Research Article

Cost Effective and Easily Configurable Indoor Navigation System

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Abstract
With the advent of Industry 4.0, the trend of its implementation in current factories has increased tremendously. Using autonomous mobile robots that are capable of navigating and handling material in a warehouse is one of the important pillars to convert the current warehouse inventory control to more automated and smart processes to be aligned with Industry 4.0 needs. Navigating a robot's indoor positioning in addition to finding materials are examples of location-based services (LBS), and are some major aspects of Industry 4.0 implementation in warehouses that should be considered. Global positioning satellites (GPS) are accurate and reliable for outdoor navigation and positioning while they are not suitable for indoor use. Indoor positioning systems (IPS) have been proposed in order to overcome this shortcoming and extend this valuable service to indoor navigation and positioning. This paper proposes a simple, cost effective and easily configurable indoor navigation system with the help of an optical path following, unmanned ground vehicle (UGV) robot augmented by image processing and computer vision deep machine learning algorithms. The proposed system prototype is capable of navigating in a warehouse as an example of an indoor area, by tracking and following a predefined traced path that covers all inventory zones in a warehouse, through the usage of infrared reflective sensors that can detect black traced path lines on bright ground. As metionded before, this general navigation mechanism is augmented and enhanced by artificial intelligence (AI) computer vision tasks to be able to select the path to the required inventory zone as its destination, and locate the requested material within this inventory zone. The adopted AI computer vision tasks that are used in the proposed prototype are deep machine learning object recognition algorithms for path selection and quick response (QR) detection.

Keywords: Industry 4.0, Global Positioning System (GPS), Indoor Positioning System (IPS), Unmanned Ground Vehicle (UGV), Artificial intelligence (AI), Computer Vision, Deep Machine Learning.

1. Introduction
The demand for making location-based services (LBS) available has been increasing tremendously due to their benefits and feasibility based on advancements in internet of things (IoT) and the diversisty of available technologies. Localization and positioning as examples of LBS and their uses have been growing fast and broad. They have been intended to expand into areas and other applications including, health care and assistive systems for visually impaired people and their navigation (Kumar et al., 2009). Moreover, monitoring elderly people and patient monitoring in hospitals, in addition to industrial usages as in warehouses for inventory control, mapping and locating finished goods as well as shop floor services are examples of areas that LBS is used.

LBS as a navigation, positioning and localization service can be divided into two main branches, outdoor and indoor LBS. The former can be easily and accurately implemented through the use of satellites, which use global positioning system (GPS) and global navigation satellite systems (GNSS). In contrast, it has a very limited applicability and poor accuracy in indoor applications, since the satellite signals are not able to penetrate buildings and signals will be absorbed and distorted (Kotanen et al., 2003). Thus, to make this service available indoors, new techniques have been developed such as, WIFI, Bluetooth low energy (BLE), radio frequency identification (RFID), ultrasound, infrared and ultra-wide band (UWB) based positioning.

Obviously, Industry 4.0 aims to convert the manufacturing processes and warehousing to be smarter and digitized through the integration of advanced technologies such as, IoT, AI, autonomous robots and Cyber physical systems. In case of a warehouse management system, the aforementioned Industry 4.0 goal can be achieved through employing smart mobile robots integrated with AI and IoT. Indoor positioning and material handling, are the most important challenges and tasks in employing smart robots in warehouses and indoor areas. Different IPS technologies can be used to ensure autonomous robot navigation and smarter material handling. The selection of the most appropriate one is dependant upon the needs and requirements. In this paper, a cost-effective hybrid technique is being proposed to achieve autonomous indoor navigation and material handling using a simple line following mechanism enhanced by deep machine learning based object recognition and computer vision. An unmanned ground vehicle (UGV) is equipped with the required sensors for line detection and obstacle avoidance، in addition to a camera that captures surrounding real-time environment and streams it to an object recognition algorithm. The adopted deep machine learning object recognition algorithm assists the navigation system by path planning and finding the path to the required destination zone where the object is located. When, the robot reaches the required destination, it can detect the required object which is labeled with a dedicated quick response (QR) code, through a computer vision based QR code detection algorithm.

The paper is organized as follows. In section 2, related works have been reviewed. Section 3 describes IPS and navigation systems, and the available technologies for its implementation. Section 4 illustrates the proposed system architecture and design. The System workflow and operation is explained in Section 5. In Section 6, the system sub-functions tests are deployed and their performance results are discussed. Section 7 concludes the paper and forecasts possible future work.

2. Related Work

There are diverse techniques and methods to implement indoor positioning and navigation in any indoor area. Some related work is mentioned in this regard. An infrared technology to estimate the location of a mobile robot in an intelligent space has been proposed (Gorostiza et al., 2011). It estimates the robot's position by using a sensorial system to measure the distances from the robot to five sensors by measuring the differential phase shifts in sinusoidal modulated infrared signal emitted by the robot, and then introducing the measured distances to a hyperbolic trilateration system.

An RFID based localization system was deployed in Italy, to locate visually impaired people (Biader Ceipidor et al., 2009) where an RFID reader is installed at the tip of a cane and RFID tags are buried in the sidewalks through which the predefined location information embedded in them and a person's location is known.

BLE technology is used to estimate the location of objects equipped with BLE tags and hence facilitates their navigation through the obtained location information. An example of BLE related work for asset tracking in a warehouse was proposed by Lee et al. (2019). Moreover in other work, (IPS) for use in a warehouse was proposed using iBeacon technology which is BLE based technology and was released by Apple Inc. (Zhao et al., 2016).

Another approach to grant autonomous navigation and positioning to UGV robots by integrating a team of UGV and unmanned aerial vehicle (UAV) is to use the UAV to assist the UGV in localization and navigation tasks by providing real-time surrounding environment information, such as using an UGV-UAV integration system collecting data on construction sites (Asadi et al., 2020). Furthermore, a vision-based target detection and localization system was proposed by using cooperative integration of an UAV and multiple UGVs to detect targets and find their locations in real-time (Minaeian et al., 2015).

A suitable UGV indoor navigation system was also proposed, using an integrated navigation system that integrates two-dimensional Light Detection and Ranging (LiDAR), odometry and Inertial Navigation System (INS) by (Liu et al., 2015).

