenarios. IEEE Robot. Autom. Lett. **3**(2), 994–1001 (2018)
3. Cadena, C., et al.: Past, present, and future of simultaneous localization and mapping: toward the robust-perception age. IEEE Trans. Robot. **32**(6), 1309–1332 (2016)
4. Mascitelli, A.: An open source platform for indoor navigation: application to the Faculty of Civil and Industrial Engineering of Sapienza, University of Rome. Bollettino Sifet n.2-Sezione Scienza (2017)
5. Schneider, O.: Requirements for positioning and navigation in underground constructions. In: Proceedings of the 2010 International Conference on Indoor Positioning and Indoor Navigation (IPIN), 15–17 September, Campus Science City, ETH Zurich, Switzerland (2010)
6. Mautz, R.: Indoor Positioning Technologies. In: Sechsundachtzigster Band +, vol. 86 (2012)
7. Ravanelli, R., Nascetti, A., Crespi, M.: Kinect V2 and RGB stereo-cameras integration for depth map enhancement. Int. Arch. Photogrammetry Remote Sens. Spatial Inform. Sci. **XLI-B5–XXIII**, 699–702 (2016)
8. Duan, C., Junginger, S., Huang, J., Jin, K., Thurow, K.: Deep learning for visual SLAM in transportation robotics: a review. Transp. Safe. Environ. **1**, 177–184 (2019)
9. Newcombe, R.A., et al.: KinectFusion: real-time dense surface mapping and tracking. In: 10th IEEE International Symposium on Mixed and Augmented Reality, pp. 127–136. IEEE (2011)
10. Izadi, S., et al.: KinectFusion: real-time 3D reconstruction and interaction using a moving depth camera. In: Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology, pp. 559–568 (2011)
11. Whelan, T., Kaess, M., Fallon, M., Johannsson, H., Leonard, J. J., McDonald, J.: Kintinuous: Spatially extended kinectfusion. Technical report, MIT CSAIL (2012)
12. Sakpere, W., Adeyeye-Oshin, M., Mlitwa, N.B.W.: A state-of-the-art survey of indoor positioning and navigation systems and technologies. S. Afr. Comput. J. **29**(3), 145–197 (2017)
13. Priyantha, N.B.: The cricket indoor location system. Doctoral dissertation, Massachusetts Institute of Technology (2005)
14. Yassin, A., et al.: Recent advances in indoor localization: a survey on theoretical approaches and applications. IEEE Commun. Surv. Tutor. **2017**(19), 1327–1346 (2017)
15. Schmidt, E., Huang, Y., Akopian, D.: Indoor positioning via WLAN channel state information and machine learning classification approaches. In: Proceedings of ION GNSS+, pp. 355–166 (2019)
16. Bahl, P., Padmanabhan, V.: RADAR: an in-building RF-based user location and tracking system. In: Proceedings of the 19th Annual Joint Conference of the IEEE Computer and Communications Societies, vol. 2, pp. 775–784 (2000)

17. Youssef, M., Agrawala, A.: He Horus WLAN location determination system. In: Proceedings of the 3rd International Conference on Mobile Systems, Applications, and Services (MobiSys 2005), Seattle, WA, USA, pp. 205–218 (2005)
18. Schmidt, E., Akopian, D.: Fast prototyping of an SDR WLAN 802.11b Receiver for an indoor positioning systems. In: Proceedings of 31st International Technical Meeting Satellite Division Institute Navigation (ION GNSS), Miami, FL, USA, pp. 674–684 (2018)
19. Wang, X., Gao, L., Mao, S., Pandey, S.: CSI-based fingerprinting for indoor localization: a deep learning approach. IEEE Trans. Veh. Technol. **66**(1), 763–776 (2017)
20. Wang, X., Gao, L., Mao, S.: CSI phase fingerprinting for indoor localization with a deep learning approach. IEEE Internet Things J. **3**(6), 1113–1123 (2016)
21. Hsieh, C.-H., Chen, J.-Y., Nien, B.-H: Deep learning-based indoor localization using received signal strength and channel state information. IEEE Access **7**, 33256–33267 (2019)
22. Chen, H., Zhang, Y., Li, W., Tao, X., Zhang, P.: ConFi: convolutional neural networks based indoor Wi-Fi localization using channel state information. IEEE Access **5**, 18066–18074 (2017)
23. Brena, R.F.; García-Vázquez, J.P.; Galván-Tejada, C.E.; Muñoz-Rodriguez, D.; Vargas-Rosales, C.; Fangmeyer, J.: Evolution of indoor positioning technologies: a survey. J. Sens. **2017**, 1–21 (2017)
24. Gabela, J., et al.: Experimental evaluation of a UWB-based cooperative positioning system for pedestrians in GNSS-denied environment. Sensors **2019**, 5274 (2019)
25. Mazhar, F., Khan, M.G., Sällberg, B.: Precise indoor positioning using UWB: a review of methods, algorithms and implementations. Wireless Pers. Commun. **97**(3), 4467–4491 (2017). https://doi.org/10.1007/s11277-017-4734-x
26. Xu, B., Sun, G., Yu, R., Yang, Z.: High-accuracy TDOA-based localization without time synchronization. IEEE Trans. Parallel Distrib. Syst. **24**(8), 1567–1576 (2013)
27. Pittet, S., Renaudin, V., Merminod, B., Kasser, M.: UWB and MEMS-based indoor navigation. J. Navig. **61**, 369–384 (2008)
28. Zhang, J., Li, B., Dempster, A.G., Rizos, C.: Evaluation of high sensitivity GPS receivers. In: International Symposium on GPS/GNSS Taipei, Taiwan. 26–28 October 2010
29. Xu, R., Chen, W., Xu, Y., Ji, S.: A new indoor positioning system architecture using GPS signals. Sensors **15**, 10074–10087 (2015)
30. D'Aranno, P.J.V.: High-resolution geomatic and geophysical techniques integrated with chemical analyses for the characterization of a Roman wall. J. Cult. Heritage **17**, 141–150 (2016)
31. Argese, F., et al.: Piattaforma HW/SW per la gestione dei Cantieri Tecnologici per Infrastrutture Civili. Atti Asita (2019)
32. ROS Website. http://www.ros.org. Accessed 15 Feb 2020
33. Turtlebot Website. http://www.turtlebot.com. Accessed 15 Feb 2020