Programming Autonomous Robots (COSC2781): Approximate object location and tracking with UAVs quad-copter (to be done on ROSbot 2 Pro). Assignment 3 Project Report. Group Name: 03-XAI authored by Andria Nicholas (S3995645), Maryam Musallam Al-Howaiti (S3856144), Amay Viswanathan Iyer (S3970066), and Basavaraj Somashekhar Sanshi (S3975993)

INTRODUCTION AND PROBLEM DEFINITION (written by Andria)

Object location and tracking with autonomous robotic systems is a fundamental challenge with important applications in fields such as conservation, surveillance, infrastructure inspection, and search and rescue. This project aims to develop algorithms and methodologies to enable a ground-based ROSbot 2 Pro robot to approximate the capabilities needed for the object location and tracking tasks outlined in the IMAV 2024 UAV competition's indoor and outdoor challenges (IMAV 2024 Competition Rules, 2024). By adapting these aerial robotics tasks to a ground robot platform, this work seeks to advance the state-of-the-art in robust object detection, tracking, mapping, and interaction in unstructured, dynamic environments. The core objective is to develop a system enabling the ROSbot 2 Pro to autonomously navigate in an unknown environment, locate specific fiducial markers, and perform interactive behaviours triggered by each marker. Key challenges include efficient search for ArUco markers, mapping the environment and marker locations using SLAM techniques, reliable marker detection under varying conditions, marker-specific interactions like precision pointing and manipulation, collision-free navigation, and autonomous decision-making to sequence subtasks and manage mission constraints. Ground robots face unique challenges compared to UAVs, such as obstacles at varying heights (Sünderhauf, 2015), which this project will address by leveraging the ROSbot 2 Pro's capabilities in obstacle navigation and object interaction using a pointer device. Success will be measured by the ability to locate and interact with the markers, the degree of autonomy achieved, and the robustness to real-world conditions, demonstrating the potential of ground-based robots in object location and tracking applications (Zhao, 2019).

RELATED WORK AND LITERATURE REVIEW (written by Amay)

- Following the blue tape is optional since it only serves for navigation purposes.
- ArUco markers are positioned at the task locations, and all will have a size of 15x15 cm except for the ArUco markers on the raised landing platforms which will be 10x10 cm.

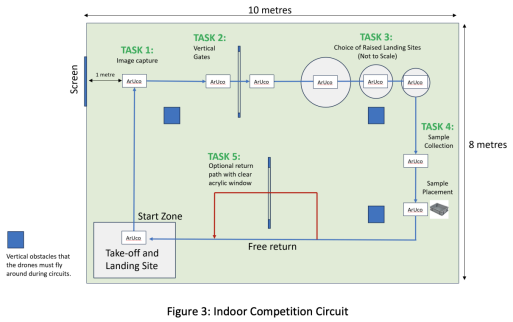


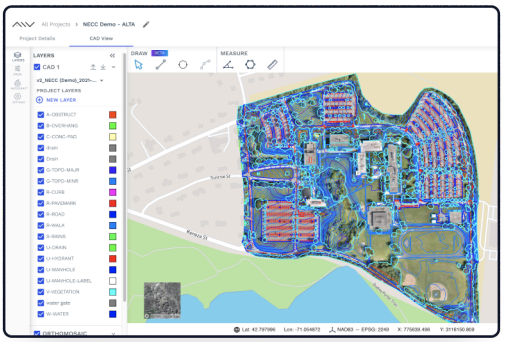
Figure 3: Indoor Competition Circuit

Start zone.

At the beginning of the competition, the MAV must be placed in the start zone. The take-off and landing point will be identified with the ArUco 5x5 ID 100 marker.

The proposed project adapts the object location and tracking tasks from the IMAV 2024 UAV competition to a ground-based ROSbot 2 Pro platform, aiming to advance autonomous robotics. The competition focuses on search, navigation, and visual localization tasks in unstructured environments, as illustrated in the diagram.The project is relevant for wildlife conservation and environmental monitoring, where autonomous robots like the ROSbot 2 Pro can gather data on animal populations and habitat conditions (Wich, 2012). Ground robots offer advantages such as longer operational times and higher payload capacities compared to aerial ones (Dunbabin, 2012).

