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Article

Autonomous IOT-Based Mobile Robot for Industrial Material Handling Using Multi-Sensor Fusion

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Abstract: The paper provides the design and implementation of sensor-fusion-guided mobile robotic vehicle in efficient and safe industrial material handling. The suggested system is implemented with the help of an Arduino Uno microcontroller with several sensors such as ultrasonic sensors, infrared (IR) sensors and wheel encoders to provide efficient perception and tracking of the environment. The fusion of these heterogeneous sensors is achieved through sensor fusion so that the weaknesses may be overcome, which allows the sensors to detect obstacles reliably, guide paths and navigate successfully in dynamic industrial settings. Ultrasonic sensors offer a range of distance measurements that are long, whereas IR sensors offer a high accuracy of short-range measurements, and the wheel encoders facilitate odometry-based estimation of movement. An ESP8266/ESP32 IoT chip is also installed in the robotic vehicle, which enables real-time tracking, assigning tasks remotely and visualizing the status of the system with the help of a cloud interface. The driver allows motor control, which is the L293D driver, and brings smooth and precise movements of wheels to move through the predetermined industrial paths autonomously. The solution suggested can greatly decrease the number of people on the work, eliminate the risks of collisions, and enhance the efficiency of the working process on the warehouse floor and factory premises. The system combines affordable hardware with smart sensor fusion and IoT connectivity to provide a scalable and cost-effective and reliable solution to modern smart industry-wide material transportation.
Keywords: L293D, IR sensor, Ultrasonic sensor, ESP8266, IOT module, motor driver

1. INTRODUCTION

The increasing demands of high productive, accuracy and safety have resulted in industrial automation as a necessity in the modern world of manufacturing and warehouses [1]. The traditional material handling systems that are human operator controlled and incorporates the fixed conveyor systems are typically inefficient, rigid, and prone to errors when in use. The physical stress of the employees, the occurrence of work-related injuries [2], and physical fatigue due to manually moving products around the factory are related to the physical distance of products, unlike fixed-path systems such as conveyors and Automated Guided Vehicles (AGVs) that require expensive systems and fail to react to changes made in the plan [3]. Since the development of smart factories and Industry 4.0 is still running at a rapid pace, there is a high demand of intelligent mobile robotic systems; that can independently deliver the material and navigate around the evolving environments, and coordinate themselves with other machines. The mobile robotic cars are a substitute to the conventional system of handling which is flexible and scalable; the system provides on-demand transportation, cheaper installations and greater operation effectiveness [4]. They can also move freely in the factory premises, alter their routes immediately and can work 24 hours without any human intervention; such robots can increase the productivity and reliability of industries drastically [5].

The key issue with the establishment of the mobile robotic vehicles in the industrial material handling issue, is the capacity to give accurate navigation and availability of obstacle evasion in the intricate and unpredictable situations [6]. The stumbling of machines, employees, cart and barrier fences adore the industrial floor and therefore extreme precision of these motions is needed to render the processes safe [7]. Most affordable robots are founded on solitary sensor founded such as ultrasonic or infrared sensors that are sensitive to noises, lack of precision and also environmentally sensitive [8]. The ultrasonic sensors cannot pick soft surfaces, angled surfaces as well as infra red sensors are also sensitive to the surrounding light and reflection on the surface [9]. Despite the convenience of the movement tracking, the wheel encoders are subject to error accretion due to the slipping of their wheels, as well as, uneven floors. The application of each of such sensors only leads to inaccuracies in positions [10], lack of obstacles detection and unsafe navigation. To overcome these disadvantages, the existing robotic systems are increasingly incorporating sensor fusion that is a process of synthesizing data of multiple sensors with the aim of offering a more precise and accurate representation of the environment that the robot is operating in [11]. Sensor fusion has the potential of significantly enhancing the accuracy and strength of navigation used in industrial applications since the process incorporates complementary sensor information [12].

