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Object Tracking-Based "Follow-Me" for Optionally Unmanned Ground Vehicles

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ABSTRACT

The paper presents the implementation of autonomously tracking and following guide simplified solution based on common sensors designed for the navigation of Unmanned Ground Vehicles (UGVs). The study investigates the effectiveness of employing a vision system to extract valuable information from a tracked object identified by a selected marker. Limitations associated with vision sensors and the impact of atmospheric conditions are highlighted in the study, emphasising constraints when relying solely on this sensor type. To address these challenges, the paper emphasizes the necessity of incorporating additional spatial sensors providing precise distance data while maintaining resilience to external conditions. The proposed simplified approach to data fusion, integrating vision systems and data from laser scanners, was validated in real operation environment. The results confirm the usefulness of descried approach for guide tracking navigation of unmanned platforms, highlighting its reliability in adverse weather conditions. Potential directions for system improvement are also addressed. This research makes a contribution to advancing autonomous vehicles capabilities, with a particular focus on improving performance in tracking scenarios.

Keywords: Unmanned mode; Light Terrain Vehicle (LST); Sensors; Object tracking

1. INTRODUCTION

The increasing demand for autonomous vehicles has driven their integration across various industries like: agriculture, construction, mining as well as military applications. Unmanned Ground Vehicles are especially crucial in situations where human safety is a concern. UGVs are indispensable in military operations, performing crucial tasks such as reconnaissance, monitoring, target identification, and logistical support, thereby enhancing operational effectiveness[1-3]. Due to situation in Ukraine and other regions there is demand to convert existing vehicles to be optionally remotely controlled as alternative to developing or production of new unmanned platforms[4]. This strategy gains further advantages through swift technology integration, enabling a more rapid response to evolving operational needs and proving especially crucial in urgent situations, such as those related to geopolitical policies.

Converted vehicles to carry out unmanned mode are expected to demonstrate precise remote control, advanced sensor capabilities, and robust communication systems for reliable and effective operation to avoid collision[5]. Their functionalities should also include ability to follow a route by selected guide or marker. This option utilizes advanced sensors to detect and track the guide's position, allowing the UGV to adjust its trajectory and speed to maintain a distance in convoy operations.

There are several technologies introduced to follow guide by unmanned platform like: ultrasound signals, GPS, and wireless technologies (Bluetooth, Wi-Fi, UWB) as well as using solemnly perception sensors[6-9]. Each of these technologies possesses distinct technical features, advantages, and challenges. Ultrasound signals, chosen for estimating distance, provide real-time measurement suitable for short-range navigation. However, their flexibility is related to their sensitivity regarding reflection phenomena and susceptibility to temperature changes, which could potentially disrupt their operation.

In relation to GPS guided navigation which ensures accurate movement over long distances through precise global positioning information, challenges emerge in areas with signal obstruction, like urban canyons or dense foliage, despite the technology's widespread availability and accuracy in rough terrain[10]. Simultaneously, satellite navigation systems, crucial for determining absolute location, face difficulties due to susceptibility to signal and electronic interference, jamming, multipath signals, and the intricacies presented by land covers such as forests, potentially hindering their effectiveness in location detection.

Wireless technologies, including Bluetooth, Wi-Fi, and Ultra-Wideband (UWB), are also used to carry out communication between the Unmanned Ground Vehicle and the guide[11]. Despite their benefits, such as reduced sensitivity to environmental conditions (due to fog or smoke) these technologies may face range limitations, necessitating either a clear line of sight or close proximity for optimal performance. Moreover, the wireless group require to equip the guide with an additional transmitter. This will increase complexity of the system and its calibration procedure.

Currently most frequently used approaches introduced to follow guide are distinguished based on on-board sensors, like cameras or and LiDARs that recognise environmental features.

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The promising method is based on vision systems with dedicated markers. Markers are utilised in tracking to prevent errors in identifying the guide offering distinctive features like color or unique patterns. This feature enhances precise tracking, particularly in dynamic environments or situations with potential visual obstructions, where markers contribute to the robustness of the tracking process. In these scenarios, the utilisation of stereo systems with two or more cameras is expected. This enables not only to visually track a person but also to estimate overall distance information regarding their movement.