3. Indoor Positioning And Navigation Systems

The ability to locate an object or people in a building or an indoor area is known as indoor positioning (Ni et al., 2003). This can be achieved through different techniques tried under IPS, which is basically composed of two main components, anchors and location tags (Mautz, 2012). On the other hand, indoor navigation systems are the systems that grant people or objects the ability to find a path to a determined destination point from their starting position and vice versa.

Diversity of available materials and obstacles with different dimensions, shape and characteristics affect the signal propagation and strength that travels between anchors and location tags installed in indoor environments. This makes IPS more complicated and challenging than outdoor positioning systems (Brena et al., 2017).

Due to the abovementioned challenges, opportunities and features that present in implementing IPSs, diverse approaches and technologies have been used for indoor positioning and navigation systems in literature, each with specific advantages and drawbacks, as mentioned below:

Proximity based systems can find object positions within a building at room level accuracy through the usage of beacons and tags. This method offers a simple IPS at almost the lowest cost compared to other techniques with the lowest accuracy.

IPS considers Bluetooth technology as a resource and a competitor to Wi-Fi based IPS techniques. BLE is a good example of this technique (Kriz et al., 2016). In recent health care work, BLE beacons were used to track patients holding BLE tags in a hospital as an indoor environment (X. Lin, 2015). Moreover, an indoor localization and navigation solution was proposed using short range BLE to identify the location of different structures, which could be used as a self-sufficient navigation system for visually impaired people using an android application (Nagarajan et al., 2020).

Another technique is known as WiFi-based systems. In this method, WiFi transmitters are used as tags (Kim et al., 2016). The position of a tag would be calculated by an algorithm that takes the information about time and strength of the packets that were transmitted by the tag to a number of different access points in the facility from a common backend. This method has the accuracy of three to five meters (Gezici, 2008). To further improve this accuracy level, additional WiFi access points should be added, since it works on the time difference of arrival (TDOA) measurement principle which would be an expensive, cost demanding method and more a more energy consuming option compared to other alternatives.

UWB is a pinpoint precision technology which is used in an indoor localization system. Although, it has the most accurate position measurement capability, its main drawback is the cost as it is the most expensive available technology for IPS. In this technique, a very wide pulse over a GHz spectrum is transmitted by several UWB transceivers. They then listen to the short coded ultra-wide response pulses generated by UWB tags. Then, a very accurate time measurement report would be sent to a central server by each of them. A human indoor localization technique is proposed by using UWB technology with time delay measurements. The localization of human position is done through UWB based distance data, in addition, a time delay localization model is employed by using an extended finite impulse response (EFIR) filter (Xu et al., 2017). High accuracy and installation cost, limit the usage of this technology to precision specific scenarios such as in material flow control in a manufacturing facility and warehousing for inventory control. While it would be a poorly utilized option if used in hospitals and places where pinpoint accuracy is not a must.

Ultrasonic or acoustic systems are another available system used in indoor positioning. This system works exactly the same way as UWB and has the same architectural design except that it uses sound waves instead of radio waves. Receivers receive ultrasonic sound waves generated by tags. This system's accuracy is roughly close to that of UWB but it has non-line of sight (NLOS) issues when the beacon and tags are interrupted by obstacles. A novel sensor grid transmitter technique has been proposed for adoption in indoor positioning applications for vehicle navigation. It uses 40 KHz ultrasonic transmitters that transmit ultrasonic signals and a vehicle position is calculated by measuring the arrival time of incoming ultrasonic signals (Kapoor et al., 2016).

Optical technology-based systems, use both visible and invisible lights for estimating a tag's position. Infra-red (IR) light pulses are used in infrared based systems for indoor positioning and localization. In this system, installed IR receivers in every area read IR pulses generated from the IR tags. This system is a very reliable way to assure room level accuracy, since it uses infra-red (IR) pulses which are light pulses that cannot penetrate the walls in contrast to radio waves. In other words, radio wave-based systems suffer more from false readings or indications due to their ability to penetrate walls, thus in some cases a dedicated tag's signals could be sensed by other readers not related to the indicated room or area through the walls. In general, radio wave-based systems perform better in open space areas such as, manufacturing warehouses, while light and sound-based systems are best suited to closed areas such as hospitals.

We can conclude that with all of the systems mentioned, their application and selection is highly dependent upon the deployment environment and required level of accuracy. However, their deployment for indoor positioning and navigation services in a warehouse or shop floor environment is highly restricted to the performance challenges of each technique in these environments.

Optical technology-based systems, IR based systems for instance, face serious issues when implemented in a warehouse environment such as the accuracy and reliability are affected by many optical signal characteristics including reflectivity and scattering when hitting obstacles, as well as the requirement of line of sight (LOS) clearance between anchors and tags. Due to these challenges, implementing IR based navigation in a warehouse is challenging and has poor accuracy due to the many different objects with different dimensions which in turn results in poor LOS (Brena et al., 2017). On the other hand, other radio wave-based techniques require special designs as they are not easily configurable to constructional changes and new area planning as well as their considerably expensive prices. Table 1 illustrates the different navigation systems with their associated advantages and drawbacks.

Table 1. Examples of indoor navigation systems and their advantages and drawbacks.

Navigation System Technology	Research	Advantages	Drawbacks
BLE	(Kriz et al., 2016; Nagarajan et al., 2020)	Needs low computing resources, very low power consumption, low cost, availabile in most smart phones with different platforms	Interference by physical barriers, which results in signal attenuation and reflection
WiFi	(Cui et al., 2019; Kim et al., 2016)	Low cost and availabile in most buildings in terms of coverage	High modification cost due to requirement of remapping activity, which could be expensive, in case of access point or building organization changes
UWB	(Tiemann & Wietfeld, 2017; Xu et al., 2017)	High precision, pinpoint positioning accuracy	Considerable high installation and maintenance cost. Cannot be easily reconfigured based on any building arrangement changes. Complexity in implementation
Optical Technology-Based Systems (IR)	(Gorostiza et al., 2011)	Low operating cost for end users	High installation cost, sensitive to obstacles in terms of reflectivity and scattering, interference with sunlight and indoor brightness levels

4. System Architecture and Design

The proposed model in this paper focuses more on navigation rather than localization. The goal is achieved through the use of low cost and easily configurable technologies. In the sections below, the paper describes the architecture and design of the system in detail.