The proposed system will be sensor-fusion-based approach, which uses ultrasonic sensors, infrared sensors and wheel encoders to provide valid perception and motion control of a robot on an industrial basis [13]. The ultrasonic sensor has a high level of obstacle detection and the robot is capable of identifying the existence of large objects at distance and prevent collisions. The infrared detectors provide quick short distance detection which is mostly useful in small aisles, loading posts as well as in the areas of the objects [14]. The wheel encoders are used to monitor the rotation of each wheel allowing the system to calculate the distance covered and calculate the position of the robot by odometry. By integrating these sensor signals the robot is capable of compensating on the weaknesses of each sensor and produce a valid and unvarying source of navigation [15]. As an example, when measurements of the ultrasonic are affected by the reflection on the surface, feedbacks to the encoders and IR signals will also be utilized to verify the position of the robot and as well as its movement [16]. This cooperative sensory system allows the robotic car to move in a dignified fashion, avoid obstacles in a smart fashion, and stay on track on its course desired even in an industrial environment that is rampant and hectic [17].

The system will enable the use of the Internet of Things (IoT) technology to provide the functionality of the robotic vehicle one more with the assistance of ESP8266 or ESP32 Wi-Fi module. The IoT connection enables real-time communication between the robot and a monitor system based on a cloud to enable the operators to see not only the status and position of the robot, but also its battery status and the progress of its work remotely [18]. This type of remote access is particularly useful in large factories and warehouses when more than a few robots can be operating. This will enable supervisors to assign pickup and delivery tasks, be informed about the hindrances or errors in the system and track the overall performance without having to be near the robot [19]. IoT-based control also enhances data recording and performance analysis which could be used to aid in optimization of the route, scheduling and predicting when maintenance is necessary. The suggested system would transform an ordinary mobile robot into a smart industrial device that would be capable of making smart decisions and controlling its resources efficiently through the autonomous navigation and cloud connection services [20].

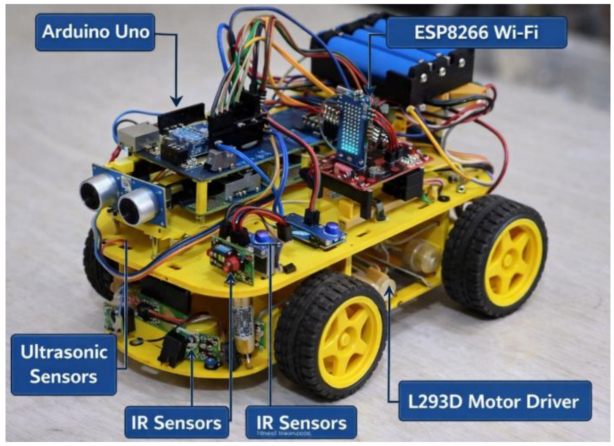

Fig.1. Hardware kit image.

Sensor Fusion Based Guided Mobile Robotic Vehicle to handle industrial material: The Sensor Fusion Based Guided Mobile Robotic Vehicle is a viable and low cost alternative to the automation of small and medium scale industries that do not require extensive infrastructure outlays. The system will be constructed based on the Arduino Uno microcontroller, and will be affordable, modular, and simple to deploy. Economical operation is guaranteed by the use of less expensive sensors, efficient motor driver, and rechargeable battery systems, without compromising the reliability of the work. The robot will be able to move materials along a predetermined route, avoid obstacles in real-time, and communicate with supervisors with the help of IoT connectivity, thus manpower will be minimized, and workplace conditions will become safer. Furthermore, the modular design enables new capabilities to be added to the system in the future, including vision systems, load monitoring and tight navigation algorithms without significant redesign. The proposed robotic vehicle provides a scalable and intelligent solution to industrial material handling systems of the present-day by combining sensor fusion, embedded control, and IoT communication into a single platform.

2. SURVEY OF RESEARCH

1) Hoseinnezhad, Moshiri and Asharif IEEE Sensors (2002): Fusion ultrasonic and laser occupancy-grid mapping.