Despite of visual context and recognition, the addition of LiDAR sensors ensures accurate distance information, compensating for the limitations in pixel granularity[12]. Advanced cameras and computer vision algorithms, enable unmanned platforms navigation by capturing and processing information to interpret complex scenes and make informed decisions for effective remote operation. Spatial sensors like LiDARs utilize laser technology to precisely measure distances and create detailed maps by emitting laser beams and measuring their return time after interacting with objects. Their resilience to adverse weather conditions, such as fog or darkness, enhances the UGV operation in challenging environments. Additionally, the three-dimensional perspective offered by LiDARs contributes to comprehensive spatial awareness, making them crucial for tasks like object detection.

In our study we have used approach based on synergy between selected marker shape tracked by vision system corelated with spatial data from laser scanners providing precise distance measurements to the define guide position. The integrated method contributes to a more reliable guide-following functionality across various vehicle operational conditions. Proposed simple algorithm for sensor data fusion was evaluated in a real environment, specifically assessing its effectiveness in off-road conditions. .

2. DESCRIPTION OF ALL TERRAIN VEHICLE LST AND INSTALLED EQUIPMENT

In order to carry out evaluation of proposed guide-following functionality Light Terrain Vehicle (LST) was used. The LST vehicle was developed by a consortium consisting of the Military Institute of Armoured and Automotive Technology (WITPIS), Military University of Technology (WAT) and company Szczesniak Pojazdy Specjalne to operate in all terrain conditions[13]. The Light Terrain Vehicle is based on Land Rover Defender 110 suspension, providing excellent drivability characteristics, high capacity, and modularity in rough terrain.

The LST is an ideal candidate for optionally unmanned platform, suitable for a range of applications, including military, humanitarian, and civilian uses.

The conversion set (Fig.1) involves several technologies, including perception, navigation, communication, and control systems. The perception system of the conversion architecture is responsible for collecting data from various sensors, such as cameras, LIDAR[14], GNSS/IMU, and processing it to generate a situation awareness of the vehicle's environment.

All sensors, typical for object recognition, were mounted on the roof of the vehicle to ensure following the object in front in all driving conditions like, bumps, turns, which can cause limited visibility.

The data provided by these sensors were processed using developed software packages that allows trucking selected guide and estimating distance to defined surface plane.