4.1. Navigation

The proposed navigation system for the mobile robot is performed by the usage of infrared reflectance-based line tracking sensor TCRT5000. It is mounted at the bottom of the robot car chassis. As illustrated in Figure 1, it basically consists of an infrared transmitter (LED) and receiver module (photo transistor) to detect reflected infrared light. It measures the amount of reflected infrared light transmitted by an LED emitter which in turn detects the transitions between dark and bright colors or surfaces. The line tracking sensor enables the robot to track a line optically by detecting the difference in infrared reflectance from surfaces of different brightness levels. In our model, the ground color is bright (white color) and black tape is used as a patrol or path.

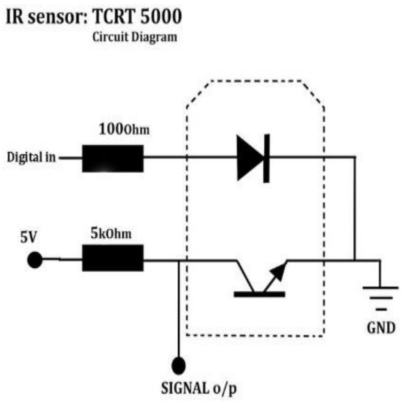

Figure 1. TCRT 5000 infrared reflective sensor.

4.2. Collision Avoidance and Obstacle Mapping

In order to guarantee proper and collision free navigation, collision avoidance and obstacle detection properties should be implemented for the aforementioned line following navigation. In the proposed prototype, this property is achieved by using ultrasonic sensors in front and rear ends of the robot car. The ultrasonic ranging sensor used in the proposed prototype is HC-SR04 which provides 2 cm to 4 m operation range with ranging accuracy of 3 mm. It consists of an ultrasonic transmitter and a receiver. It transmits eight 40 kHz ultrasonic pulses then checks any reflected signal (ECHO) during which the interval between pulse transmission and feedback is measured. As a result, the distance from the obstacle or object can be calculated using Eq.(1)

$$Distance = (timeinterval * soundvelocity)/2 \qquad (1)$$

Where sound velocity in air = 340 m/s

As mentioned before, the proposed navigation system functions based on line following principle plus object recognition using deep machine learning which will be explained in the next section.

4.3. Object Recognition Using Deep Machine Learning

The role of machine learning is for identifying the desired destination among multiple available options resulting from using a line following mechanism. While the robot is on the main patrol and there are other branches available out from the main patrol, the machine learning algorithm will take the lead to decide which branch should be chosen based on the image recognition algorithm. It can also be used for tracking and detecting the required item through optical QR code scanning using the robot camera and OPENCV library, QR-detection algorithm. When the robot is in the right zone where the required item exists, it starts scanning the shelves to find the required item, picks it up and then transports it.

4.4. System Architecture

The prototype architecture consists of two main sections, hardware and software. In the hardware section, a vehicle robot is equipped with necessary sensors and parts required for successful collision free navigation. Whereas, the software section is responsible for the robot navigation program which is written in Python and image processing for computer vision tasks using OPENCV library and convolutional neural network (CNN) based on deep machine learning object recognition algorithms. The object recognition model is established by using deep machine learning using Keras and TensorFlow GPU backend. The architecture is illustrated in Figure 2. The hardware section consists of raspberry pi3B microcomputer as robot's main controller, servo motors and their corresponding PWM driver, ultrasonic sensor HC-SR04 sensor for obstacle detection and distance measurement, infrared reflective sensor TCRT5000 grants line following ability to the robot. Furthermore, the robot is equipped with a 2MP camera for capturing surrounding environments video in real time which will be used for object recognition and QR-code scanning for tracking the required item's position.

The program that makes the robot functional is written in Python. The robot controller streams real-time video captured by the camera to the main edge computing device for computer vision and object recognition tasks. The object detection and recognition algorithm used in the prototype is single shot multi box detector (SSD) based on VGG16 convolutional neural network architecture model (Liu et al., 2016). In this prototype as mentioned previously, tensorflow object detection application programming interface (API) is used as a machine learning platform, and Keras is used as the API to train the deep learning convolutional neural network and more specifically "ssd_mobilenet_v2_coco" model is used, which is able to recognize 100 different object classes, moreover it can be trained for any user specific object classifications.

5. System Workflow

Figure 3 is the flowchart that illustrates the working mechanism of the prototype. The request center continuously scans for new requests. The request is from a database containing the required item's location information and its available quantity. When the new request is placed, the job organizer forwards the data to the robot. The robot starts navigating to the required area, finding and transporting the requested object. The navigation process will be done by following the main patrol by using the feedback from a infrared reflective sensor. The robot keeps tracing on the patrol while sending real-time video streams of the surrounding environment to the image processing edge device, which is a powerful PC equipped with Nvidia GTX1060 graphics processing unit (GPU). Simultaneously, the streamed data will be processed by an image processing and object recognition edge computing device, which acts as a client for the robot (server). When the required zone where the item is located is found and recognized by the object recognition algorithm, the robot will lean to the detected zone. Here, the second part of the requested item's location data will be searched for, which is the item itself. When the robot reaches the correct zone that shelves of materials are located it uses another computer vision algorithm by OPENCV to scan the QR-codes stuck to the shelves as illustrated in Figure 4. As the required item is scanned the robot picks up the part and starts following the path, which will head to its initial position where the data requested.

This process will work continuously as long as there are requests available. There are some assumptions that have been made in this prototype. Since there is just a robot or robots in the area, the main patrol is assumed to be free for the robot and dedicated for it uniquely. Whenever the robot detects any temporary obstacle, it stops and waits until the path is cleared, if the obstacle remains for more than ten seconds an audible alarm will be actuated to warn warehouse supervisor.