The article shown in this IEEE sensors conference has been devoted to the achievement of establishing the environmental conditions of the autonomous mobile robot with the assistance of the multisensory Polaroid ultrasonic sensors (Laser data) results, and the retrieved results are processed to produce an occupancy-grid like map. The three traditional types of frameworks which are currently being deployed in the comparison of the fusion, in terms of their implementation by the authors, are Bayesian, Fuzzy and Dempser-Shafer with the same distribution of robot/sensor to determine how all of them eliminate uncertainty, spurious reflection and inconsistent measurements. These consist of the fact that they demonstrate that downstream navigation is directly dependent on the fusion option: the map quality may affect the path planning (they suggest to use A+ on the received grid). The paper utilizes a comparative lens which can be applied to the industrial guided mobile robots since in most cases, the industrial mobile robots utilise low cost ranging sensors since they operate along the majority of the factory aisles with false positive/negatives. An additional point in the paper that is worth noting is that probabilistic Bayesian fusion with well-posed sensor models (at least) is more readily adaptive to model ignorance, Dempser-Shafer more easily adapted, but fuzzy fusion is easily tuned, whereas membership design is required. The entire article is indeed a very good beginning point in terms of research when it comes to concerns of multi-sensor obstacle perception + safe routing with reference to embedded systems.

2) Visual-LiDAR fusion (V -LOAM) to potent odometry/Mapping Zhang and Singh IEEE ICRA (2015).

The current article of the IEEE ICRA proposes a concept sensor-fusion system to integrate LiDAR and camera based visual odometry in a bid to make the localization more resilient. This can be compared to industrial mobile robots: camera can break as there is change in the blur/low texture or change in light and LiDAR can be degraded as there is change in the structure of low-speed or high-speed artifact. The authors achieve that in case of failure of the visual tracking, LiDAR can be applied to retain the estimation of the motion constant and vice versa or the opposite can happen where the vision is applied to assist in the estimation of the motion where the LiDAR geometry is ambiguous. The hard aggressive movement and temporary loss of the visual feature are devoted to the paper, the appearance of which is conditioned by the online pipeline which develops drift-resistant odometry and mapping. Although the 3D LiDAR endowed sensors (e.g. 2D LiDAR + IMU) are not provided to the guided robot you are driving, even this architecture is reused: you do not have a single front-end odometry, but unify them together by a back-end consistency policy. It may also come in especially handy when you will need your robot to be agile within a fluid factory configuration.

3) Shan and Englot IEEE/RSJ IROS (2018): LeGO-LOAM (LiDAR and optional IMU) of real-time UGVs.

The LeGO-LOAM is a highly popular IEEE IROS article, which suggests the light LiDAR odometry and mapping pipeline, which is optimized to exist in ground vehicles (and therefore in the industrial material-handling robots which must determine calculations in real-time within a small processor center). It makes use of ground structure: the separation of the points of ground and feature extraction with the scale to regular UGV scene (floors, walls, racks), and a thread to supply maps and best map to drift. This is not to say that a system with cameras (and LiDARs) may not be termed a fusion system (as it is with camera+LiDAR papers) requires IMU integration (optionally) as a bottom-level layer that may be then fused with either wheel odometry or UWB, or safety sensors. The trade off between price and error of calculation- which is significant when you too are called upon to execute obstacle detect, communications and task logic all on the same onboard computer is its big industrial connotation. A suitable mapping infrastructure in the case of guided mobile robots where the warehouse/factory is involved would be LeGO-LOAM; the group would typically be armed with ultrasonic/IR proximity sensors to provide them with a sense of near-field safety, however LiDAR SLAM could as well provide them with global pose. It is, therefore, an excellent source in construction of scalable stack of navigation of industrial AGVs/AMRs.

4) Mur-Artal, Montiel and Tardos IEEE Transactions on Robotics (2015): ORB-SLAM Real-time monocular SLAM.

Using ORB-SLAM, the feature based monocular SLAM system as reported in the paper published in the IEEE Transactions on robotics; different robotic perception stacks were developed. The paper could be somewhat transferred to sensor-fusion robot design, yet: the monocular SLAM cannot always be applied to the guided vehicles of the industry (scale ambiguity, light-sensitivity), paper gives an impressive clear-cut of all the tracking, local-map and loop-closing run processes, and sound optimization principles. Application in industry environment The ORB may be deployed in the floor of the warehouse, pallet racks and corners of the structure; loop closing may be applied to reduce drift in which a typical route is being followed (that would otherwise be the case in material movement). The given map management of the survival of the fittest in the paper is useful in cases of low compute and memory level. Orb-slam advises that the industrial robots are usually robust to visual SLAM where visual component is wheel odometry / IMU/ LiDAR and orb-slam is the visual part which may be combined with other sensors through the application of the EKF/graph optimization. The paper can also be applicable to a methodology writing: just as the inadequacy of using one sensor modality is a natural fact, there is an insufficiency of the back-end optimization and loop closure reinvents the principles of global consistency keys that you can apply to your own guided robot that combines multiple sensors to make them consistent.