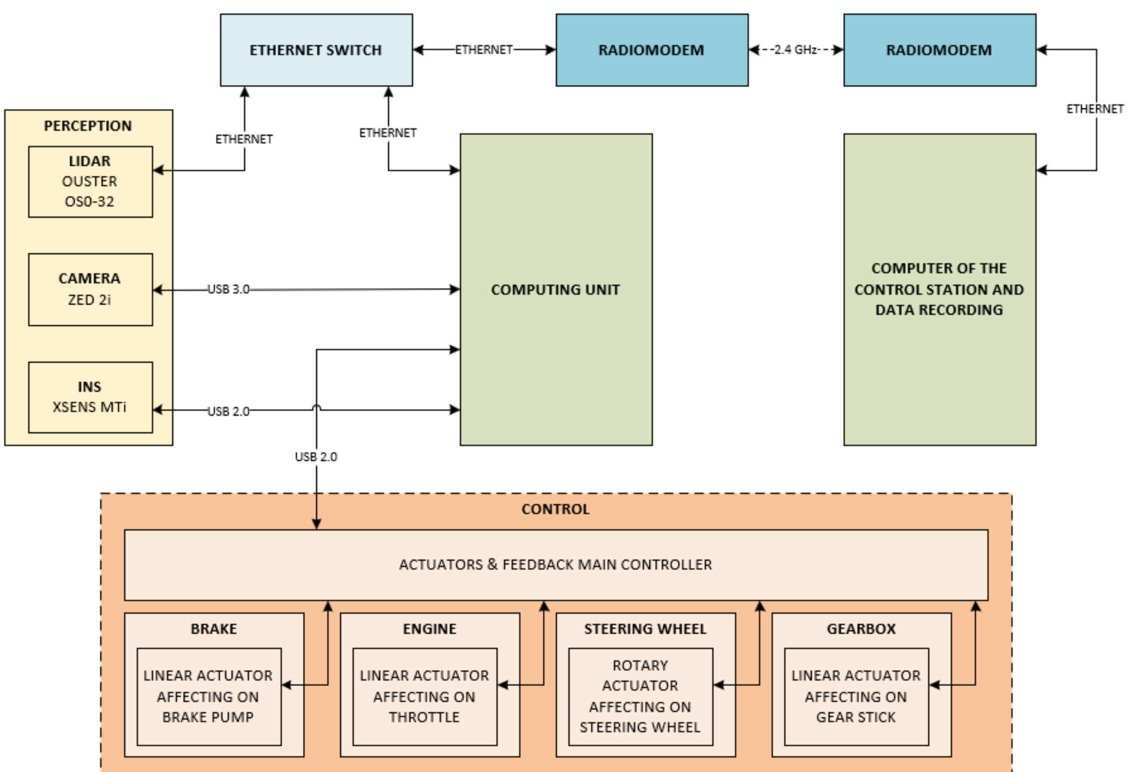
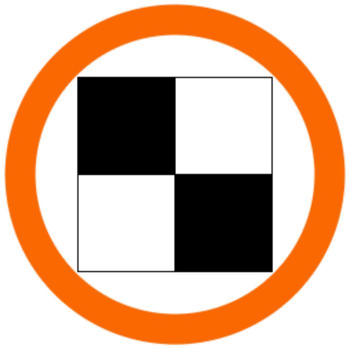
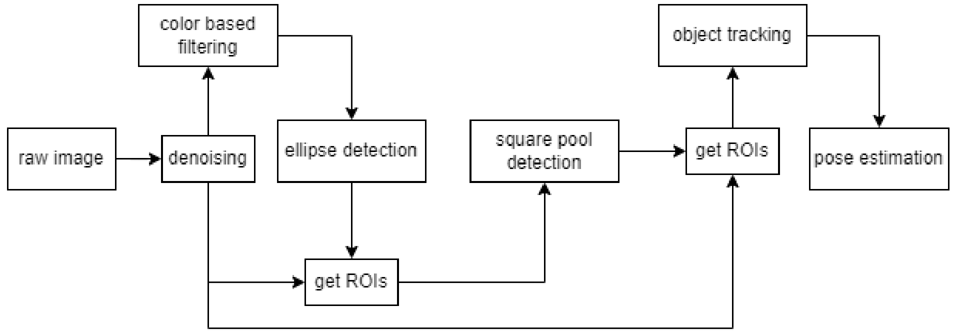


Figure 1. Block diagram of installed conversion set.



(a)



(b)

Figure 2. (a) Design of used marker; and (b) Processing flow diagram.

3. IMPLEMENTED TRUCKING ALGORITHMS

Initial goal of the research was to develop software that generates vehicle control data based on the installed vision system[15]. Algorithm should track a marker, positioned on the guide, by a digital camera. It was assumed that the marker in a disc form with contrasting color patterns, enabling the generation of useful data considering the variable image contrast during the system’s operation. The software incorporates a calibration option, enabling the collection of reference data regarding the dimensions of the calibrated marker. This allows the approximate distance estimation of the marker (or object) from the camera based on its size in the corresponding image. During operation, the algorithm dynamically tracks changes in the image, providing output data that includes the approximate angle of deviation from the optical axis of the camera and the measured distance from the vehicle with installed sensor.

3.1 Vision Based Marker Tracking Method

The selection of an appropriate marker for tracking an object is a challenging task to ensure precision and avoid errors associated with other objects influence. The chosen marker should possess distinctive features, such as unique shapes, colors, or patterns, that enable the tracking system to unequivocally identify and follow the intended object.

According to the literature review, pose estimation is a critical aspect of various computer vision applications, involving the establishment of correspondences between real-world points and their 2D image projections[16]. Such process is carried out mainly using synthetic or fiducial markers. Binary square fiducial markers are a popular choice due to their ability to provide sufficient correspondences (four corners) for obtaining camera pose. The inner binary codification enhances their robustness, allowing the implementation of error detection and correction techniques.

Initially the well-known ArUco markers, stand for Augmented Reality University of Cordoba markers were considered[17]. Characterised by a square grid with a black-and-white pattern, these markers are meticulously designed for optimal recognition by computer vision algorithms, ensuring reliable detection under varying lighting conditions. ArUco markers offer versatility in various sizes and grid configurations.

