Enhancing Reconnaissance Missions Through Multiple Unmanned Systems in ROS

Anees ul Husnain
Department of Electrical Engineering, Faculty of Engineering, University of Malaya, Malaysia
The Islamia University of Bahawalpur, Pakistan

Norrima Mokthar
Department of Electrical Engineering, Faculty of Engineering, University of Malaya, Malaysia

Takao Ito
Hiroshima University, Japan

Siti Sendari
Universitas Negeri Malang, Indonesia

Muhammad Farris Kyasudeen
University Technology MARA (UiTM), Malaysia

Muhammad Badri M Noor
Universiti Malaya, Malaysia, Ifcon Technology Sdn Bhd, Malaysia

Heshalini Rajagopal
Department of Electrical and Electronics Engineering, MILA University, 71800 Nilai, Negeri Sembilan, Malaysia

Email: norrimamokhtar@um.edu.my

Abstract

The synergistic collaboration between UAVs and UGVs addresses the limitations of individual platforms, offering a versatile solution for reconnaissance tasks in diverse environments. The proposed system employs ROS as the underlying architecture to facilitate seamless communication and coordination among multiple UAVs and UGVs. We delve into the intricacies of developing a robust communication framework that enables real-time data exchange and decision-making, fostering a synchronized and adaptive operation. Furthermore, the article explores strategies for path planning and navigation, considering the unique mobility constraints of UAVs and UGVs. Optimal coverage is ensured through efficient exploration and coverage of the reconnaissance area, under by comparing raster-scan, expanding spiral and zig-zag area exploration approaches. The article concludes by discussing potential extensions, such as the integration of machine learning techniques for enhanced autonomy and the scalability of the system for larger-scale missions by presenting a ROS-based framework that maximizes the synergy between UAVs and UGVs.

Keywords: Heterogeneous unmanned systems, Cooperative Path Planning, Reconnaissance, UAV, UGV, ROS

1. Introduction

With the surge in utilization of unmanned systems for research and their applications, the need for cooperation among heterogenous systems has made to the spotlight. The cooperation among heterogeneous systems exploits the diversity of features in unmanned system to achieve such mission objectives which are near impossible for homogenous systems. Forming a cooperative reconnaissance strategy for multiple unmanned vehicles in unknown areas has proven to be reliable and improves the heading errors of the vehicles [1]. Effective reconnaissance in modern military applications possesses the key for a strategic advantage, and also helps to neutralize surprise attacks, ambushes and can prevent the damages through improvised explosive devices (IEDs) with proactive sensory modules [2]. This is why combining Unmanned Ground Vehicles

(UGVs) alongside UAVs to coordinate area reconnaissance combines the technical and tactical capabilities of both to achieve the same. However, there are certain challenges linked with combing these unmanned systems.

This work addresses one of such challenges that naturally appears when the UAVs and UGVs are required to perform a coordinated reconnaissance in an unknown area. The nature of terrain and obstacles can affect the conditions required to maintain the reconnaissance formation between the aerial and ground vehicles [3]. A set of conditions is established which comprises two key components: a). The unmanned vehicles, UAV and UGV, have to explore the territory in close proximity. b). Minimize the impact of terrain-based slowness of UGV on the UAV.

This work presents a novel technique and coordination architecture that ensures the conditions above and explores the area effectively.

2. Proposed Method

2.1. UAV / UGV Coordination Architecture

The requirements for reconnaissance formation are primarily derived from the differences in maneuverability between both of the vehicles and impact of terrain on movability of UGV. The relative positions of the heterogenous vehicles, reconnaissance objectives and the environment data (grid map) are combined to generate the planning data, as shown in Fig. 1. The planning data further combines with the relative positions of UAV and UGV, and the trajectory data from UAV is fed to the path planning unit. The path planning unit, considering the conditions mentioned in Section 1, generates instructions for both UAV & UGV for coordinated maneuvers alongside requirements like collision avoidance.

