
Fall Test Plan

PatrolKnight

Intelligent Patrol Security Robotics System

Team E



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Contents

1	Introduction	1
2	Logistics	1
2.1	Equipment	1
2.2	Personnel	1
2.3	Location	1
3	Schedule	2
4	Tests	3
	Appendix A: System Requirements	13

1 Introduction

This document presents the Fall verification plan for the PatrolKnight autonomous security-patrol system. The plan contains ten tests that progressively verify the system’s mission-management, autonomous-navigation, IoT-perception, anomaly-detection, and operator-interaction capabilities. Tests T.P.01–T.P.03 verify mission creation and persistence, lanelet-based patrol-route generation and visualization, and AI-assisted anomaly heatmaps. Tests T.P.04–T.P.05 verify multi-device registration and status monitoring through Zenoh and autonomous Husky patrol navigation. Tests T.P.06–T.P.07 verify skeleton-based person detection and persistent tracking, followed by lying-down, trespassing, and loitering detection. Tests T.P.08–T.P.09 verify anomaly-triggered robot redirection, live investigation, operator decisions, mission-history recording, and patrol resumption. The final test, T.P.10, is the Fall Validation Demonstration (FVD), which validates the integrated Mission Manager, Husky Robot, IoT, and Anomaly Detection subsystems in an end-to-end security-patrol mission. The schedule associates these tests with the planned Progress Reviews and applicable system requirements.

2 Logistics

2.1 Equipment

Mission-management tests use a computer running the Mission Manager frontend, backend, database, map interface, route-generation interface, and heatmap-generation module. Integrated field tests use a Husky A200 mobile robot equipped with an NVIDIA Jetson Orin NX, Velodyne VLP-16 LiDAR, FIXPOSITION Vision-RTK 2 GNSS/IMU, front-facing camera, joystick controller, and network-communication equipment. IoT and perception tests use one or more IoT towers equipped with a DGX Spark, Intel RealSense D456 camera, tripod, monitor, and power bank, together with a lab computer for anomaly detection. The Mission Manager, Husky, IoT towers, and lab computer communicate through ROS 2 and Zenoh. Test-specific measurement, logging, and safety equipment is identified in each test.

2.2 Personnel

The test program is conducted by Pin-Wen (Maddie) Wang, Hongyi (Sam) Dong, Tzu-Cheng (Joshua) Tsai, Chenxi (Leo) Xu, and Po-Ting (Koko) Ko. Individual test tables identify the personnel responsible for setup, execution, monitoring, and data collection. All outdoor Husky tests require an operator to monitor vehicle behavior and maintain access to the joystick or emergency-stop control.

2.3 Location

Mission Manager and software-only tests are conducted in Newell-Simon Hall B506 or the AI Maker Space in Tepper. Indoor perception tests are conducted on Level B of Newell-Simon Hall. Outdoor perception, autonomous-navigation, redirection, investigation, and integrated-system tests are conducted in the area in front of Newell-Simon Hall and around Smith Hall. The FVD and FVD Encore use the same outdoor operating area. Specific device positions, geofences, loitering regions, patrol waypoints, and anomaly locations are defined during the applicable test setup.

3 Schedule

Table 1: Fall Semester Demonstration and Milestone Verification Plan

Event	Date	Milestones	Tests	Requirements
PR7	Sep 9	Create, edit, save, select, and reload patrol missions; generate and visualize lanelet-based routes.	T.P.01 T.P.02	F.R.4, F.R.5 M.F.2 M.F.4 M.N.1
PR8	Sep 23	Register and monitor the Husky and multiple IoT towers through Zenoh; detect skeletons and maintain persistent person IDs.	T.P.04 T.P.06	F.R.1, F.R.7 M.F.4 M.N.2
PR9	Oct 7	Construct map and demonstrate autonomous Husky navigation along a predefined patrol route; interrupt the patrol and redirect the Husky to the nearest reachable Lanelet2 position.	T.P.05 T.P.08	F.R.2–4, F.R.8 M.F.1–3
PR10	Oct 28	Use an anomaly heatmap to support waypoint placement; classify and localize lying-down, trespassing, and loitering anomalies; stream live video, record TRUE/FALSE and STAY/DISMISS decisions, and resume the interrupted patrol.	T.P.03 T.P.07 T.P.09	F.R.1, F.R.2, F.R.5–7, F.R.9 M.F.2–3, M.F.5 M.N.2–3
PR11	Nov 11	Conduct a full FVD dress rehearsal from mission selection and heatmap-assisted editing through anomaly investigation and patrol resumption.	T.P.10	F.R.1–9 M.F.2–5 M.N.1–3
FVD	Nov 16	Demonstrate the integrated autonomous security-patrol mission, including mission management, device monitoring, robot patrol, anomaly detection, live investigation, operator resolution, and patrol resumption.	T.P.10	F.R.1–9 M.F.2–5 M.N.1–3
FVD Encore	Nov 23	Repeat the complete FVD sequence and verification criteria.	T.P.10	F.R.1–9 M.F.2–5 M.N.1–3