However, after deep analysis ArUco markers were rejected due to their overly complex shape, presenting difficulties in recognition within operational conditions. Due to the visual complexity of the non-urbanised environment, it was necessary to use a marker that was distinctive in both color and shape. It should be highlighted that vision-based object tracking system consist of several stages: color filtering, preliminary identification of candidates based on shape, proper identification using a neural network, tracking of detected tags and estimation of their position and location. For this purpose, the marker was specially designed to be detectable at each stage (Fig.2(a)).

Following the proposed marker design, we developed a process flow diagram (Fig. 2(b)) and related software modules. The initial stage of the marker detection process focuses on image de-noising to effectively reduce artifacts. Subsequently, a color filtering step is employed, resulting in the identification of potential ellipses, referring to orange ring in Fig. 2(a). The detection of these ellipses leads to the generation of a set of potential Regions of Interest (ROIs), which are subsequently validated against the black and white squares from the center of Fig. 2(a). This validation process is based on a series of ROIs that are then passed to the tracker, allowing for the estimation of the position and orientation of the detected markers based on the ellipse parameters.

The next step is denoising using a GPU-run bilateral filter to increase performance. Bilateral filtering is a non-iterative and locally applied technique designed to smooth images while preserving edges. It can be achieved by combining gray levels or colors based on both their spatial proximity and their similarity in intensity. This method favors values that are close to each other in both domain (geometric closeness) and range (photometric similarity). While some filters treat the three color channels independently in a color image, bilateral filtering aligns with the perceptual metric of the CIE-Lab color space. This technique enables the smoothing of colors while preserving edges in a manner finely tuned to human perception. Additionally, bilateral filtering eliminates phantom colors along edges in color images and mitigates their appearance in the original image, distinguishing it from standard filtering approaches. In our study the filter parameters were chosen experimentally based on real field recordings. The use of the Gaussian filter was also tried, but inferior results were achieved, particularly when dealing with markers located at a considerable distance (>10 m).

It was necessary to implement also color filtering based on an adaptive filter, using the frame histogram to selectively distinguish colors and diminish the volume of data forwarded to subsequent stages. This effectively mitigates the impact of ambient lighting conditions on the filtering quality, particularly concerning the outer marker circle's color perception variations under different lighting conditions throughout the day. Through histogram equalization and adaptive adjustments, the detection rate increased of 15 %, as well as 10 % reduction in false positives.

Due to the chosen marker shape, ellipse detection was implement, analysing edge curvature and convexity. The method uses this information to group edge contours, computing search regions for each contour. The parameters of the ellipse (axis length and center position) allowed at a later stage to determine the position of the ROI, which was then passed to the next stage of the process validating approach.

Checkerboard detection was performed using a HAAR cascade neural network[18]. In the initial phase, the frame was converted to grayscale. A custom 3-stage model was created and trained on the prepared data set. The pattern sought was the black and white squares seen in the center of Fig. 2(a).

3.2 Marker Detection Performance in the Real Environment

A series of tests were carried out to validate the effectiveness of the developed detection method in the environment representing vehicle operational conditions. Preliminary study focused on evaluating the accuracy of pattern recognition under considered range.

In the first stage, the marker was placed in a stationary position and the distance of the vision system was changes up to operational range. The dimensions of the marker were 30×30 cm. This approach enables verification of the marker's detectability across different distances. The measurements were conducted under good weather conditions in the area with vegetation, ensuring optimal visibility and evaluating the system's performance in favourable conditions. Testing conditions are shown in Fig. 3.

The results of the system's performance measurements are summarised in Table 1 taking into account variations in the camera's orientation relative to the marker.

The primary test, encompassing diverse scenarios such as stationary positioning, dynamic distance adjustments, and varying camera orientations, consistently validates the resilience of the meticulously designed marker pattern and the efficiency of the implemented algorithm. The marker demonstrates reliable detectability, pattern recognition, and adaptability across different working conditions. Achieved results instil confidence in the marker's ability to effectively support the „follow me" function, enabling the unmanned mode of the vehicle to operate autonomously while adeptly tracking the marker in diverse environments. The overall performance underscores the practicality and reliability of the devised system for real-world applications.

Figure. 3 Detection results with confidence level.