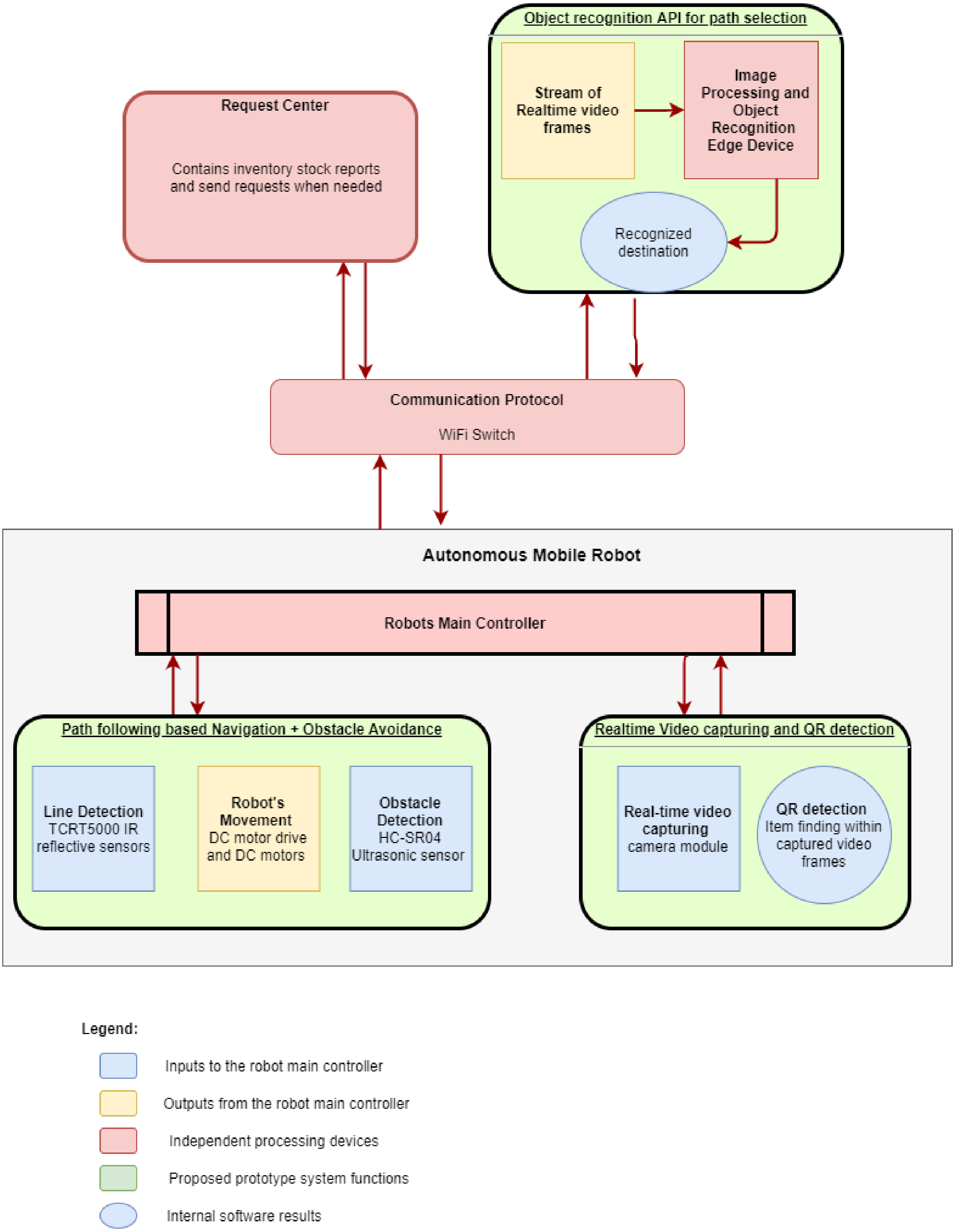

Figure 2. The proposed system architecture.

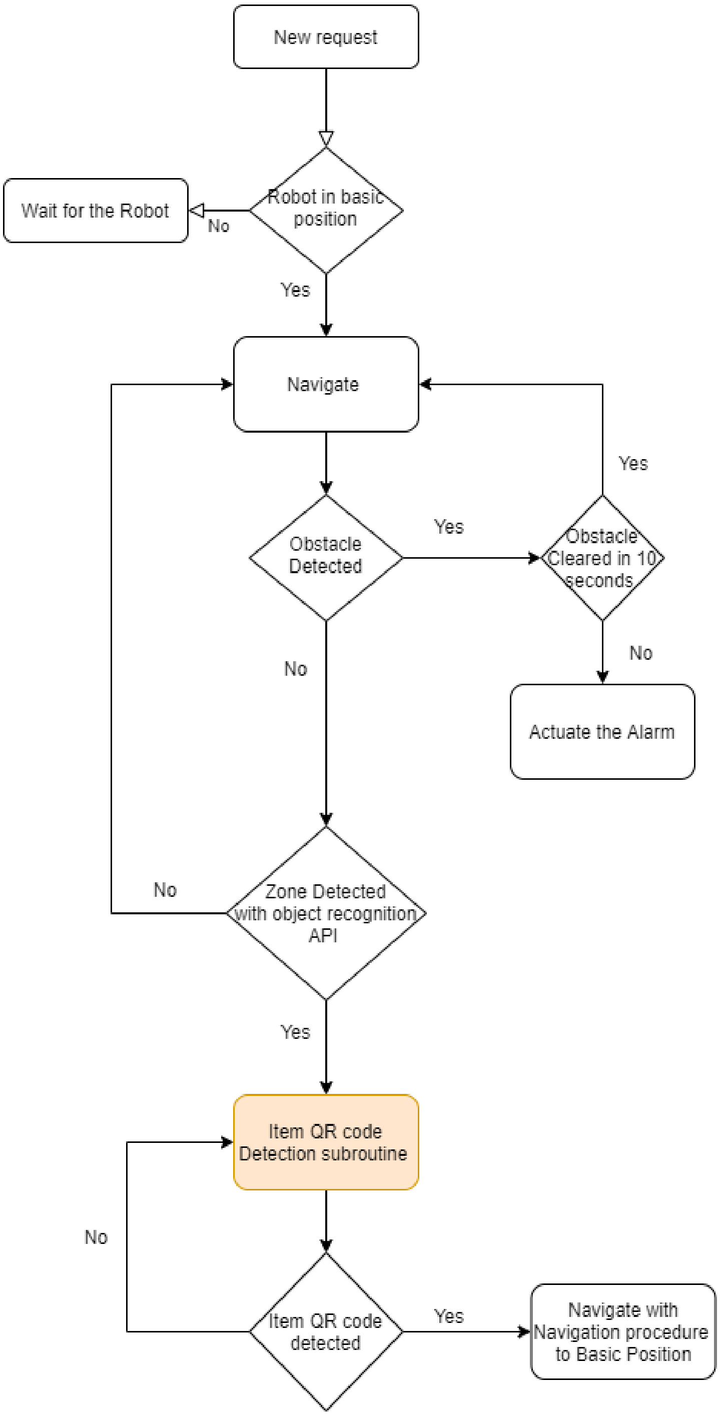

Figure 3. The proposed system workflow.