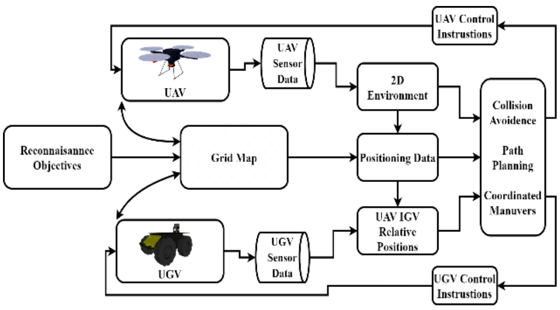

Fig. 1. UAV/UGV Coordination Architecture

2.2. Measure of Objectiveness in coordination

Self-assembly is a technique to attain cohesion in heterogenous robots which is perceived as robotic intelligence. The robots are required to assemble themselves that may not be possible through maneuverability [4]. There are three primary objectives under self-assembling the UAV and UGV to generate maneuver instructions and capitalize on interaction between them to work on complex tasks more efficiently.

(i) Robustness: To reperform the task while maintaining the cohesion in proximity in case of any missing area to be explored.

(ii) Versatility: To adjust and readjust the maneuvers because of uneven terrain and ground obstacles for the UGV.

(iii) Cost reduction: To minimize the cost for the above. Here the cost is computed in terms of the time lapsed and number of turns a robot has to take. through design of large numbers of robots.

2.3. Attraction / Repulsion Mechanism in UAV / UGV

There are two primary tasks which are being performed at all the time: collision avoidance for the ground vehicle and flocking of UAV with respect to the ground vehicle. Collision avoidance in this work is basically a necessary condition for the UGV to maintain a minimum safe distance from its surroundings objects.

This work is inspired from a recent published work which engaged heterogenous robots in an ‘invisible binding’ by implementing an “Attraction / Repulsion” mechanism using Voronoi partitioning, based on Voronoi Diagrams for collision avoidance [5]. However, our approach exploits the idea of attraction-repulsion for heterogenous robots and generates path instructions in a zone-based coordinate system. Aggregation and dispersion are the two phenomena which are derived from the inter-robot’s distance and their distribution in the area needed to be explored. This work mitigates this problem through establishing zones based on the distances and focuses on reconnaissance of the territory.

The proposed model consists of four constraints i.e. placement, repulsion, attraction, and orientation. The placement may take place either randomly or with some prior information from the area of reconnaissance. The model is based on a set of universal equations proposed by Ian Couzin cited by [6]. Referring to Eq. (1), Eq. (2)

and Eq. (3), where dr, do and da represent the radii of repulsion, operation and attraction zones with i and j representing coordinates. Fig. 2 presents an illustration for the three scenarios.

$$d_r(t+\tilde{L}) = -\sum_{j\neq i}^{M_r} \frac{rij(t)}{|rij(t)|} \tag{1}$$

$$d_o(t+\tilde{L}) = \sum_{j\neq i}^{M_o} \frac{Vj(t)}{|Vj(t)|} \tag{2}$$

$$d_a(t+\tilde{L}) = -\sum_{j\neq i}^{M_a} \frac{rij(t)}{|rij(t)|} \tag{3}$$

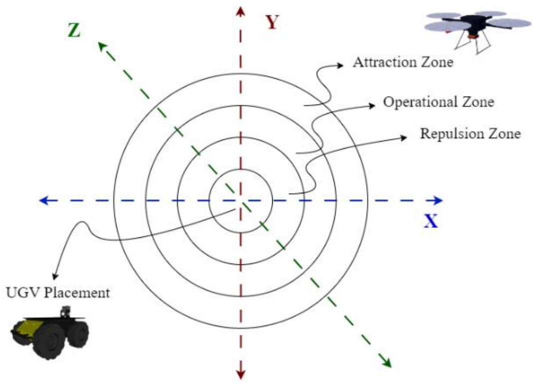

Fig. 2. Attraction Repulsion Mechanism with Placement and operational zone

2.4. Parallel Maneuver Generations for UAV / UGV

Here it is important to mention that either of the heterogeneous robots has to be set as the leader or follower. Moreover, the radii of the zones are adaptable according to the terrain and area under consideration. The maneuver generation takes sensor and positioning data from both unmanned vehicles and create relative positions of UAV and UGV, refer to the Fig. 1. This data generates maneuvering instructions in a 2D workspace, assuming a constant altitude of the UAV. Fig. 3 presents the maneuver generations of for both UAV and UGV. To better understand the flow of an instruction generation, consider the UAV and UGV in the placement zone.