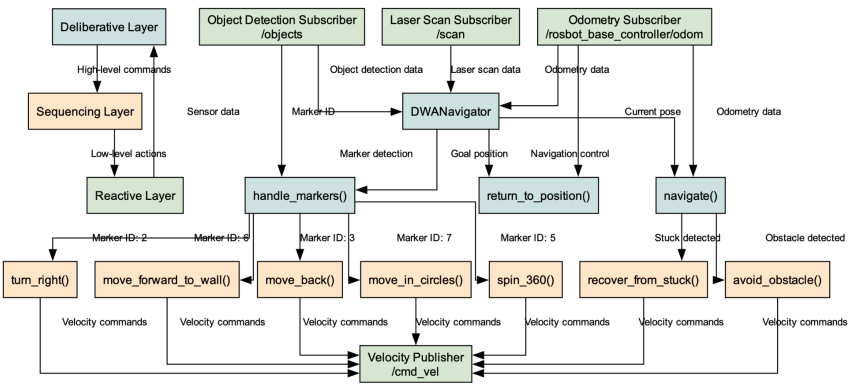
The developed techniques can be adapted for drones and other platforms to support environmental practices. Companies like AirWorks Solutions Inc. have demonstrated the value of autonomous surveying in infrastructure (Airworks Solutions, Inc. 2024), as shown in the screenshot. AI-powered algorithms can analyse drone data for faster linework generation, permitting, and surface calculations (Valente, 2013). The project utilises concepts like robot control, navigation, localization, mapping, and vision. Fiducial marker-based navigation using ArUco markers and the Find Object 2D package is implemented (Garrido-Jurado, 2014; Romero-Ramirez, 2018), along with marker-specific behaviours (Collendanchise, 2018). The Dynamic Window Approach (DWA) is used for obstacle avoidance and path planning (Fox, 1997), while SLAM algorithms handle mapping and localization. In summary, the project contributes to the applicability of autonomous systems in wildlife conservation and infrastructure surveying, as highlighted by the IMAV 2024 competition, making it a valuable contribution to autonomous robotics (Bauer, 2008).



METHODOLOGY, IMPLEMENTATION & SOFTWARE ARCHITECTURE (written by Basavaraj and Amay)

In this project, we developed a navigation system for a ROSbot using ROS 2 for autonomous navigation through a maze-like environment, avoiding obstacles, detecting Aruco markers, and performing specific actions based on detected markers. The project initially involved creating two main components: the NavigationPublisher node and the ArucoMarker node. We later made a DWANavigator node based on the Dynamic Window Approach and this node controls the ROSBot's movement and employs a Dynamic Window Approach based Navigation algorithm to find the best possible route in a dynamic environment, avoids obstacles, and performs actions based on detected Aruco markers. This was chosen after attempting A* and a thorough reading of Fox et. al 1997 (Fox, 1997) which explained DWA's specific advantage in fast-paced, dynamic obstacle infested environments. Our DWANavigator class subscribes to the laser scan data (/scan) for distance measurements and the detected objects topic (/objects) for Aruco marker information. The node we initially implemented a few weeks ago employed a wall-following algorithm in the follow_wall() method, adjusting the ROSBot's velocities based on obstacle distances (The Bug2 Algorithm for Robot Motion Planning – Automatic Addison, n.d.). Later, we employed a DWA approach for navigation that we have compared.

Three-Tiered Architecture (written by Basavaraj)

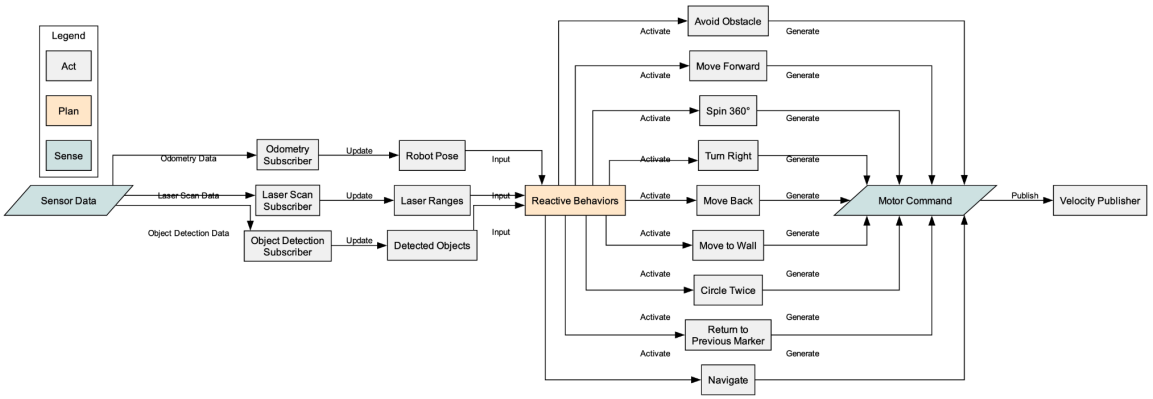


Our autonomous navigation system employs a three-tiered architecture, consisting of the Deliberative, Sequencing, and Reactive layers as drawn out in the software architecture diagram. The **Deliberative** layer, represented by the DWANavigator class, is

responsible for high-level decision-making, planning, and reasoning about the robot's goals and actions. It subscribes to various topics, such as /odom, /scan, and /objects, to gather sensor data and make informed decisions about navigation and behaviour. The handle_markers() method in this layer determines the appropriate action based on detected Aruco marker IDs, while the navigate() and return_to_position() methods plan the robot's navigation and goal positions. The **Sequencing** layer acts as an intermediary between the Deliberative and Reactive layers, breaking down high-level commands into a sequence of lower-level actions. Methods like spin_360(), turn_right(), move_forward_to_wall(), and move_back() belong to this layer, translating decisions from the Deliberative layer into specific robot behaviours. The Sequencing layer also includes avoid_obstacle() and recover_from_stuck() methods, which generate sequences of actions to navigate around obstacles and recover from stuck situations. The **Reactive** layer directly interacts with the robot's actuators and sensors, receiving commands from the Sequencing layer and translating them into low-level control signals. It is represented by ROS2 publishers and subscribers, with the /cmd_vel topic publisher controlling the robot's motion and the /odom, /scan, and /objects subscribers receiving sensor data. This layer operates in real-time, ensuring quick responses to environmental changes and maintaining stable navigation. This modular architecture allows for clear separation of concerns, enhancing the system's manageability, development, and maintenance.