Obviously, the TCRT5000 IR reflective sensor used for line tracking accuracy might be affected by other sources of light such as sun light and indoor lighting. This noise is eliminated by a denoising mechanism.

The main objective of this paper is to propose the implementation of Industry 4.0 in warehouses or shopfloor stores. In order to make this implementation successful, an optimum interaction and cooperation between recent technologies is required for indoor positioning and navigation systems. In regards to indoor navigation and positioning systems, it's obvious that there are a number of available advanced technologies that can be deployed according to the needs and system requirements, each with specified advantages and disadvantages. Regarding the proposed method, this paper attempts to focus on the final requirement which is proper material handling and tracking. The main advantage of the proposed method over other advanced technologies is that it can be easily applied and configured to different environments with minimum cost. Moreover, it is compatible and can be reconfigured according to any constructional changes without requiring considerable effort and cost. It also achieves the same final result in terms of navigation and material handling as other available IPS technologies like UWB, BLE, WIFI etc.

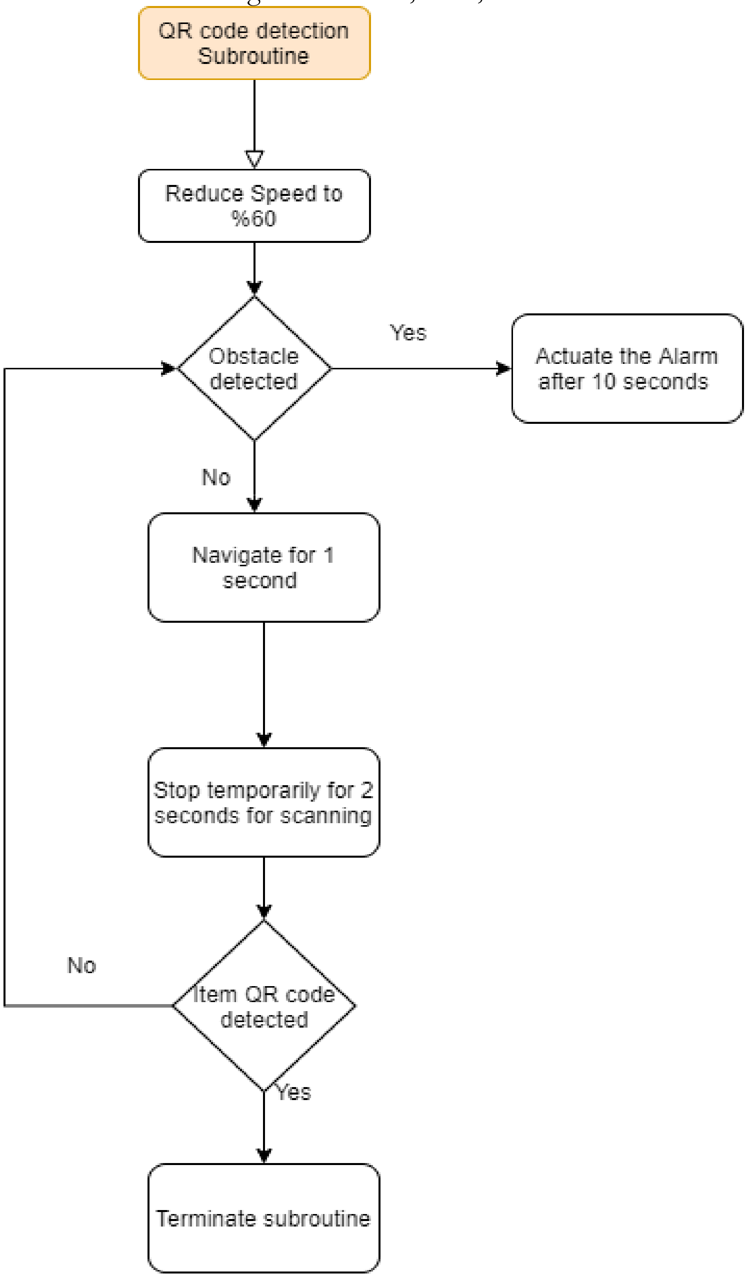

Figure 4. The QR-code detection subroutine.

6. Results and Discussion

In order to check the effectiveness and reliability of the proposed system, the functionality of all used technologies in the prototype was tested in different realtime scenarios and the relevant codes of the program are shown and discussed below.

6.1. Line Following Navigation and Obstacle Avoidance Tests

Collision free navigation is a very important aspect of the proposed system as it guarantees safe navigation of the robot. The precision of obstacle detection and its distance from the robot is vital. Therefore, the ultrasonic sensor (HC-SR04) test was deployed and the result was positive as illustrated in Figure 5. Meanwhile, the base patrol detection navigation mechanism accuracy was tested with different path organizations and conditions in terms of straight paths, normal turns and sharp turns. The navigation mechanism was basically implemented by the usage of infrared reflectance-based line tracking (TCRT5000) sensors installed at the fore-end bottom of the robot car chassis. The line following navigation with two IR reflective sensors on the right and left side of the fore end of the robot chassis was able to accurately follow straight and wide turns, while it did not perform well with sharp turns. This issue was overcome by using some optimization techniques in the navigation code, motor drive PWM control and by increasing the number of IR reflective sensors to three sensors, that were distributed evenly between the right, middle and left sensors. The results of the ten successive tests using different testing conditions and environment brightness levels are illustrated in Figure 6.