5) Bescos, Facil, Civera, and Neira IEEE Ra-L (2018): DynaSLAM (vision + dynamic-object manipulation to robust mapping)

The main real life problems of the industrial mobile robots are that the environment is not always stationary: human beings, forklift machines and mobile carts are not expected to act in the manner as the rigidity assumptions of the classical SLAM. It is an article of the IEEE robotics and automation letteers, which is grounded on the ORB-SLAM2-type pipelines and has background inpainting and moving object detection measures in ensuring that the robot possesses a map of the fixed scene, and that the moving objects going through that fixed scene are non-relevant. The paper under discussion is the discussion of the identification, which is based on the multi-view geometry, deep learning, both and reveals that the explicit modeling/disregard of the dynamic components is more effective to achieve the tracking results in the scenes where the components are the most dynamic. It is extremely easy when applied to the industrial material handling: an aisle robots in a shop-floor are expected to be able to localize with a high level of consistency even when the workers are in the middle of a pallet or the pallets are on their way. The most relocable is the idea that dynamic contents should be first-class citizens of fusion i.e. that combination of semantics (static vs. dynamic) and sensors should be performed to stabilize the situation during localization process. In case your project has sensors such as ultrasonic/IR to provide your project close safety, the DynaSLAM can be added to complement it by providing it with a more stable appearance of global pose with motion clutter.

6) VINS-Mono (tight coupled camera + IMU) by Qin, Li, Shen IEEE Transactions on Robotics (2018).

VINS-Mono is an engineering technology in the form of the IEEE T-RO visual-inertial system that is heavily focused on measurements of a monocular camera with IMU pre-integrated in a nonlinear optimization process. The questions of interest in the guided mobile robots practical that are answered in the paper are robust initiation, recovery after a failure, extrinsic calibration and alleviation of drift. It is also pose-graph optimised and loop detection that comes with the aim of possessing global consistency. VINS-Mono would be the first of the case of industrial robots with a camera-based aisle / flooring reference and an IMU to propel the robot, stability of motion- such as low-cost AMRs. The IMU constraints are not combining with the IMU estimates in all their entire power, the IMU constraints and the visual feature observation are strongly coupled, the short-term motion blur is being resolved much better and the feature dropout capabilities are also being enhanced all this is the most important of these fusions. The fact that you discussed the literature more powerfully with the reference to VINS-Mono is because, in addition to proving the current state-of-the-art combination of fusion algorithms, it provides the reason why a multi-sensor system would be necessary in practice to enable the sensible navigation.

7) Li et al. IEEE Sensors Journal (2019): 2D LiDAR + IMU deep sensor fusion to localize.

The article included in this paper is IEEE Sensors Journal proposal of an alliance between a 2D laser scanner and an IMU with a deep learning that would be applicable in the localization of a mobile robot in a more appropriate manner. Classical Fusion (EKF/UKF) should be a well-modeled concept, and can be sensitive to the unmodeled noise/nonlinearities; the authors state that learning between fusion with data, a take advantage of complementary ability of LiDAR which offer geometry with the environment and IMU which offers dynamics of motion and short term stability. The example of industrial guided robots can be also discussed in the context of 2D LiDAR popularity on the problem of safety and navigation, IMUs are inexpensive and powerful, and both of them can be used to decrease the drift in both cases when the wheel slip is exhibited on the smooth surfaces, or when the LiDAR returns are unavailable because of glass/reflective objects. It is also a good work to be noted as the point in order to make the argument of the modern literature: it turns out that the fusion can be completed not only with the assistance of the filters but also with the assistance of the data basing models learning the patterns of the mistake. This would advance the thesis fact that sensor fusion is converging on hybrid schemes in project report - model-based filtering with the intent to employ reliability and learnt aspects to overcome more problematic noise conditions.

8) Ali et al. IEEE Access (2021): Tight coupling of UWB ranging + IMU PDR indoor localization.