Table 1. Accuracy of marker detection

	Distance to the marker		
	<3m	3 m - 20 m	20 m - 40 m
Accuracy*	99 %	87 %	78 %

*Corresponding false positive (1 % ; 2 %; 2,3 %)

3.3 Marker Detection Performance in the Real Environment

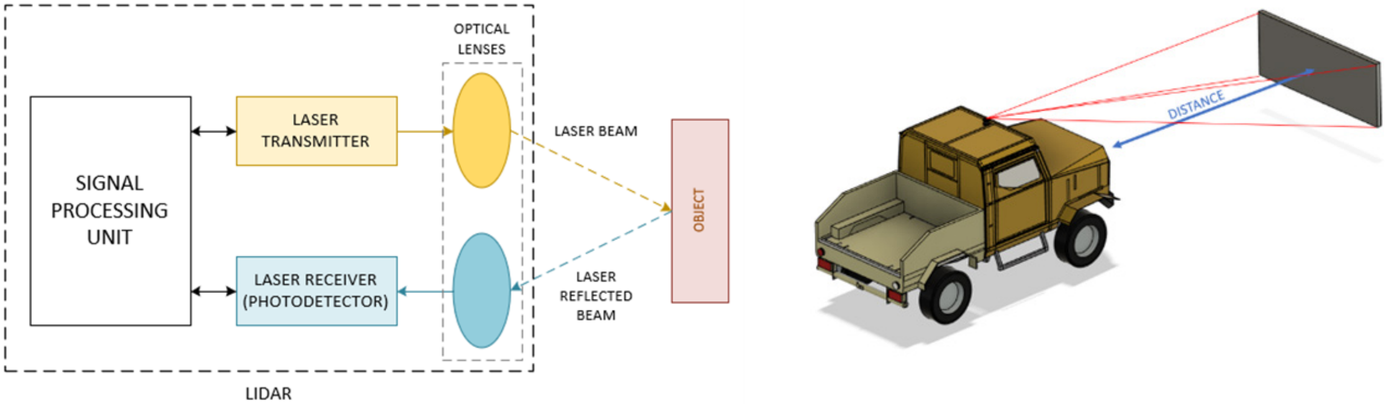
In UGV applications, vision systems are commonly used however, one of the major limitations of vision systems is their sensitivity to lighting conditions. Direct sunlight can temporarily blind sensor leading to missed detections or false positives.

It should be highlighted that vision based algorithms in operational environment faces significant challenges, including adverse weather conditions such as heavy rain, snow, fog, and intense sunlight, which distort images and compromise marker identification accuracy. Low light conditions at night or in poorly illuminated areas potentially leading to misinterpretations and false positives or negatives. The finite field of view of camera sensors introduces blind spots further hinder the system's performance.

The limited precision of estimating distance through a vehicle's vision system poses challenges influenced by factors such as object size variations and perspective distortion. This is particularly significant for UGVs, leading to suboptimal decision-making and an increased risk of collisions. Accurate distance information is crucial for control algorithms to navigate the vehicle safely. To overcome this limitation, the trucking system in our study uses additionally LIDAR as the data source. LIDAR is a remote sensing technology based on laser beams to measure distances to objects in the operational environment (Fig. 4). Unlike cameras, LIDAR is less sensitive to lighting conditions and can operate effectively in bright sunlight or complete darkness.

Distance to the object moving in front of the test vehicle, is estimated by developed algorithm considering received point cloud from defined surface plane. The size of truced surface is indicated by the operator to ensures that the perception system can accurately detect and track objects in various road conditions, collecting accurate data for "follow me" subsystem. The launched algorithm takes into account the visibility conditions of the vehicle in front, which can vary depending on factors such as the road surface and corners.

The developed software integrates vision-based marker tracking and extends distance measurements using spatial



(a) (b)

Figure 4. (a) The LiDAR sensor measurement principles; and (b) Configuration of LiDAR based trucking algorithm.

sensors. Placing the marker directly on the tracked object mitigates the risk of false surface detection. This combined approach provides greater stability and resistance to weather conditions and interferences, ensuring reliable performance across various environments. This methodology was employed to conduct tests in a suburban area, validating the effectiveness of the developed method.