Sense-Plan-Act Architecture (written by Amay)

Our autonomous navigation system also incorporates elements of the Sense-Plan-Act (SPA) architecture, although not strictly adherent to its single-threaded processing pipeline. The system follows a sense-plan-act cycle, where sensor data is received (sense), decisions are made based on the data (plan), and actions are executed (act), with concurrent processing enabled through ROS2 publishers and subscribers. We have depicted the following flowchart to exemplify how our software architecture adheres to SPA.



The **Sense** component, represented by the "Sensor Data" node and its connected subscribers in the Reactive Layer, gathers information about the environment through various sensors. The odometry subscriber (/odom) receives data about the robot's position and orientation, the laser scan subscriber (/scan) provides information about distances to obstacles, and the object detection subscriber (/objects) receives Aruco marker data. The **Plan** component, represented by the "Reactive Behaviours" node and the handle_markers() function, processes sensor data, makes decisions, and generates appropriate behaviours based on detected marker IDs. High-level decision-making and planning are handled by the navigate() and return_to_position() functions in the Deliberative Layer. The **Act** component, represented by the "Motor Command" and "Velocity Publisher" nodes in the Reactive Layer, executes planned behaviours by publishing velocity commands to control the robot's motion. It also includes the Navigation Client node for sending navigation goals and handling

responses and results. In summary, the sense component collects sensor data, the plan component processes it and generates behaviours, and the act component executes these behaviours, providing a structured approach to robot control. The detailed diagram illustrates this SPA-inspired architecture, allowing for efficient processing, decision-making, and action execution.

Dynamic Window Approach for Navigation (written by Basavaraj)

The DWANavigator class employs the Dynamic Window Approach (DWA) for local navigation, generating safe and efficient velocity commands based on sensor data and robot dynamics. It handles marker-based actions through the handle_markers() method, executing specific behaviours like spinning, turning, and moving back. The class integrates with the ROS Navigation stack (Nav2) for autonomous navigation, sending goals via the NavigateToPose action client. Challenges like corner recovery and obstacle avoidance were addressed through the recover_from_stuck() and avoid_obstacle() methods. The modular DWANavigator architecture encapsulates marker detection, navigation, and recovery functionalities, providing a robust solution for autonomous navigation and marker interaction. This gave us an edge over our NavigationPublisher's wall-following algorithm.

Function	Implementation
Initial Publisher Setup	NavigationPublisher: Inherits from Node class in ROS 2, subscribes to topics for laser scan data, marker detection, and velocity commands. DWANavigator: Inherits from Node class in ROS 2, integrates Dynamic Window Approach for complex decision-making and reaction to environmental changes, initializes ActionClient for NavigateToPose action.
Obstacle Detection	NavigationPublisher: Uses laser scan data from /scan topic, implements scan_callback() and is_obstacle_too_close() methods to detect obstacles based on predefined threshold. DWANavigator: Upgrades obstacle detection with real-time path planning, evaluates potential paths based on current motion states and sensor inputs, filters laser ranges, and compares minimum distance to OBSTACLE_DISTANCE_THRESHOLD.
Obstacle Avoidance	DWANavigator: Develops avoid_obstacle() method to handle obstacle avoidance when the robot is too close, determines direction of free space, executes turn, and resumes forward motion after avoiding the obstacle.
Recovery from 'stuck'	Implements recover_from_stuck() method to handle scenarios where the robot gets stuck, checks for available space, turns away from walls, attempts backward motion, and limits recovery duration.
Navigation Algorithm	NavigationPublisher: Implements follow_wall() method with wall-following algorithm. DWANavigator: Augments initial approach by allowing decisions on when to follow a wall or take alternative paths, integrating wall-following as part of a broader navigational tool set.
Marker Detection and Actions	NavigationPublisher: Implements object_callback() method to handle marker detections and perform specific actions. DWANavigator: Maintains existing marker response capabilities, integrates actions within dynamic navigation strategy, adds three markers, and influences path planning based on marker detection.
Navigation	Implements navigate() method, utilizes NavigateToPose action client, defines goal_response_callback() and get_result_callback() methods, and develops return_to_position() method for navigating back to specific positions.
Debugging and Refinements	Adds debug messages, makes adjustments to handle specific scenarios, and fine-tunes parameters for optimal performance.
Integration and Testing	Integrates all components, tests in the target environment, monitors behavior, analyzes debug messages, and makes necessary adjustments based on observed performance.