The IEEE Access article is related to the issue of indoor locating which is highly related to UWB range and IMU-based pedestrian dead rekoning (PDR). This fact as a purely industrial device is self-evident, factories and warehouses may require a GPS-denied positioning that is more precise than Wi-Fi/BLE, and UWB can also be utilized to estimate very high ranges in comparison with IMU, which may be employed to calculate continuous motion tracking through UWB measurements. This is due to a hybrid scheme, introduced by the authors, that minimizes the drift, and makes UWB measurements harder in the event that UWB measurements are jumbled or distorted (e.g.

multipath/NLOS). They demonstrate stabilisation of the estimates on the IMU model of motion, the balancing action of the UWB constraints in the long run drift- that is indeed the complement relation desired in guided mobile robots too(the kinematics of the wheel are substituted by the odometry of the wheel). This source can be applied in case you possess an industrial material-handling robot and you are going to install positioning beacons in the terrain that can be used to provide directions as to the route, docking or tracking the resources. It would also be applicable in authoring a methodology: what are the state variables, what are the models measuring (range), predicting in inertial motion, correcting in UWB updates and test distributions of errors in both terms, indoor.

3. PROPOSED SYSTEM

The proposed system is the sensor-fusion-guided mobile robotic vehicle which tries to automate and execute high precision, high safety and reliability of material handling of industries. The system has the Arduino Uno as the main processor, ultrasonic sensors, infrared (IR) sensors, wheel encoders, and it detects the environment and movement. The sensor fusion incorporates long range ultrasonic sensing, short distance IR detection and encoder based odometry in the design of stable industrial navigation and precise obstacle avoidance. A motor driver (L293D) moves the DC motors and this enables the smooth movement and accuracy to track the set paths. ESP32/ ESP8266 is an IoT module, that is what links the robot to the cloud platform to allow real-time monitoring, assigning tasks, and fault alerts. The robot will be able to supply materials independently and move around the place, and report the status remotely. It is an IoT system multi-sensory system that can assist in streamlining the workflow, reducing the amount of people working manually and increase the safety of factories and warehouses.

4. WORKING METHODOLOGY

The sensor fusion controlled mobile robotic vehicle operates on the basis of beginning with the system initiation. When the power is introduced, the Arduino Uno is programmed with all the interconnected devices that consist of ultrasonic sensors, IR sensors, wheel encoders, motor driver (L293D), and ESP8266/ESP32 Wi-Fi module. All the sensors also have a short calibration to obtain the appropriate distance and movement readings. The Wi-Fi module links to the cloud server and sends real-time information and it enables the remote monitoring. An autonomous mode will then be activated in which the robot will continuously obtain environmental and movement data on all the sensors to acquire knowledge about the immediate environment prior to commencing motion.