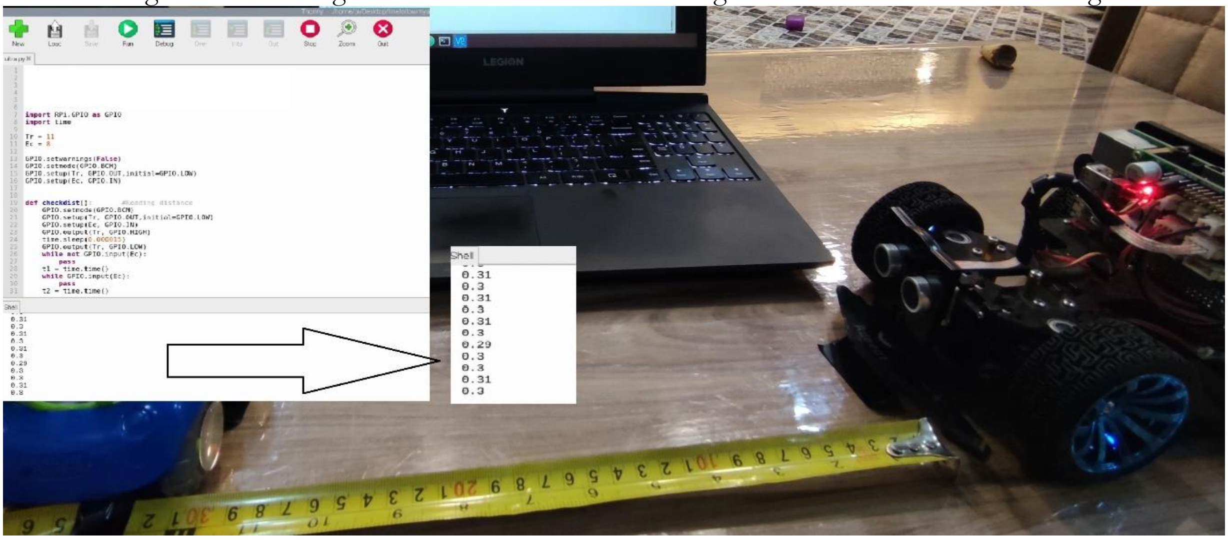

Figure 5. Obstacle avoidance and distance measurement test. Distance results are in meters.

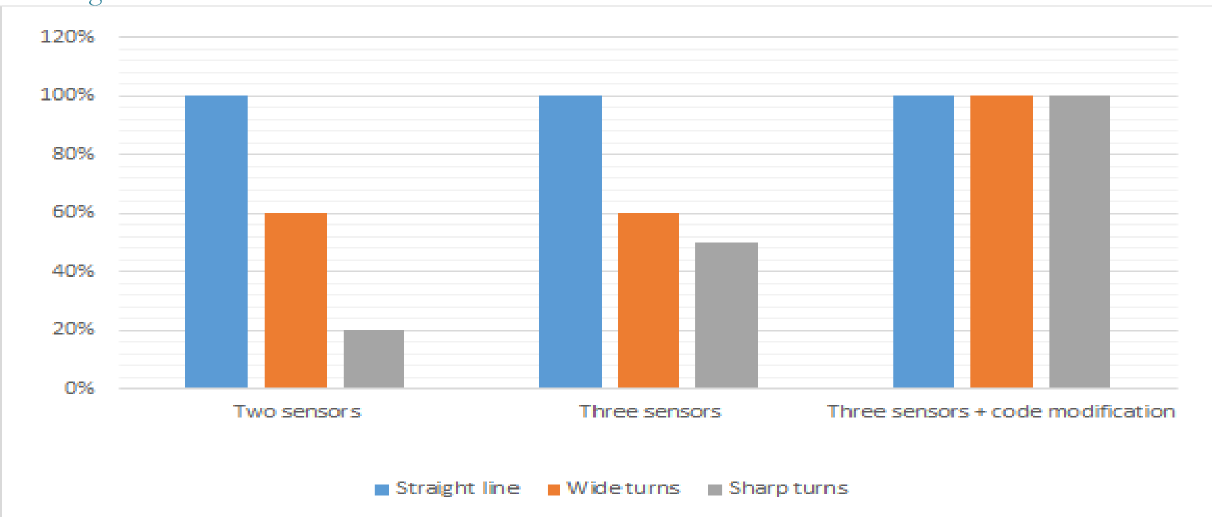

Figure 6. Results of 10 successive tests with different modifications and optimization techniques.

6.2. Object Recognition and Deep Neural Network Model Tests

As mentioned in previous sections, deep machine learning algorithm-based image processing and object recognition API are trained and used to empower the reliable and successful navigation in terms of path planning and path selection among multiple available paths. Figure 7 and Figure 8 show the results of image processing and object detection to select the required zone, in addition to QR-code detection to detect and track required item. The test result shows that object recognition and QR-code scanning are reliable when they are within the video frame area and predictions are accurate. However, when the robot is used to detect material, QR codes in real testing environment it is obtained that the results are not consitent and success is affected by the robot's navigation speed when it is scanning for materials for the QR codes in the desired inventory zone and the environment's brightness level. To solve this shortcoming and to maintain reliable QR scanning, some modifications and optimization measures have been taken as illustrated in Figure 9. As a good practice measure, to overcome the aforementioned issues, the navigation code was modified to introduce short stops to the robot while the scanning procedure was in progress, to ensure the camera frame settled to avoid mis-scanning. In addition, extra lighting was added to the inventory area.

6.3. Summery

Table 2 shows the test results of the prototype and its sub-function tests in different environmental conditions. Undoubtedly, the prototype parts are all performing well as shown in the results. The overall prototype performance for autonomous navigation is limited to the performance of different hardware parts used in this study. However, it is optimized by implementing modifications in codes and working conditions. In addition, more robust and better performing parts were replaced for instance, the quality and power rating of the main drive motor, steering servo motors and the corresponding drives.

Table 2. The prototype sub-function test results.

Tests Performed	Results
Different obstacle detection and distance measurement	Succeeded
QR-code detection	Succeeded
Recognize multiple objects in the same frame	Succeeded
Patrol line detection with different environment brightness levels	Succeeded
Line following mechanism accuracy at high speeds and in straight lines	Succeeded
Line following mechanism accuracy using sharp and wide turns	Succeeded
Accuracy at slow speeds and leaning (curved) lines	Succeeded
Real-time navigation	Succeeded

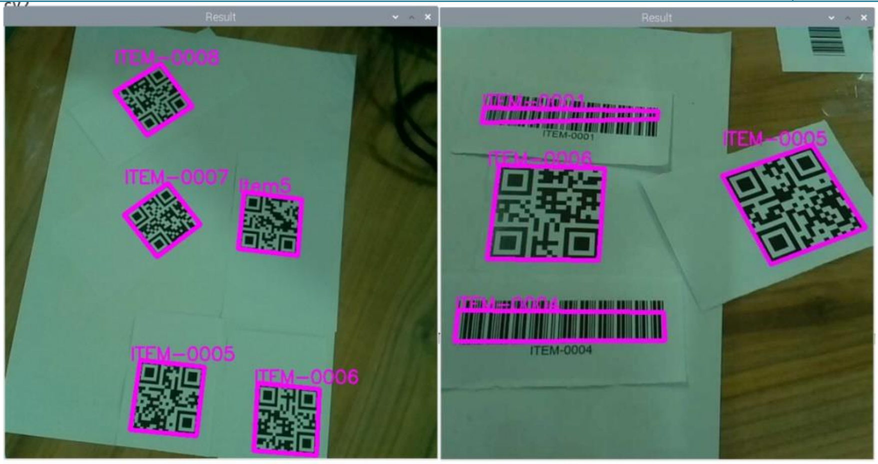

Figure 7. QR-coode detection results.