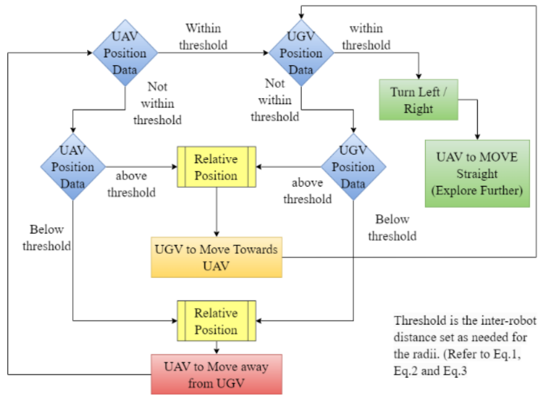

Fig. 3. Parallel Maneuver Generation for UAV /UGV

3. Implementation

3.1. Simulation Setup

Robot Operating System (ROS) is an opensource platform that provides libraries for and tools for a diverse range of robotic applications. These libraries include the hardware abstraction, driver packages, data visualizers, inter-module communication packages and protocols [7]. Gazebo on the other hand simulates the robotic application in a simulated environment [8]. Both these projects are lead by a community called open robotics [9].

For this work, we consider HUSKY and HECTOR which are emulated versions of opensource UGV and UAV, respectively. The integration of Husky and Hector within ROS provides the foundation of collaborative autonomous systems, showcasing the potential coordination among heterogeneous robots. There are four key components for setting up this collaboration:

(i) Sensor data Integration
(ii) Communication of sensor data, control instructions and status of UAV / UGV
(iii) Motion Control and Mission Planning.
(iv) Mapping and Navigation.

3.2. Experimentation

The experimental scenarios are established for a comprehensive evaluation of the collaboration and exploration capabilities of Hector and Husky. There are two primary considerations in mind before setting up experimental scenarios:

(i) To validate the ability of this collaboration system for exploration and mapping
(ii) To evaluate the adaptiveness of the system against the challenges in the environment. (Under this work, the challenges refer to static obstacles and uneven terrain.)

3.3. Flow of Activities

(i) Initialize the ROS-Gazebo environment through ROS launch file. For uneven terrain, there is a stock environment available in Gazebo which has been deployed.

(ii) Deploy Hector UAV and Husky UGV equipped with LiDAR sensors.

(iii) Command Husky for Autonomous Exploration and Hector for aerial mapping.

(iv) Initiate the program for exchanging Lidar and positioning data between Husky and Hector and compute relative positions. The relative data and position histories are stored and explored regions are marked with the coordinates of the environment.

(v) Constraints initialization: This is the main program which generates the thresholds from the relative positions. This module also utilizes LiDAR data from Husky for its collision avoidance.

(vi) Creation of unified map that combines the explored area from both of the platforms.

(vii) Collection of performance parameters which are percentage of area explored, number of maneuvers required, and overall time taken.

(viii) Analysis of exploration data and suggestions for optimizations.

4. Results and Discussion

Since there isn't any notion of geo-referenced coordinates in Gazebo, therefore, the positioning data in the simulation, for both the platforms, is collected in Cartesian Coordinate space. Fig. 4 presents the screenshot of deployment of both platforms while coordinating repulsive motion.

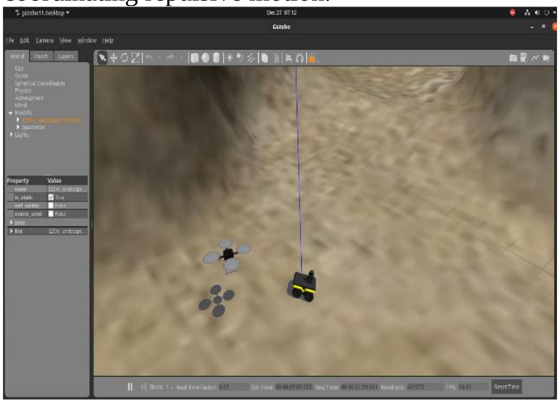

Fig. 4. Hector and Husky Deployment in a stock environment in Gazebo

The synergic collaboration between the two autonomous platforms performed simultaneous mapping based on the combining the aerial and ground data. The UGV is instructed to follow a programmed exploration strategy which can be modified as needed, while the Hector UAV performs the mapping of the aerial mapping of the environment.