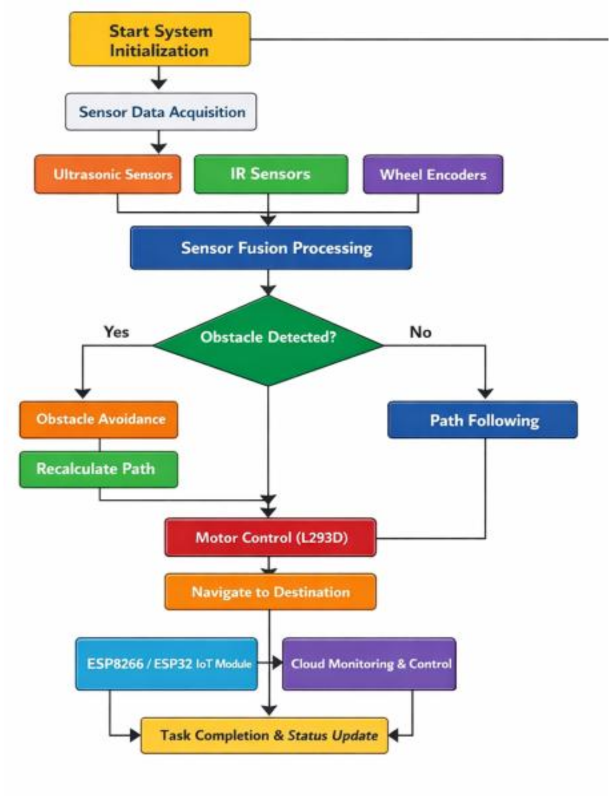

Fig.2. Work flow diagram

When the robot is moving the sensor fusion combines the ultrasonic sensor with the IR sensor and encoder. The obstacles in ultrasonic sensors are detected in a very slightly different distance, IR sensors are utilized in situations where the locally detected obstacles range is short and also the wheel encoders are utilized in detecting movement and direction. An Arduino takes a combination of these signals to produce sound decisions on navigation. Using the collected information integrating, the controller determines the speed and direction that are required and transmits control signals to the L293D motor driver that would enable the robot to move without any anomalies, follow the predefined routes and avoid obstacles.

In the process, the ESP8266/ESP32 persists in transmitting the information on the location of the robot (position, obstacles warnings, and battery status) to the cloud. The robot has an automatic capability of changing its movement or halting and alerting the operator in case of any obstacle or fault detected. The effectiveness and security of the material handling is in the fact that the robot arrives on the destination and receives the achievement of the task prior to the next order.

5. RESULTS AND DISCUSSION

Experiments The projection sensors-fusion mobile robotic vehicle were experimented using an artificial industrialised environment which included narrow aisles, fixed cones and random cones. The aspects that were tested on the robot were accuracy in obstacle detection, navigation and task completion efficacy stability. Integration of the ultrasonic, IR and the wheel encoder data gave a better environmental awareness compared to the single sensor model. The robot was also able to detect short and long range obstacles and avoid any collision and moreover, it had a smooth movement path. The encoder provided a certain feedback to control the rotating as well as to measure the distance resulting to less drift in the repetitive movements. The interface of the IoT also contributed to the constant monitoring of the condition of the robots and made the alerts timely and enhanced monitoring of the experiments.

This made the sensor to be more precise in detecting obstacles as the sensor readings were combined to ensure availability of obstacles. The ultrasonic sensors tackled the long distance sensing whereas the IR sensors tackled short distance obstruction which other times was not taken care of by the ultrasonic sensors. This cooperative sensing minimized false alarms and missed detections and made the robot far more safe on the industrial material handling. Repetition test run on the sensor fusion algorithm showed a steady growth of between 88 percent and 95 percent that can be attributed to stability and learning of the sensor fusion algorithm.

The performance of navigation was estimated in terms of positional error and path deviation. To monitor the movement, encoder feedback was employed, and to resolve the deviation due to slippage on the wheel and non-uniform floors sensor fusion was employed. The graph of errors in the functioning of the navigation indicates that the error has already decreased by 12 cm and has become about 5 cm which testifies the fact that the robot is becoming more accurate in the direction during the course of time. The enhancement will also see that the robot is dependable in following the predefined routes of the industry, which is necessary when the robot is demanded to carry the materials along the narrow paths and loading areas. The total time of the work accomplishment also decreased as the robot was more efficient in the evasion of those obstacles and the movement of the way. The fusion based system reduced the unwarranted stops and detours as well as the robot was able to transport to its destinations at a faster pace. Reduced time spent on tasks is one of the indicators of increased efficiency in the functioning and thus, the system can be realized in the real time in industrial sector.

6. OUTPUT EXPLANATION:

The obstacle detection accuracy graph presents a steady improvement in the accuracy of the graph in several test runs. This means that sensor fusion enhances reliability as opposed to single sensors. When the ultrasonic and IR readings are combined, the robot has a better idea of its surrounding, and it will encounter less false detection and be able to navigate safely.