6.4. Discussion

The proposed prototype can provide simple and easily configurable navigation indoors, with predefined path planning that includes possible multi-paths branching from a main patrol line. The UGV can follow the patrol since it is equipped with infrared refractive sensors that can detect dark line that are traced on bright ground. The test results have shown that the system can effectively and successfully follow the path. The path selection to any required zone is decided by zone detection properties using an object recognition and image processing algorithm. When the robot is in the required zone, it uses QR-code detection with in the video frames to detect and track the required item.

As previously mentioned, the proposed indoor navigation prototype can be easily deployed in different applications and environments other than warehouses and shopfloors, such as, hospitals for navigating vision impaired people to the desired destination.

7. Conclusion and Future Work

This study aims to propose a low cost and easily configurable indoor navigation and material handling system for asset tracking purposes in different environments. In the study, the propsed model was used for autonomous navigation and material handling in a warehouse. Performance metrics were defined and studied throughout the experiments. The system achieved material handling and navigation through the integration of a simple collision free pattern following mechanism empowered by computer vision and object recognition using deep machine learning CNN model. The UGV always keeps following a fixed multipath predefined pattern, selects the required pattern based on a deep machine learning object recognition algorithm and tracked the wanted item through a QR code detection algorithm. The proposed system prototype integrates and empowers robot navigation with AI tasks through deep machine learning neural network model-based applications which in turn provides flexibility and adaptability to the system. Advantages include flexibility in re-configurations due to environment and infrastructural changes in implemented indoor area with minimum cost compared to other available techniques, in addition to the simplicity of implementation in various different indoor environments other than warehouses, such as in tour guide vehicle robots, and health care and patient transportation in hospitals etc.

The focus of future work should be on identifying the real-time pinpoint location information of the robot with the aid of possible integration of some other available technologies and enhancements in deep machine learning algorithms. In addition, implementing the system in hospital navigation systems for the visually impaired and people with special care needs, and incorporating additional functionalities such as voice command and narration services should be explored.

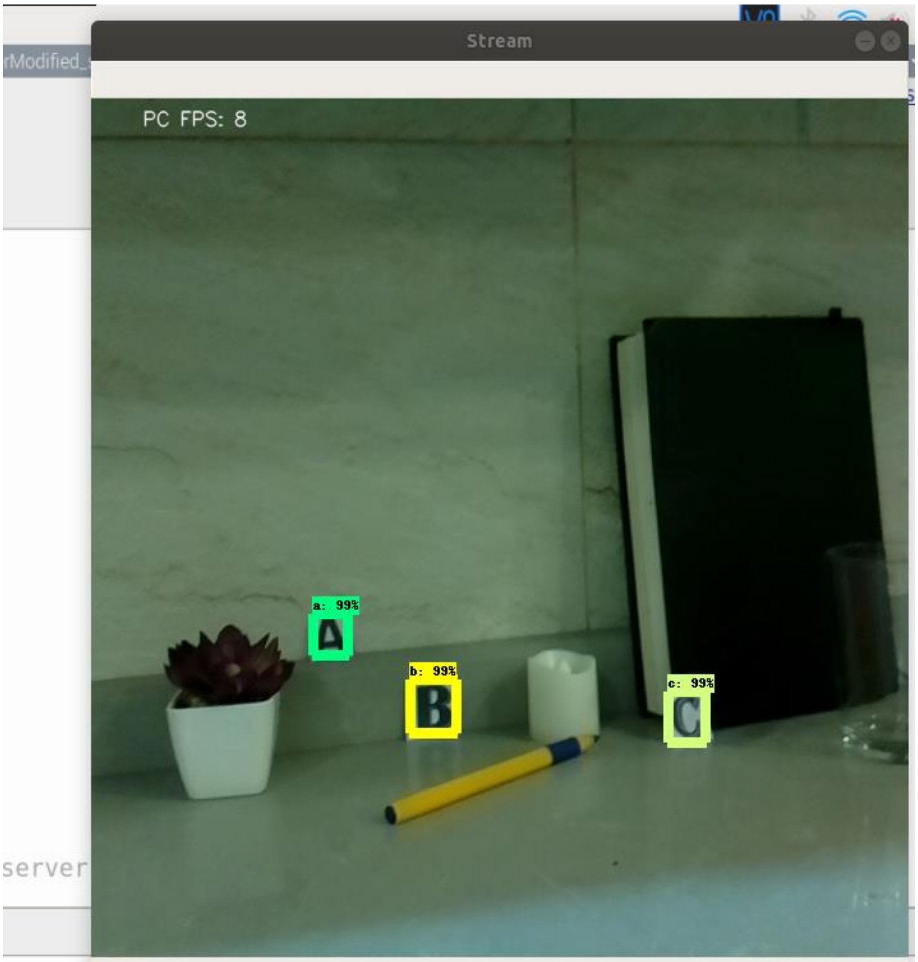

Figure 8. Object recognition results for the trained deep neural network model.