Fig. 5 presents the initialization of exploration through Husky in the pattern given to it. While Fig. 6 presents the aerial mapping of Hector of the environment shown in Fig. 4.

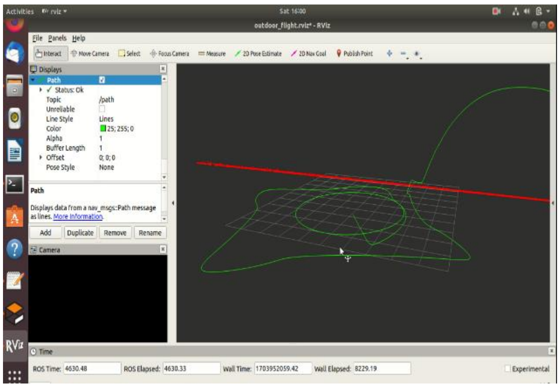

Fig. 5. Expanding Circular Exploration lead by Husky UGV, path trail in RVIZ visualizer

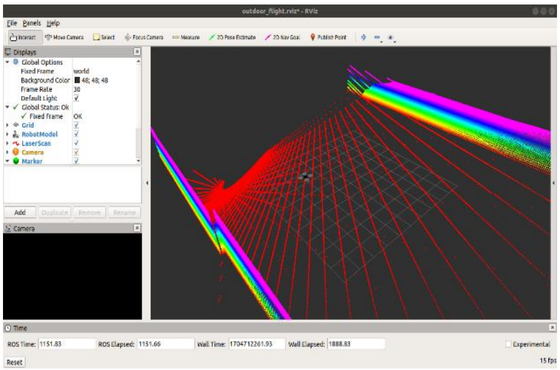

Fig. 6. Aerial Mapping being conducted through Hector UAV, LiDAR data being shown in RVIZ

5. Conclusion

The work demonstrated a successful integration of two heterogeneous autonomous unmanned systems in ROS-Gazebo environment, proving their potential to use them for reconnaissance applications in unknown workspaces. The key feature of this work was to propose an attraction-repulsion mechanism among the aerial and ground vehicles for a strategic and coordinated exploration. This work is at the early stages of experimentation and possess the potential for further enhancements which primarily include optimization of exploration algorithms and strategies. Moreover, this work just incorporates two unmanned systems which can be expanded to exhibit a swarm intelligence behavior among UAVs or UGVs. We believe that the future of exploratory missions in unknown or hostile environments is very promising when it comes to unmanned systems.

6. Acknowledgements

This work is conducted under research group formed at University of Malaya, Kuala Lumpur in which the individuals from diverse universities and industries participate. The author gratefully acknowledges ACR Lab, Faculty of Engineering, University of Malaya and their members for providing assistance during assembling and testing.