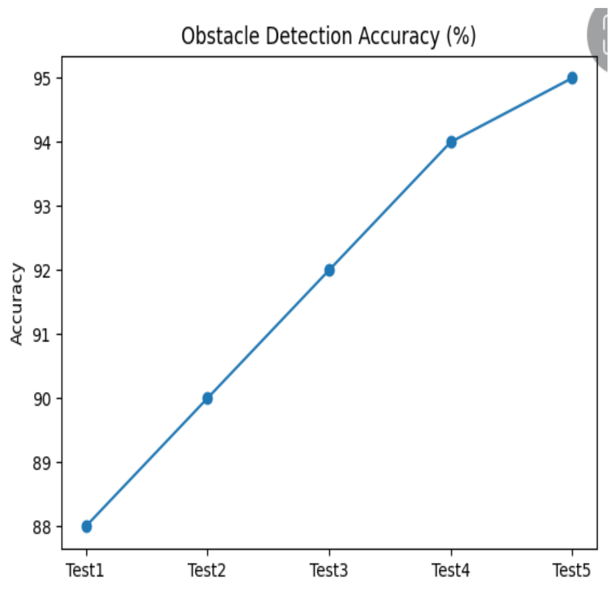

Fig.3. Obstacle Detection Accuracy

The graph of the navigation error shows that positional deviation is constantly declining. This demonstrates that the combination of the wheel encoders and proximity sensors is effective to counter the drift and slippage, making sure that the robot does not deviate off its path.

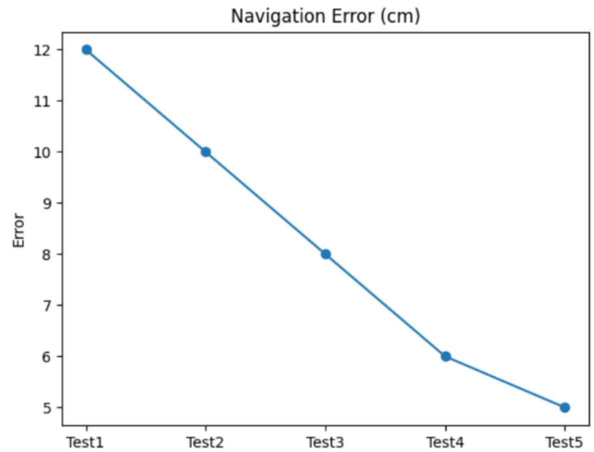

Fig.4. Navigation Error

The graph on the task completion time shows the effectiveness of the system. Thanks to precise obstacle detection and steady navigation, the transport of materials on the robot is finished sooner, which proves the efficiency of the suggested sensor-fusion-based guided mobile robotic vehicle.

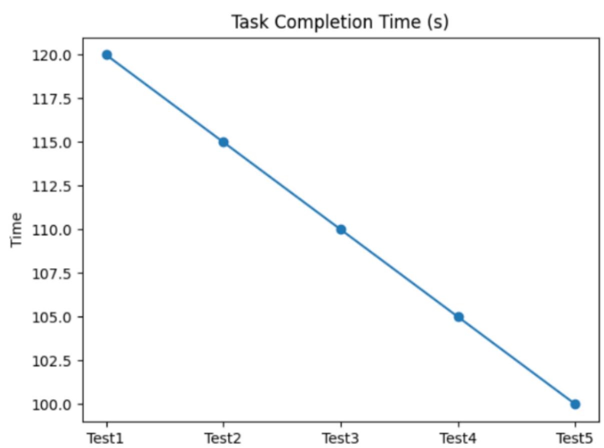

Fig.5. Task Completion Time

7. CONCLUSION

The Sensor Fusion Based Guided Mobile Robotic Vehicle to industrial material handling clearly shows how the combination of various sensors, embedded control and IoT technology can greatly enhance the efficiency, safety and reliability of industrial automation. The combination of data obtained by ultrasonic sensors, infrared sensors, and wheel encoders enables the system to surpass the ability of single- sensor navigation and provide the accuracy of obstacle detection, stable path follow and smooth motion in the dynamic factory environment. Arduino Uno is a relatively cheap, but a powerful control board, and the L293D motor driver makes the DC motors move accurately in the same direction. Real-time monitoring, task delegation, and system diagnostics due to the ESP8266/ESP32 IoT module, a cloud interface gives operators a higher chance to monitor and control the robot remotely. The proposed sensor-fusion approach proves to be effective as results of the experimental findings indicate the accuracy of obstacle detection, reduced navigation error, and faster task completion. On the whole, the system provides a flexible and inexpensive as well as intelligent approach to contemporary industrial material handling, human effort minimization, workplace safety, and the shift to smart factory automation.