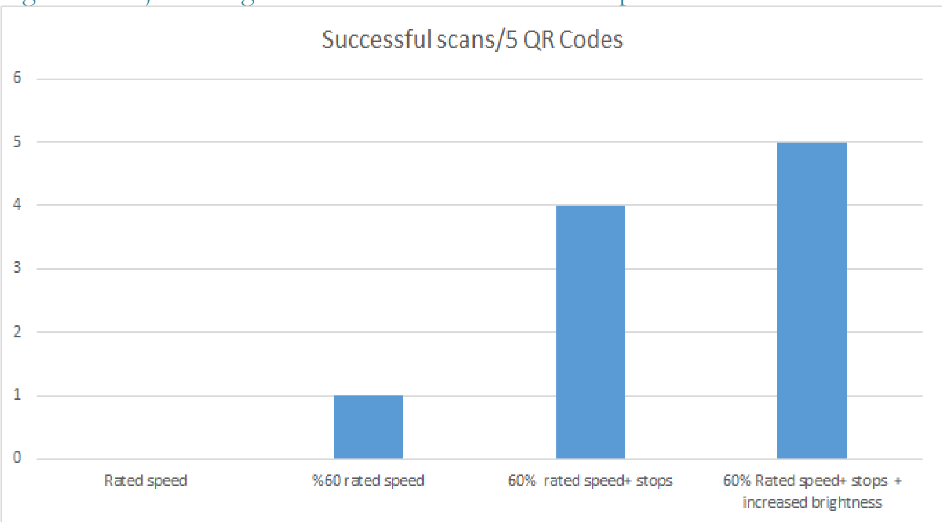

Figure 9. QR code detection test in real-time environments and with different conditions and optimization techniques.

References

Asadi, K., Suresh, A. K., Ender, A., Gotad, S., Maniyar, S., Anand, S., Noghabaei, M., Han, K., Lobaton, E. & Wu, T. (2020). An integrated UGV-UAV system for construction site data collection. *Automation in Construction,* 112, 103068.

Biader Ceipidor, U., Medaglia, C. M., Serbanati, A., Azzalin, G., Barboni, M., Rizzo, F. & Sironi, M. (2009). SeSaMoNet: an RFID-based economically viable navigation system for the visually impaired. *International Journal of RF Technologies,* 1, 214-224.

Brena, R. F., García-Vázquez, J. P., Galván-Tejada, C. E., Muñoz-Rodriguez, D., Vargas-Rosales, C. & Fangmeyer, J. (2017). Evolution of Indoor Positioning Technologies: A Survey. *Journal of Sensors,* 2017, 2630413.

Cui, Y., Zhang, Y., Huang, Y., Wang, Z. & Fu, H. (2019). Novel WiFi/MEMS integrated indoor navigation system based on two-stage EKF. *Micromachines,* 10, 198.

Gezici, S. (2008). A survey on wireless position estimation. *Wireless personal communications,* 44, 263-282.

Gorostiza, E. M., Lázaro Galilea, J. L., Meca Meca, F. J., Salido Monzú, D., Espinosa Zapata, F. & Pallarés Puerto, L. (2011). Infrared sensor system for mobile-robot positioning in intelligent spaces. *Sensors,* 11, 5416-5438.

Kapoor, R., Ramasamy, S., Gardi, A., Bieber, C., Silverberg, L. & Sabatini, R. (2016). A novel 3D multilateration sensor using distributed ultrasonic beacons for indoor navigation. *Sensors,* 16, 1637.

Kim, W., Yang, S., Gerla, M. & Lee, E.-K. (2016). Crowdsource based indoor localization by uncalibrated heterogeneous Wi-Fi devices. *Mobile Information Systems,* 2016.

Kotanen, A., Hannikainen, M., Leppakoski, H. & Hamalainen, T. D. (2003). *Experiments on local positioning with Bluetooth.* Proceedings ITCC 2003. International Conference on Information Technology: Coding and Computing, 2003. IEEE, 297-303.

Kriz, P., Maly, F. & Kozel, T. (2016). Improving indoor localization using bluetooth low energy beacons. *Mobile Information Systems,* 2016.

Kumar, S., Qadeer, M. A. & Gupta, A. (2009). Location based services using android (LBSOID). 2009 IEEE international conference on internet multimedia services architecture and applications (IMSAA), 2009. IEEE, pp. 1-5.

Lee, C. K. M., Ip, C., Park, T. & Chung, S. (2019). A Bluetooth Location-based Indoor Positioning System for Asset Tracking in Warehouse. 2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), 2019. IEEE, pp. 1408-1412.

Liu, S., Atia, M. M., Karamat, T. B. & Noureldin, A. (2015). A LiDAR-aided indoor navigation system for UGVs. *The Journal of Navigation,* 68, 253-273.

Liu, W., Anguelov, D., Erhan, D., Szegedy, C., Reed, S., Fu, C.-Y. & Berg, A. C. (2016). SSD: Single Shot MultiBox Detector. 2016 Cham. *Springer International Publishing*, pp. 21-37.

Mautz, R. (2012). Indoor positioning technologies, ETH Zurich, Department of Civil, Environmental and Geomatic Engineering, Institute of Geodesy and Photogrammetry, Schweizerische Geodätische Kommission, pp. 86.

Minaeian, S., Liu, J. & Son, Y.-J. (2015). Vision-based target detection and localization via a team of cooperative UAV and UGVs. *IEEE Transactions on systems, man, and cybernetics: systems,* 46, 1005-1016.

Nagarajan, B., Shanmugam, V., Ananthanarayanan, V. & Sivakumar, P. B. (2020). Localization and Indoor Navigation for Visually Impaired Using Bluetooth Low Energy. *Smart Systems and IoT: Innovations in Computing.* Springer.

Ni, L. M., Liu, Y., Lau, Y. C. & Patil, A. P. (2003). LANDMARC: indoor location sensing using active RFID. Proceedings of the First IEEE International Conference on Pervasive Computing and Communications, 2003.(PerCom 2003). 2003. IEEE, 407-415.

Tiemann, J. & Wietfeld, C. (2017). Scalable and precise multi-UAV indoor navigation using TDOA-based UWB localization. 2017 International Conference on Indoor Positioning and Indoor Navigation (IPIN), 2017. IEEE, 1-7.

X. Lin, T. H., C. Fang, Z. Yen, B. Yang And F. Lai, (2015). A mobile indoor positioning system based on iBeacon technology. 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Milan, 2015, pp. 4970-4973. doi: 10.1109/EMBC.2015.7319507

Xu, Y., Shmaliy, Y. S., Li, Y. & Chen, X. (2017). UWB-based indoor human localization with time-delayed data using EFIR filtering. *IEEE Access,* 5, 16676-16683.

Zhao, Z., Fang, J., Huang, G. Q. & Zhang, M. (2016). *iBeacon enabled indoor positioning for warehouse management.* 2016 4th International Symposium on Computational and Business Intelligence (ISCBI), 2016. IEEE, 21-26.