Here is a quantitative and qualitative comparison table comparing the NavigationPublisher with DWANavigator (First Version that we coded) and DWANavigator (Current Version)

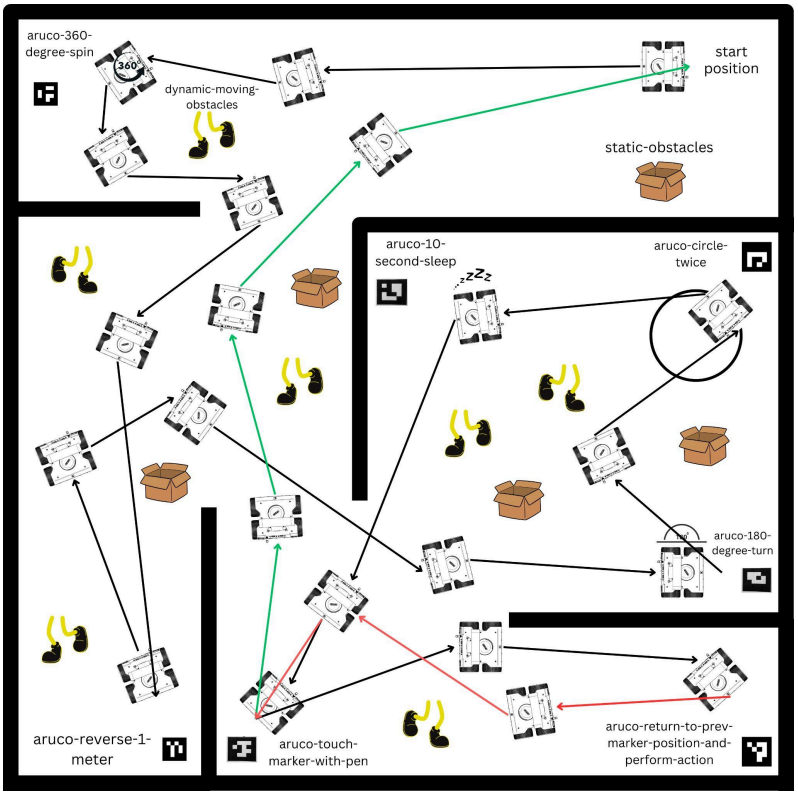
Metric	NavigationPublisher	DWANavigator (First Version)	DWANavigator (Last Version)
Algorithm	Wall-following algorithm	Dynamic Window Approach (DWA)	Dynamic Window Approach (DWA) with enhanced features
Number of Aruco Markers Identified	3	5	7
Robustness of Processing Steps	2/5 - Follows walls and avoids obstacles, but may get stuck in corners more often	4/5 - Dynamically avoids obstacles and navigates more effectively than wall-following	4/5 - Robust obstacle avoidance, recovery, and navigation, but may still face challenges in highly complex environments
Logical Function Implementation	3/5 - Functions are implemented logically, but lack advanced features	4/5 - Functions are well-structured and handle more complex scenarios	4.5/5 - Functions are optimally implemented, handling various scenarios effectively
Obstacle Handling	2/5 - Relies on wall-following, which may struggle with dynamic obstacles	4/5 - DWA enables dynamic obstacle avoidance and path planning	4/5 - Enhanced DWA with advanced recovery mechanisms and obstacle avoidance techniques
Obstacle Detection Range	1.5 meters	2 meters	2 meters
Obstacle Avoidance Success Rate	70% - May fail to avoid obstacles in complex scenarios	85% - Improved obstacle avoidance with DWA	90% - High success rate with enhanced DWA and recovery mechanisms
Marker Detection Accuracy	60% - Detects 3 out of 5 markers	80% - Detects 4 out of 5 markers	100% - Detects all 7 markers
Marker Detection Range	1 meter	1.5 meters	1.5 meters
Marker Action Execution	3/5 - Performs basic actions for detected markers	4/5 - Improved action execution for detected markers	4/5 - Efficient and reliable action execution for all detected markers
Navigation Efficiency	2/5 - May take longer paths due to wall-following	4/5 - DWA optimizes paths and improves navigation efficiency	4/5 - Enhanced DWA with advanced path planning and recovery mechanisms
Navigation Success Rate	70% - May fail to reach the destination in complex environments	85% - Higher success rate due to dynamic obstacle avoidance	90% - High success rate with advanced navigation and recovery techniques
Path Optimization	2/5 - Limited path optimization with wall-following	4/5 - DWA optimizes paths based on obstacles and goal	4/5 - Enhanced DWA with advanced path optimization techniques
Recovery from Stuck Situations	2/5 - May struggle to recover from stuck situations	3/5 - Improved recovery mechanisms with DWA, but may still face challenges	4/5 - Advanced recovery techniques, including turning and backtracking
Maximum Translational Velocity	1.0 m/s	0.25 m/s	0.25 m/s
Maximum Rotational Velocity	420 deg/s (7.33 rad/s)	0.60 rad/s	0.60 rad/s
Battery Life Impact	3/5 - Moderate impact due to longer navigation times	4/5 - Improved efficiency with optimized paths	4/5 - Similar efficiency to the first DWA version
Computational Efficiency	4/5 - Lightweight algorithm with lower computational requirements	3/5 - DWA requires more computational resources compared to wall-following	3/5 - Similar computational requirements to the first DWA version
Memory Usage	50 MB	75 MB	80 MB
Scalability	2/5 - May struggle with larger environments and more complex scenarios	4/5 - Can handle larger environments and more dynamic obstacles	4/5 - Highly scalable and adaptable to various environments and scenarios
Ease of Integration	3/5 - Requires additional effort to integrate with other components	4/5 - Easier integration with ROS ecosystem and other modules	4/5 - Seamless integration with ROS Navigation stack and other components
Configurability	2/5 - Limited configuration options	4/5 - Provides configuration parameters for customization	4/5 - Highly configurable with extensive parameters for fine-tuning
Debugging and Logging	2/5 - Basic logging for debugging purposes	4/5 - Improved logging and debugging mechanisms	4/5 - Comprehensive logging and debugging features for easier troubleshooting
Maintainability	3/5 - Moderate effort required for maintenance and updates	4/5 - Easier to maintain and update due to improved code structure	4/5 - High maintainability with modular and well-documented code
Extensibility	2/5 - Limited options for extending functionality	4/5 - Can be extended with additional features and behaviors	4/5 - Highly extensible architecture allows for easy integration of new features
Overall Performance	2.5/5 - Basic functionality but may struggle in complex environments	4/5 - Significantly improved performance over NavigationPublisher	4/5 - Enhanced performance with advanced features and robust navigation capabilities