References

1. H. Zhang, T. Yang, and Z. Su, "A formation cooperative reconnaissance strategy for multi-UGVs in partially unknown environment," Journal of the Chinese Institute of Engineers, vol. 46, no. 6, pp. 551-562, 2023/08/18 2023, doi: 10.1080/02533839.2023.2227879.
2. J. Nohel, P. Stodola, J. Zezula, P. Zahradníček, and Z. Flasar, "Area reconnaissance modeling of modular reconnaissance robotic systems," The Journal of Defense Modeling and Simulation, p. 15485129231210302, 2023, doi: 10.1177/15485129231210302.
3. A. Wang, F. Jing, X. Huang, C. Gong, and S. Xu, "Structure Keeping Control for Heterogeneous Formations Based on Consistency Theory and Graph Theory," in 2023 9th International Conference on Mechatronics and Robotics Engineering (ICMRE), 10-12 Feb. 2023 2023, pp. 139-145, doi: 10.1109/ICMRE56789.2023.10106518.
4. K. S. N. Ripon, E. Jakobsen, C. Tannum, and J. M. Montanier, "Assessing the effect of self-assembly ports in evolutionary swarm robotics," in 2016 IEEE Symposium Series on Computational Intelligence (SSCI), 6-9 Dec. 2016 2016, pp. 1-8, doi: 10.1109/SSCI.2016.7850181.
5. A. Eudes, S. Bertrand, J. Marzat, and I. Sarras, "Distributed Control for Multi-Robot Interactive Swarming Using Voronoi Partioning," Drones, vol. 7, no. 10, doi: 10.3390/drones7100598.
6. M. Aguilera, J. A. R. Linan, and L. M. Torres-Treviño, "Change of Behavior on Swarm Robotics Using Repulsion and Attraction," in 2015 Fourteenth Mexican International Conference on Artificial Intelligence (MICAI), 25-31 Oct. 2015 2015, pp. 169-172, doi: 10.1109/MICAI.2015.32.
7. R. Wiki. "About ROS." Wiki. http://wiki.ros.org/ (accessed January 21, 2024).
8. GazeboSim. "About - Gazebo Simulator." https://gazebosim.org/home (accessed January 21, 2024).
9. OpenRobotics. "About - Openrobotics." OpenRobotics. https://www.openrobotics.org/ (accessed January 21, 2024).

Authors Introduction

Mr. Anees ul Husnain

Anees is currently pursuing his Doctoral in Electrical Engineering at University of Malaya, Malaysia. He holds a master's degree in computer engineering from UET Taxila, Pakistan. He is working on autonomous path generation of UAVs to monitor fugitive emissions.

Ir. Dr. Norrima Mokhtar

Norrima Mokhtar received the Bachelor of Engineering (B. Eng) degree in Electrical Engineering from University of Malaya in 2000. She was appointed as a lecturer to serve the Department of Electrical Engineering, University of Malaya immediately after graduating with her Master of Engineering. As part of her career development, she received SLAB/SLAI scholarship to attain her Ph.D. in 2012. She is now serving Department of Electrical Engineering, University of Malaya.

Dr. Takao Ito

He is Professor of Management of Technology (MoT) in Graduate School of Engineering at Hiroshima University. He is serving concurrently as Professor of Harbin Institute of Technology (Weihai) China. He has published numerous papers in refereed journals and proceedings, particularly in the area of management science, and computer science. He has published more than eight academic books including a book on Network Organizations and Information (Japanese Edition). His current research interests include automata theory, artificial intelligence, systems control, quantitative analysis of inter-firm relationships using graph theory, and engineering approach of organizational structures using complex systems theory.

Dr. Siti Sendari

She is a lecturer at Universitas Negeri Malang, Indonesia, specializing in intelligent systems, robotics, and evolutionary computation. She holds the position of Head of Laboratory in the Department of Electrical Engineering at the Faculty of Engineering. Her work focuses on intelligent systems and related areas, contributing to the academic community.

Ir. Muhammad Farris Kyasudeen

He is associated with Universiti Teknologi MARA (UiTM) in Malaysia. He is part of the Faculty of Electrical Engineering at UiTM's branch in Pulau Pinang, where he holds the position of Ir. (Ir.) indicating his professional engineering qualification. He has also received recognition for winning third place in a competition related to Electrical Engineering at UiTM. His contributions include research on an Autonomous Ground Vehicle (COR-AGV) disinfectant system using far-UVC light exposure.

Mr. Muhammad Badri M Noor

He is associated with Ifcon Technology, as mentioned in the search results. He is linked to the University of Malaya, specifically in the Department of Computer System & Technology, Faculty of Science Computer & IT. Moreover, he has contributed to a research paper on Remote Desktop Power Management System using Single-Board Computer, showcasing his expertise in this field.

Dr. Heshalini Rajagopal

She received her PhD and Master's degree from the Department of Electrical Engineering, University of Malaya, Malaysia in 2021 and 2016, respectively. She received the B.E (Electrical) in 2013. Currently, she is an Assistant Professor in UCSI University, Kuala Lumpur, Malaysia. Her research interest includes image processing, artificial intelligence and machine learning.