4. VALIDATION OF PROPOSED ALGORITHM IN OPERATIONAL ENVIRONMENT

The proposed approach was validated using data from the operational environment diverse off-road conditions. The accuracy of the “follow me” system was evaluated through an analysis of the tracking system’s output. This output furnishes details regarding both the distance to the guide and the angle of deviation from the optical axis of the sensors installed. This output includes data on the distance to the guide and the angle of deviation from the optical axis of the installed sensors.

In order to carry out the measurements in the real conditions two vehicles were used: a LST vehicle and commercial Hyundai.

The initial step was related to defining the guide location in the developed software, marking the designated region for tracking. Through a graphical user interface (GUI), the operator specified this region precisely to ensure alignment for the subsequent tracking phase. In this case the tracking algorithm was assigned to the Hyundai’s trunk, providing an unobstructed surface that maximized LiDAR data capture. As shown in Fig. 5, yellow boundary marked the surface to be continuously monitored, ensuring the system’s tracking stability. This setup allowed for the collection of high-density data points considering the fidelity of the LiDAR-generated point cloud and providing a robust dataset for real-time analysis.

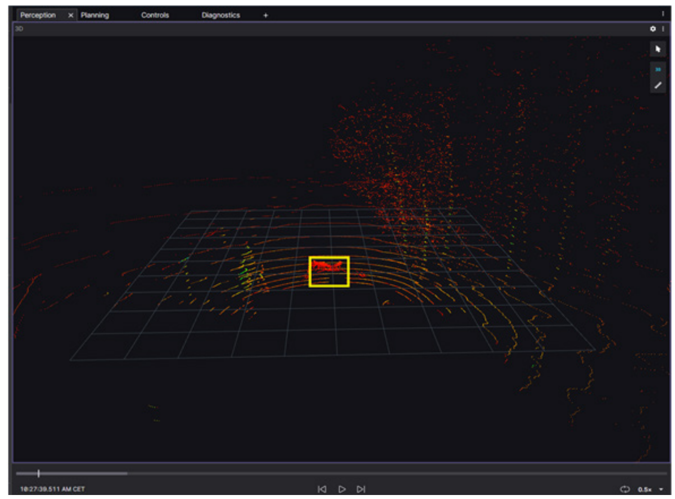
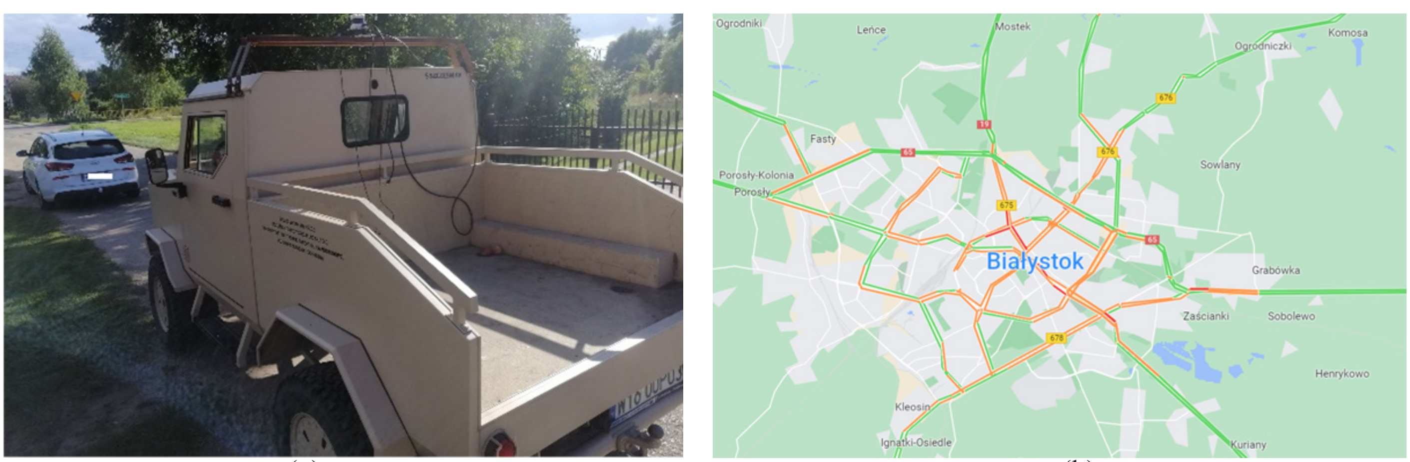


Figure 5. Captured number of points for selected guide surface from LIDAR sensor.