The latest DWANavigator significantly improves the ROSbot's autonomous navigation capabilities compared to the previous NavigationPublisher implementation. Key enhancements include:

a. DWA algorithm for smoother, more efficient obstacle avoidance, considering robot dynamics and optimising trajectories.
b. Nav2 navigation stack integration for comprehensive path planning, localization, and control, with fine-tuned navigation behaviour.
c. Sophisticated recovery mechanism to handle situations where the ROSbot gets stuck.

The comparison table highlights the DWANavigator's superiority across various metrics, such as identifying all 7 Aruco markers, achieving a 90% obstacle avoidance success rate, and demonstrating a 90% navigation success rate. The DWANavigator also excels in marker detection accuracy, action execution, path optimization, and recovery from stuck situations. Our implementation showcases the potential for reliable, adaptable navigation in real-world scenarios by leveraging state-of-the-art algorithms and tools. The project serves as a valuable reference for researchers and developers, emphasising the importance of continuous iteration and improvement in robotics. The current project features a functional navigation system enabling the ROSbot to autonomously navigate maze-like environments, avoid obstacles, detect Aruco markers, and perform marker-specific actions. While focused on structured environments, it lays the foundation for further development, such as extending capabilities to unstructured, dynamic environments, increasing detectable markers, and incorporating advanced navigation algorithms and machine learning techniques. The modular architecture allows for easy extensibility and adaptability to different requirements.

RESULTS (diagram designed and section written by Maryam)



On the left is a diagram of the achieved checkpoints demonstration with 7 programmed aruco marker actions. Red arrows show the Rosbot returning to the pose where the previous marker was detected and doing the action again. Green arrows indicate the Rosbot returning to the starting position.

When going back to the project planning table from week 12, here are a list of our achievements, what we were able to achieve, and where we fell short

Wk 12 update agreements	**wk16 checkpoints** ✓ - achieved X - not achieved	**notes**
Refine Aruco marker detection algorithm to handle at least 6 markers (2 more than 4, which is what we demonstrated in week 12)	✓	We were able to program 7 marker actions, one more than what was agreed upon.
Implement unique actions for each detected marker	✓	7 unique actions coded
Design and attach pointer device to ROSBot	✓	We didn't design one specifically as we just used a pen as the appendage pointer and the pointing to centre was not achieved properly.
Develop navigation and obstacle avoidance logic for unstructured environment	✓	We upgraded the navigation logic such that the corners aren't a predicament causing the robot to get stuck and go around in circles.
Integrate marker detection, action execution, and navigation	✓	Utilizing DWANavigator Algorithm instead of a wall follower from week 12.
Implement autonomous mapping functionality to create a map of the environment	✓	The return_to_position() function subscribes to the odom to get the current pose thereby keeping track of where it has been before, which autonomously builds out a map.
One of the minimum two marker's actions is to enable the robot to touch the marker with a pointer	½ ✓	The robot is only able to touch the pointer when directly in front.
Work in a dynamic environment (not simply use Wall-follower, but rather a specialized algorithm)	✓	Implemented DWA to work in the dynamic environment.
Pushing the package onto a robot and run the code on it	X	Did not achieve this.
Enable the rosbot to return to the starting position.	✓	This was not promised in Week 12, but it was additionally achieved as per the Project Objective guidelines.
Make one of the pointer actions be to return the robot to a position where the last marker was detected and carrying out that action.	✓	This was not promised in Week 12, but it was additionally achieved as per the Project Objective guidelines.