4 Tests

T.P.01 - Mission Creation, Editing, Selection, and Persistence	
Objectives	
Verify that an operator can create and manage multiple patrol missions through the Mission Manager, including adding, deleting, and repositioning waypoints, configuring the mission loop count, saving missions to the database, selecting a mission for execution, and reloading previously saved missions for reuse.	
Equipment	Computer, Mission Manager software
Elements	Mission Manager (include software, backend, database, and map interface)
Personnel	Po-Ting Ko
Location	B506 Lab or AI Maker Space (AIMS Tepper)
Preconditions	• The Mission Manager frontend and backend are running. • The mission database is online and accessible. • The lanelet map is built, loaded and displayed correctly. • No mission is currently being executed by the robot.
Procedure	
1. Open the Mission Manager and create a new mission. 2. Add at least two waypoints to form a loop of the mission by selecting locations on the patrol map. 3. Drag and reposition the waypoints to new locations. 4. Delete waypoint and verify that it is removed from the mission. 5. Add a new waypoint after the deletion and verify that the waypoint sequence is updated correctly. 6. Set the mission loop count to a value greater than one. 7. Save the mission and verify that it appears in the saved-mission list. 8. Create and save at least two additional missions with different waypoint configurations and loop counts. 9. Switch between the saved missions and verify that the corresponding waypoint configuration and loop count are displayed. 10. Select one saved mission as the active mission. 11. Close and reopen the Mission Manager. 12. Reload the previously saved missions and verify that their configurations are preserved. 13. Edit one of the saved missions, save the changes, and reload the mission to verify persistence of the updated configuration.	
Verification Criteria	
1. Newly added waypoints appear on the map and are included in the mission waypoint sequence. 2. Dragged waypoints are updated to their new map locations and retain the correct waypoint ordering. 3. Deleted waypoints are removed from both the map display and the mission waypoint sequence. 4. The configured loop count is correctly associated with the corresponding mission. 5. Multiple missions can be created, saved, and displayed independently without overwriting one another. 6. Selecting a saved mission displays the correct waypoint configuration and loop count. 7. The operator can select one of the saved missions as the active mission. 8. After restarting the Mission Manager, 100% of the tested saved missions retain their waypoint locations, waypoint ordering, and loop counts. 9. Changes made to an existing mission remain persistent after saving and reloading the mission.	

Table 2: Mission Creation, Editing, Selection, and Persistence

T.P.02 - Patrol Route Generation and Visualization	
Objectives	
Verify that the Mission Manager can request a patrol route from the Map Server using an operator-defined waypoint sequence and present the generated lanelet-based route and associated mission information to the operator for review before mission execution.	
Equipment	Computer, Mission Manager software
Elements	Mission Manager (include software, backend, database), route-generation interface, pre-built lanelet map
Personnel	Po-Ting Ko
Location	B506 Lab or AI Maker Space (AIMS Tepper)
Preconditions	• The Mission Manager frontend and backend are running. • The Map Server is online and accessible from the Mission Manager. • The patrol map and corresponding lanelet map are loaded. • At least three test missions with different waypoint configurations are available. • The test waypoints are located within the supported operating area.
Procedure	
1. Create or load a mission containing at least two waypoints. 2. Request patrol-route generation from the Mission Manager. 3. Verify that the Mission Manager sends the ordered waypoint sequence to the Map Server. 4. Observe the route returned by the Map Server and displayed on the patrol map. 5. Verify that the generated route follows the lanelet network and connects the mission waypoints in the specified order. 6. Verify that the Mission Manager displays the calculated route distance and associated mission information. 7. Modify the location of at least one waypoint using the mission editor. 8. Regenerate the patrol route and verify that the route visualization and route distance are updated accordingly. 9. Repeat the route-generation process using at least three missions with different waypoint configurations.	
Verification Criteria	
1. The Map Server receives the complete waypoint sequence in the same order defined by the operator. 2. A patrol route is successfully generated and returned for each valid test mission. 3. The generated route connects all mission waypoints in the specified order without disconnected route segments. 4. The displayed route follows the permitted lanelet network and does not contain route segments outside the supported navigation area. 5. The generated patrol route is clearly displayed on the Mission Manager map for operator review. 6. The Mission Manager displays the route distance returned or calculated for the generated patrol route. 7. Modifying a waypoint and regenerating the route updates both the displayed patrol route and its associated route information. 8. All three tested mission configurations produce a route consistent with their respective waypoint sequences.	