(a) (b)

Figure 6. (a) Testing setup; and (b) Map showing measuring conditions.

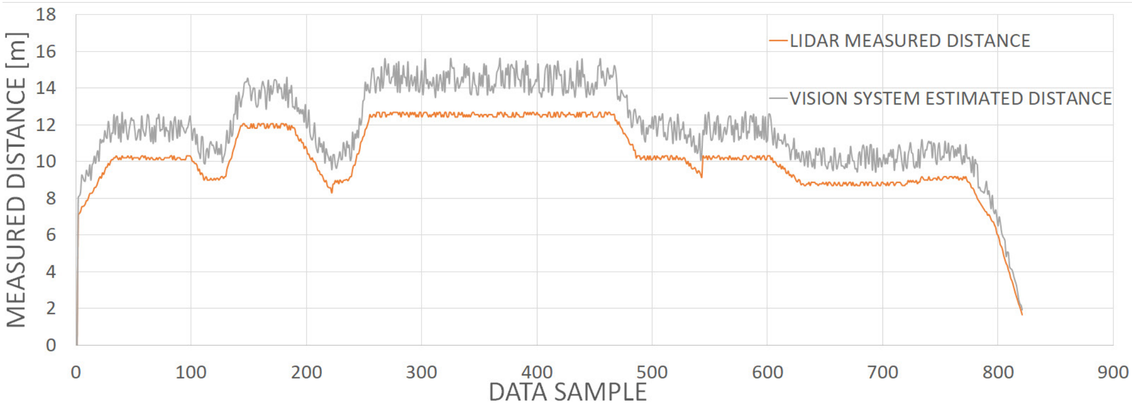


Figure 7. Comparison of distance measurements using LIDAR and vision based tracking marker system.

This calibration step was essential, as it ensured that the guide-assigned surface remained consistently tracked throughout the process, minimizing any deviations.

After calibration, the test vehicle followed the commercial car at various distances required by traffic regulations and adapting to changing road conditions. The measurements were carried out in suburbs of Bialystok city (Poland) to simulate different driving conditions (Fig. 6(b)).

Based on the recorded test data, a comparative analysis of distance estimation was conducted. The results of this analysis are presented in Fig. 7.

The received results confirm that the distance to the object is precisely calculated by averaging the values of the assigned points obtained from LIDAR, which are grouped together to form a single object. The vision system's depth analysis estimations may not be as precise, the fusion of data from both LIDAR and the vision system enhances the accuracy of distance calculations. Integrating data from multiple sources, including LIDAR and the vision system, the system can achieve more accurate and reliable distance estimations, ultimately improving its performance in tracking objects in off-road environments.

5. CONCLUSIONS

The study investigates the effectiveness of employing a vision system to extract valuable information from a tracked object identified by a selected marker. Limitations associated with vision sensors and the impact of atmospheric conditions are highlighted in the study, emphasising constraints when relying solely on this sensor type. To address these challenges, the paper emphasizes the necessity of incorporating additional spatial sensors providing precise distance data while maintaining resilience to external conditions.

The proposed simplified approach to data fusion, which integrates vision systems with data from laser scanners, was validated in a real operational environment. The results confirm the usefulness of descried approach for guide tracking navigation of UGV, highlighting its reliability in adverse weather conditions. This research makes a contribution to advancing autonomous vehicles capabilities, with a particular focus on improving performance in tracking scenarios.