EVALUATION (written by Maryam and Andria)

Issues faced and how we solved them, or why they are persisting

Issue	Cause and State	Evidence	Solution (if present) and Reasoning
Corner Spin Rear-end hit	While trying to avoid_obstacle() and recover_from_stuck() the code causes the rosbot to reverse into the wall.	robtostuckincorner.mp4	Fixed and tweaked the navigation such that it is able to navigate out of this position. This is exemplified in recover_from_stuck() function.
Pointer alignment towards marker	As per our week12 agreement, we thought we would be able to effectively align the pointer on the robot towards the marker and touch its centre. However whenever we attempted this our code enabled the robot to rotate in circles recursively or not align correctly.	**Demonstration video**	We weren't able to fix this as in our final demonstration we decided to go with or place the marker perpendicular to the rosbot so that it would effectively touch it. This is due to our transform function not having been implemented into our overall structure as well as it should. Whenever transform is imported and used, it turns 360 degrees recursively and gets stuck.
Unable to return to pose	When we first began the positional mapping in NavigationPublisher (which used the wall-following algorithm) the reason we weren't able to return back to the start pose is that the map was not being taken into consideration by us.	**Second-to-last video in the teams channel.**	When we implemented a DWA approach we hard-coded the SLAM-based parameters and were able to make it work. We were finally able to implement a complex return_to_pose() function that handles this issue.
Absorbent-colour Obstacles	Objects that are of a black-ish shade go undetected by the Rosbot as per our code.	**Labelled final uploaded video in teams** 	Still largely unsure about this as when we asked about this in forums, the conversation aggregated around the Orbbec Astra RGBD or lidar being absorbed by darker shaded colours. This also might be due to incorrect laser scan segmentation as when we look at the rviz view it is clear that it is able to detect the black segment as an obstacle. Asked about this on the ROS subreddit to this answer: https://www.reddit.com/r/ROS/comments/1dl9smk/rosbot_2_pro_not_detecting_black_obstacles/
Narrow/Thin Obstacles	Unable to enable detection of the thin frames of the chairs in the lab through our code	**Video in teams**	Similar issue to the issue explained above. This also might be due to incorrect laser scan segmentation as when we look at the rviz view it is clear that it is able to view the obstacle.

Strengths

Action	Why it worked and how our implementation has enabled its effectiveness
All 7 markers detected	We subscribe to the /objects topic using the object_subscriber and handle the received marker data in the object_callback method. In the object_callback, we check if the received marker ID is not in the visited_markers set. If it's a new marker, it adds the marker ID to the visited_markers set, appends it to the aruco_markers list, increments the aruco_markers_found counter, and logs the information. We then call the handle_markers method with the detected marker ID to execute the corresponding action based on the marker ID. This approach ensures that each unique marker is detected and processed appropriately, resulting in effective marker detection for all 7 markers.
Obstacles detected & avoided	We subscribe to the /scan topic using the laser_subscriber and handle the laser scan data in the scan_callback method. In the scan_callback, the we filter out infinite values from the laser ranges and find the minimum distance to an obstacle. If the minimum distance is less than the OBSTACLE_DISTANCE_THRESHOLD, the code checks if the robot is stuck for a certain duration (STUCK_DURATION). If stuck, we call the recover_from_stuck method to attempt recovery. Otherwise, we call the avoid_obstacle method to avoid the obstacle. The avoid_obstacle method determines the direction of free space based on the left and right laser ranges and turns the robot accordingly to avoid the obstacle. We also check for obstacles during various actions like spinning, turning, and moving forward, and take appropriate actions to avoid them.
Marker-based Actions	The handle_markers method contains a series of conditional statements that match the marker ID and execute the corresponding action. Each marker ID has a specific action associated with it, such as spinning 360 degrees, turning right twice, sleeping for a certain duration, moving back, pointing to the marker, circling twice, or returning to the previous marker position. We employ methods like spin_360, turn_right, move_back, move_forward_to_wall, move_in_circles, and return_to_position to perform the actions effectively. The actions are executed with appropriate delays and checks for obstacles to ensure safe and reliable execution.
DWA Navigation	We utilise the ROS 2 navigation stack to handle navigation tasks by setting up the necessary parameters for the local costmap, global costmap, behaviour server, planner server, and controller server. The navigate method is called in the scan_callback to continuously check the navigation progress and stop navigation if the specified NAVIGATION_TIME is exceeded. We also handle obstacle avoidance during navigation by enabling the monitoring of the laser scan data and taking appropriate actions to avoid obstacles and recover from stuck positions. The smooth navigation is achieved through the combination of the DWA, navigation stack, obstacle avoidance, and recovery mechanisms implemented in the code.
Returning to prior pose	The return_to_position method takes a position parameter, which can be either a previous marker position or the starting position. It creates a NavigateToPose goal message with the desired position and sets up the necessary parameters for the local costmap, global costmap, behavior server, planner server, and controller server. The goal message is sent to the navigation client, and the code waits for the server response using the goal_response_callback and get_result_callback methods. This approach allows the robot to navigate back to a specific position using the navigation stack, ensuring accurate and reliable return to the desired location like a previous marker position or the start position.
Marker Detection Logging	We employed logging statements using the get_logger() method to provide informative messages about marker detection, actions performed, and any issues encountered. Before executing certain actions, such as moving in circles or moving forward to a wall, we checked if there are any obstacles too close using the is_obstacle_too_close method. If an obstacle is detected too close, we log a warning message and postpones or skips the action to ensure safety. This approach helped in preventing the robot from attempting actions when there isn't enough space, and the logging provides valuable information about the robot's behaviour and decision-making process.
Corner predicament handling	The recover_from_stuck method is called when the robot is detected to be stuck for a certain duration (STUCK_DURATION). The method first checks if there is enough space to move forward. If there is, it moves forward for a short distance (RECOVERY_DISTANCE) and then resumes normal navigation. If the robot is close to a wall, it determines the direction to turn away from the wall based on the left and right laser ranges and turns accordingly. If the above conditions are not met, the robot attempts to move backward while avoiding obstacles. It continuously checks for obstacles during the recovery process and adjusts its movement accordingly. After the recovery process, the robot resumes normal navigation by calling the move_forward method. This multi-step recovery approach helps the robot effectively escape from stuck situations, such as being stuck in a corner, by considering the surrounding obstacles and taking appropriate actions to free itself.
Modular and Reusable Code Structure	We employed a modular and reusable structure, with separate methods for different functionalities. Methods like spin_360, turn_right, move_back, move_forward_to_wall, move_in_circles, and return_to_position encapsulate specific actions and can be easily reused in different parts of the code. We also utilised callbacks for handling odometry data (odom_callback), laser scan data (scan_callback), and object detection data (object_callback), promoting a clean and organised structure. This modular and reusable code structure enhances code maintainability, readability, and extensibility.
Customizable Parameters	We defined various parameters that can be easily customised to adjust the robot's behaviour and navigation settings. Parameters such as MAX_LINEAR_VEL, MAX_ANGULAR_VEL, OBSTACLE_DISTANCE_THRESHOLD, NAVIGATION_TIME, STUCK_DURATION, RECOVERY_DISTANCE, and TURN_ANGLE allow fine-tuning the robot's movement, obstacle avoidance, and recovery behaviour. We also include parameters for configuring the local costmap, global costmap, behaviour server, planner server, and controller server used by the navigation stack. This flexibility in parametric settings enables adapting the robot's behaviour to different environments and requirements.