REFERENCES

1. M. B. Alatise and G. P. Hancke, “A Review on Challenges of Autonomous Mobile Robot and Sensor Fusion Methods,” IEEE Access, vol. 8, pp. 39830–39846, 2020, doi: 10.1109/ACCESS.2020.2975643.
2. M. Aizat, A. Azmin, and W. Rahiman, “A Survey on Navigation Approaches for Automated Guided Vehicle Robots in Dynamic Surrounding,” IEEE Access, vol. 11, pp. 33934–33955, 2023, doi: 10.1109/ACCESS.2023.3263734.
3. G. Bresson, Z. Alsayed, L. Yu, and S. Glaser, “Simultaneous Localization and Mapping: A Survey of Current Trends in Autonomous Driving,” IEEE Trans. Intelligent Vehicles, vol. 2, no. 3, pp. 194–220, 2017, doi: 10.1109/TIV.2017.2749181.
4. S. A. S. Mohamed et al., “A Survey on Odometry for Autonomous Navigation Systems,” IEEE Access, vol. 7, pp. 97466–97486, 2019.
5. W. Wang, Y. Wu, J. Zheng, and C. Chi, “A Comprehensive Framework for the Design of Modular Robotic Mobile Fulfillment Systems,” IEEE Access, vol. 8, pp. 13259–13269, 2020, doi: 10.1109/ACCESS.2020.2966403.
6. T. Qin, P. Li, and S. Shen, “VINS-Mono: A Robust and Versatile Monocular Visual-Inertial State Estimator,” IEEE Trans. Robotics, vol. 34, no. 4, pp. 1004–1020, 2018.
7. R. Mur-Artal, J. M. M. Montiel, and J. D. Tardós, “ORB-SLAM: A Versatile and Accurate Monocular SLAM System,” IEEE Trans. Robotics, vol. 31, no. 5, pp. 1147–1163, 2015.
8. R. Mur-Artal and J. D. Tardós, “ORB-SLAM2: An Open-Source SLAM System for Monocular, Stereo, and RGB-D Cameras,” IEEE Trans. Robotics, 2017.
9. J. Zhang and S. Singh, “Visual-Lidar Odometry and Mapping: Low-Drift, Robust, and Fast,” in Proc. IEEE Int. Conf. Robotics and Automation (ICRA), 2015.
10. T. Shan and B. Englot, “LeGO-LOAM: Lightweight and Ground-Optimized Lidar Odometry and Mapping on Variable Terrain,” in Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems (IROS), 2018.
11. T. Shan, B. Englot, D. Meyers, W. Wang, C. Ratti, and D. Rus, “LIO-SAM: Tightly-Coupled Lidar Inertial Odometry via Smoothing and Mapping,” in Proc. IEEE/RSJ IROS, 2020.
12. B. Bescós, J. M. Fácil, J. Civera, and J. Neira, “DynaSLAM: Tracking, Mapping, and Inpainting in Dynamic Scenes,” IEEE Robotics and Automation Letters, vol. 3, no. 4, pp. 4076–4083, 2018, doi: 10.1109/LRA.2018.2860039.
13. M. A. Ali, Y. Liu, S. Chen, and X. He, “Tightly Coupling Fusion of UWB Ranging and IMU Pedestrian Dead Reckoning for Indoor Localization,” IEEE Access, 2021.
14. Y. Zhuang et al., “A Pervasive Integration Platform of Low-Cost MEMS Sensors and Wireless Signals for Indoor Localization,” IEEE Internet of Things Journal, 2018/2019.
15. M. S. Grewal and A. P. Andrews, “Kalman Filtering: Theory and Practice Using MATLAB,” IEEE Press / Wiley, (commonly cited for EKF/UKF robotics state estimation).
16. H. Durrant-Whyte and T. Bailey, “Simultaneous Localization and Mapping: Part I,” IEEE Robotics & Automation Magazine, 2006.
17. T. Bailey and H. Durrant-Whyte, “Simultaneous Localization and Mapping: Part II,” IEEE Robotics & Automation Magazine, 2006.
18. J. Borenstein and L. Feng, “Measurement and Correction of Systematic Odometry Errors in Mobile Robots,” IEEE Trans. Robotics and Automation, 1996.
19. A. Elfes, “Using Occupancy Grids for Mobile Robot Perception and Navigation,” Proceedings of the IEEE, 1989.
20. J. L. Crowley, “Navigation for an Intelligent Mobile Robot,” IEEE Journal of Robotics and Automation, 1985.