REFERENCES

1. Haijie, G.; Boyang, W.; Xurui, W, Hai'ou, L. & Huiyan, C. A review on the development of military unmanned ground system with mission payload. *Acta Armamentarii*, 2023, **44**(11), 3333-3344
2. Ni, J.; Hu, J. & Xiang, C. A review for design and dynamics control of unmanned ground vehicle. Proceedings of the Institution of Mechanical Engineers, Part D. *J. Automobile Engin*. 2012, **235**(4), 1084-1100. doi:10.1177/0954407020912097
3. Pekarev, J. Attitudes of military personnel towards unmanned ground vehicles (UGV): A study of in-depth interview. *Discov. Artif. Intell.,* 2023, **24**(3). doi: 10.1007/s44163-023-00058-4
4. Zhou, X; Huang, L; Xu, Y; Chen, Y. & Bai, F. Research on the development of unmanned systems for joint operations. Chinese Institute of Command and Control Proceedings of 2023 11th China Conference on Command and Control. C2 2023. Lecture Notes in Electrical Engineering, 2023, **1124**. Springer, Singapore. doi: 10.1007/978-981-99-9021-4_54
5. Mrowicki, A.; Krukowski, M.; Turoboś, F. & Kubiak P. Determining vehicle pre-crash speed in frontal barrier crashes using artificial neural network for intermediate car class. *Forensic Scie. Int.*, 2020, **308**, 110179., doi:10.1016/j.forsciint.2020.110179;
6. Pradeep, B.V.; Rahul, E.S., & Bhavani, R.R. Follow me robot using bluetooth-based position estimation. *In* 2017 International Conference on Advances in Computing, In Communications and Informatics (ICACCI), 584-589.
7. Kim, J.; Jeong, H. & Lee, D. Single 2D lidar based follow-me of mobile robot on hilly terrains. *J. Mech. Sci. Technol.*, 2020, **34**, 3845–3854. doi: 10.1007/s12206-020-0835-7
8. Pradeep, B.V.; Rahul E.S. & Bhavani R.R. Follow me robot using bluetooth-based position estimation. *In* 2017 International Conference on Advances in Computing, Communications and Informatics (ICACCI), *In*Udupi, India, 2017, pp. 584-589. doi: 10.1109/ICACCI.2017.8125903.
9. Janczak, D.; Walendziuk, W.; Sadowski, M.; Zankiewicz, A.; Konopko, K. & Idzkowski, A. Accuracy analysis of the indoor location system based on bluetooth low-energy

RSSI measurements. *Energies*, 2022, **15**, 8832. doi: 10.3390/en15238832

10. Rybansky, M.; Kratochvíl, V.; Dohnal, F.; Gerold, R.; Kristalova, D.; Stodola, P. & Nohel, J. GNSS signal quality in forest stands for off-road vehicle navigation. *Appl. Sci.*, 2023, **13**, 6142. doi: 10.3390/app13106142
11. Typiak, R.; Rykała, Ł.; Typiak, A. Configuring a UWB based location system for a ugv operating in a follow-me scenario. *Energies.*, 2021, **14,** 5517. doi: 10.3390/en14175517
12. Dekkata, S.C; Yi, S; Muktadir, M.A. & Garfo , S. LiDAR-based obstacle detection and avoidance for navigation and control of an unmanned ground robot using model predictive control. *J. Mechatronic. Robotics*, 2023, **7**(1), 27-41. doi: 10.3844/jmrsp.2023.27.41
13. Nowakowski, M. Perception technology for conversion of off-road vehicles for the purposes of unmanned missions. *J. Civil Engin. Transport*. 2023, **5**(4), 15-27. doi: 10.24136/tren.2023.014
14. https://ouster.com/ (Accessed on 12 June 2024).
15. Gajjar, P.; Saxena, A.; Ranpariya, D.; Shah, P. & Das, A. Empirical analysis of hybrid classical variational quantum neural networks for target classification from SAR Data. In: Sisodia, D.S., Garg, L., Pachori, R.B., Tanveer, M. (eds) Machine Intelligence Techniques for Data Analysis and Signal Processing. Lecture Notes in Electrical Engineering, Springer, Singapore, **997**. doi: 10.1007/978-981-99-0085-5_39
16. Farkhodov, K.; Lee, S. & Kwon, K. Object tracking using CSRT tracker and RCNN. Proceedings of the 13th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2020) - Bioimaging; ISBN 978-989-758-398-8; SciTePress, pages 209-212. doi: 10.5220/0009183802090212
17. Filus, K.; Sobczak, Ł.; Domańska, J.; Domański, A. & Cupek, R. Real-time testing of vision-based systems for AGVs with ArUco markers, 2022. *In* IEEE International Conference on Big Data (Big Data), Osaka, Japan, 2022, pp. 6290-6298. doi: 10.1109/BigData55660.2022.10020817.
18. Mohamed, A.; Issam, A.; Mohamed, B. & Abdellatif B., Real-time detection of vehicles using the haar-like features and artificial neuron networks. *Procedia. Comput. Scie.*, 2015, **73**, 24-31. doi: 10.1016/j.procs.2015.12.044

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