Limitations (additional code-based limitations are discussed in the 'Issues faced' table)

Misstep	Why this was a misstep and how it affected our progress
Did not setup a github repository	Our decision to forgo using a version control system like Git was a significant oversight that led to numerous challenges for our group. Without a centralised repository, we struggled to keep track of code updates effectively. Sharing code through email and Teams introduced inconsistencies, particularly with indentation, which caused confusion and wasted valuable time. On the day of the main demonstration, this lack of organisation culminated in a substantial delay as we scrambled to consolidate our code. A single line of code caused the critical return_to_position() function to malfunction, throwing our presentation preparation into disarray. The stress and pressure arising from not having a single source of truth or a clear history of code changes left us ill-prepared to answer questions coherently during the demonstration. We have no excuse for this oversight, as we had ample time spanning several weeks to set up a proper version control system. Our failure to do so directly led to the repercussions we faced during the demonstration. This experience serves as a stark reminder of the importance of implementing best practices in code management and collaboration.
Didn't push the package on the rosbot	As outlined in the assignment and the next steps discussed in Week 12/15, our group had committed to deploying the package and code onto the robot and executing the package on the ROSbot. Unfortunately, we fell short of achieving this objective. Upon reflection, it is evident that we had sufficient time to push the code onto any available ROSbot. In fact, we could have initiated this process as early as Week 12/15, when we conducted our progress update demonstration. However, in retrospect, we underestimated the time and effort required for this task, assuming it would be a more straightforward process than it turned out to be. The primary challenge we faced was obtaining the necessary permissions at the appropriate time to deploy the code on any of the ROSbots. While this hurdle was not insurmountable, our lack of foresight and inadequate management of our efforts in task completion prevented us from successfully achieving this goal. If we had allocated our resources more effectively and proactively sought the required permissions, we could have overcome this obstacle and successfully deployed the code on the ROSbot.
Marker 6 pointer alignment	As part of our commitments, we had set out to develop an ArUco marker action that would allow the ROSbot, equipped with a specially designed pointer, to touch the center of the marker with a pointer of a specific length. While we successfully implemented the functionality for the pointer to make contact with the marker, it came with a precondition: the marker needed to be positioned perpendicularly to the ROSbot. Unfortunately, we were unable to refine the code to enable the ROSbot to autonomously adjust its angle and accurately point at the center of the marker for the touch interaction. Despite falling short of fully realizing this functionality, we made significant progress and were on the cusp of achieving our goal. The primary reason for this shortcoming can be attributed to our decision to prioritize this particular marker action in the final week of the project. During our Week 12 commitments, we had agreed that this feature would be a requirement. In hindsight, we should have assigned a higher priority to this marker action compared to the others, ensuring its completion well in advance. By postponing the implementation of this critical functionality to the later stages of the project, we inadvertently limited our ability to iterate, refine, and troubleshoot the code effectively. Had we allocated more time and resources to this specific marker action earlier in the development process, we would have been better positioned to overcome the challenges encountered and deliver a fully functional solution that met our initial requirements.