Table 3: Patrol Route Generation and Visualization

T.P.03 - AI-Assisted Anomaly Heatmap	
Objectives	
Verify that the system can use historical patrol and anomaly-detection records to generate an anomaly heatmap, display the identified anomaly-prone regions on the Mission Manager map, and provide the heatmap as decision-support information for operators when defining future patrol missions.	
Equipment	Computer (running mission manger, database and inference model), Mission Manager software
Elements	Mission Manager (include frontend, backend, and database), AI/statistical heatmap-generation module, map interface
Personnel	Po-Ting Ko
Location	NSH B506 or AI Maker Space (AIMS Tepper)
Preconditions	• The Mission Manager frontend and backend are running. • The patrol map is loaded and displayed correctly. • The mission and anomaly database is online and accessible. • Historical anomaly-detection records with associated locations are available in the database. • The historical test data contains known regions with higher anomaly occurrence than surrounding regions. • The AI/statistical heatmap-generation module is operational. • The mission manager in the mission edit mode.
Procedure	
1. Open the Mission Manager and enter mission editing mode. 2. Enable the anomaly heatmap visualization. 3. Request heatmap generation using the available historical patrol and anomaly data. 4. Verify that the generated heatmap is overlaid on the patrol map. 5. Add or reposition a mission waypoint near the identified region using the mission editor. 6. Save the modified mission and reload it to verify that the heatmap-assisted waypoint modification is preserved. 7. Generate the patrol route for the modified mission and verify that the added or repositioned waypoint is included in the resulting patrol route.	
Verification Criteria	
1. The heatmap-generation module successfully processes the historical patrol and anomaly-detection records stored in the database. 2. The generated anomaly heatmap is correctly overlaid on the corresponding Mission Manager patrol map. 3. Regions containing higher concentrations of historical anomaly records are represented as higher-priority regions on the generated heatmap. 4. The operator can visually identify anomaly-prone regions from the heatmap while remaining in mission editing mode. 5. The heatmap does not prevent normal mission-editing operations, including adding, deleting, and repositioning waypoints. 6. A waypoint added or repositioned based on the heatmap is correctly stored as part of the selected mission. 7. The heatmap-assisted mission modification remains persistent after saving and reloading the mission. 8. The patrol route generated from the modified mission includes the waypoint added or repositioned near the identified anomaly-prone region.	

Table 4: AI-Assisted Anomaly Heatmap

T.P.04 - Multi-Device Registration and Status Monitoring	
Objectives	
Verify that multiple heterogeneous devices, including the mobile robot and IoT towers, can connect to the Mission Manager through Zenoh, be uniquely identified and registered, and provide real-time device information to the operator. Verify that the Mission Manager displays each device on the map and device list, provides detailed device information through the device inspector, and permits mission execution only when an applicable mobile robot is connected and available.	
Equipment	Husky mobile robot, IoT towers, Computer, and network communication
Elements	Mission Manager (include frontend and backend), Device Registry, Zenoh communication interface, Husky robot, IoT towers, map visualization, and video-streaming interface
Personnel	Po-Ting Ko
Location	In front of Newell-Simon Hall and around Smith Hall.
Preconditions	• The Mission Manager frontend and backend are running. • The Zenoh communication infrastructure is operational. • The Husky robot and IoT towers are powered on and capable of connecting to the Zenoh network. • Each device is configured with a unique device identifier and corresponding Zenoh key expression. • Devices capable of localization provide their current location. • Devices equipped with an available camera/video service are configured for video streaming. • At least one valid patrol mission is available for mission-execution testing.
Procedure	
1. Start the Mission Manager with the Husky robot and IoT towers disconnected and verify the initial device state. 2. Connect the Husky robot and multiple IoT towers to the Mission Manager through Zenoh. 3. Verify that each connected device is registered independently and appears in the Mission Manager device list with the correct device name and device type. 4. Verify that devices providing location information appear as separate device markers at their reported locations on the Mission Manager map. 5. Publish or update device status information, including available location, operating state, battery level, and connection state, and observe the corresponding updates in the Mission Manager. 6. Select each device from the device list and verify that the corresponding Device Inspector is opened. 7. Verify that the Device Inspector displays the status information associated with the selected device. 8. For a device with an available video stream, open the Device Inspector and verify that its live video is displayed. 9. Select a valid mission while the Husky robot is connected and available, and verify that mission execution can be initiated. 10. Disconnect the robot from the Zenoh network and observe the corresponding connection state in the Mission Manager. 11. Attempt to execute a mission while no applicable mobile robot is connected and verify that mission execution is prevented. 12. Reconnect the Husky robot and verify that its online status and latest device information are restored and mission execution becomes available again. 13. Disconnect and reconnect one IoT tower and verify that only the corresponding device status changes while the remaining registered devices continue to be displayed and monitored.	
Verification Criteria	
1. All connected test devices are uniquely registered and associated with the correct device identifier. 2. Status messages received through different device-specific Zenoh key expressions are associated with the correct registered devices without cross-device data assignment. 3. All registered devices appear independently in the Mission Manager device list. 4. Devices providing location information are displayed as individual markers on the Mission Manager map, and the displayed locations correspond to the latest locations reported by the respective devices. 5. Changes in device location, operating state, battery level, and connection state are reflected by the Mission Manager without requiring a manual dashboard refresh. 6. Selecting a device from either its map marker or the device list opens the Device Inspector for the correct device. 7. The Device Inspector displays the latest available status information for the selected device, including device identity, type, connection state, operating state, battery level, and location when provided. 8. For devices with an available video stream, it displays the video stream associated with the selected device. 9. A valid patrol mission can be initiated when an applicable mobile robot is connected and available. 10. Mission execution is prevented when no applicable mobile robot is connected and available. 11. Disconnecting one device changes the connection state of the corresponding device without incorrectly changing the identity or status of other registered devices. 12. After reconnection, the device is correctly recognized as the same registered device and its status monitoring resumes.	