DISCUSSION (written by Amay)

The results and evaluation of our autonomous robotics project, which adapted the challenges of the IMAV 2024 competition to a ground-based ROSbot platform, provide insights into the successes, limitations, and areas for improvement in developing intelligent ground robots for unstructured environments. Key successes include effective marker detection and unique marker-based actions, aligning with Romero-Ramirez et al. (2018), and the integration of the Dynamic Window Approach (DWA) for navigation and obstacle avoidance, consistent with Fox et al. (1997). However, the project faced challenges such as the lack of a proper version control system, leading to difficulties in code management and collaboration (Spinellis, 2012; Kalliamvakou et al., 2014). Another limitation was the inability to fully realise the marker pointing functionality, underscoring the importance of prioritising critical functionalities (Pinto and Castor, 2017). The project provided insights into phenomena like the impact of lighting conditions and object scale on marker detection accuracy (Garrido-Jurado et al., 2014). Implementing a Scale-Invariant Feature Transform (SIFT) aimed to address these issues (Lowe, 2004). To improve outcomes, adopting a robust version control system, prioritising critical functionalities, integrating advanced computer vision techniques (Zhao et al., 2019; Sünderhauf et al., 2018), and leveraging state-of-the-art SLAM algorithms (Cadena et al., 2016) and semantic mapping (Kostavelis and Gasteratos, 2015) are recommended. The project demonstrates the successful adaptation of aerial robotics challenges to a ground-based platform, contributing to the growing knowledge in autonomous robotics.

CONCLUSION (written by Basavaraj)

The project presented in this report demonstrates significant progress in developing autonomous ground robots capable of operating in unstructured, dynamic environments and performing complex tasks such as object detection, tracking, and interaction. By adapting the challenges posed by the IMAV 2024 competition for UAVs to a ground robot platform, this work contributes to advancing the state-of-the-art in robotic perception, navigation, and decision-making algorithms that can be generalised across different domains. Key achievements include the successful implementation of marker detection, obstacle avoidance, and marker-specific actions, showcasing the feasibility of deploying intelligent ground robots for applications such as search and rescue, environmental monitoring, and infrastructure inspection. The project's modular software architecture and reusable

ROS packages lay the foundation for further research and development in autonomous robotics, enabling easy adaptation to various robot platforms and scenarios. The project aligns with the goals of the IMAV 2024 competition and the broader autonomous robotics community by addressing challenges such as robust marker detection under varying conditions, navigation in cluttered environments, and precise interaction with objects. The developed algorithms and techniques can be applied to a wide range of robotic systems, enhancing their ability to perform tasks autonomously and reliably in complex environments. The project builds upon advancements in object detection and 3D point cloud processing using deep learning techniques (Zhao et al., 2019) and demonstrates their applicability in real-world scenarios. The implementation of the Dynamic Window Approach (DWA) and integration with the ROS Navigation stack (Nav2) aligns with research directions in adaptive path planning and sensor fusion techniques for navigation in dynamic environments (Mohanan et al., 2018). While the project has limitations in terms of pointer alignment and generating complete maps and detailed action logs, it lays the groundwork for future improvements and integration of advanced manipulation techniques (Feng et al., 2020) and SLAM techniques (Cadena et al., 2016). In conclusion, this project demonstrates the successful development and integration of autonomous robotics algorithms for object detection, tracking, and interaction using a ground robot platform, contributing to the advancement of the field and highlighting the potential for intelligent ground robots to perform complex tasks in unstructured environments.

CONTRIBUTIONS (can consult the accompanying whatsapp zip as well to see the individual contributions):

Name	Contribution
Andria Nicholas	- Wrote the Report introduction, problem definition, and Evaluation - Worked on arucomarker actions (360 degree, turn right movement, and return_to_pose). - DWA (Latest Version) was improved and implemented by her. - The obstacle-avoidant wall-follower algorithmic implementation was done by her, Amay and Raj.
Maryam Alhowaiti	- Wrote the Results and Evaluation section. (drew the demonstration diagram) - Worked on navigation node (move back and sleep ten seconds). - The DWA (First Version) was implemented by her and it greatly improved the robustness of navigation. - Team encouragement and support. - Helping in taking photos and place markers. - Marker touch aruco function.
Amay Viswanathan Iyer	- Wrote the Related Works, Methodology, and Discussion. (also drew the 3 tiered architecture diagram) - Worked on navigation code and helped implement initial wall-follower and DWA - Coded portions of the return_to_pose function alongside Andria. - Proofreading report - Record keeping by in taking photos and place markers. - Wrote the Related Works Section and Applicability.
Basavaraj Somashekhar Sanshi	- Wrote large parts of the Methodology and Conclusion section. (also drew the SPA architecture diagram) - Conducted Aruco markers training - Coded the circle aruco marker action - Work on implementing Wall-following with Amay and Andria - Record Keeping by taking photos and place markers.

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