Table 5: Multi-Device Registration and Status Monitoring

T.P.05 - Husky Autonomous Patrol Navigation	
Objectives	
Verify that the Husky robot can use its onboard sensors to construct its surroundings, perceive the environment, localize itself within the map, detect and avoid obstacles, plan collision-free paths through specified waypoints, generate appropriate motion-control commands, and autonomously execute the assigned patrol route.	
Equipment	Husky A200 mobile robot, NVIDIA Jetson Orin NX computer, Velodyne VLP-16 LiDAR, FIXPOSITION Vision-RTK 2 GNSS/IMU, joystick controller, operator laptop, network communication equipment
Elements	Autware autonomous driving stack, sensor drivers and interfaces, localization, map management, obstacle detection, path planning, waypoint following, vehicle control, collision avoidance, TF and coordinate transformation, and Husky vehicle interface.
Personnel	Joshua Tsai
Location	In front of Newell-Simon Hall and around Smith Hall.
Preconditions	• The Husky A200 robot and onboard computer are powered on and operational. • Required sensors are connected and publishing valid ROS 2 data. • The joystick is connected and functional for manual override of the Husky robot. • A valid map of the test environment is available and loaded. • A valid patrol route with predefined waypoints is available. • The emergency-stop mechanism is functional and accessible.
Procedure	
1. Power on the Husky robot, onboard computer, sensors, and joystick. 2. Use the joystick to manually drive the Husky robot to the designated starting position. 3. Launch the required ROS 2 and Autware modules. 4. Verify that the required sensor data and vehicle-state topics are available. 5. Construct point cloud map using recorded rosbag and draw corresponding lanelet2 map. 6. Load the map, initialize the robot pose, and verify that the localization estimate correctly represents the robot's position and orientation within the map. 7. Receive the predefined patrol waypoints and verify that all waypoints are valid and reachable by the robot. 8. Start autonomous patrol and verify that a collision-free path is generated through the predefined waypoints. 9. Verify that the robot publishes the correct system status throughout the test, including initialization, stopped, patrolling, and other defined operating states. 10. Introduce an obstacle along the planned route and verify that the robot detects the obstacle and stops before collision. 11. Verify that the robot generates appropriate control commands and follows the planned path. 12. Verify that the robot completes the full patrol route. 13. Activate both the physical emergency-stop button and the joystick emergency-stop command during autonomous patrol and verify that the Husky stops successfully.	
Verification Criteria	
1. The Husky, onboard computer, sensors, and joystick shall power on without hardware faults or unexpected shutdowns. 2. The Husky shall respond to forward, backward, and turning joystick commands and reach the designated starting area without loss of manual control. 3. All required ROS 2 and Autware nodes shall remain active after startup, with no node termination or critical launch errors. 4. All required sensor and vehicle-state topics shall continuously publish data during the test. 5. The localized LiDAR point cloud shall remain aligned with major map features, such as walls and boundaries, without visible persistent translation or rotation mismatch. 6. All received patrol waypoints are valid and reachable by the navigation system without triggering a planning failure. 7. A collision-free path connecting the required patrol waypoints shall be generated within 1 s after the waypoint route is received. 8. The published robot status shall change to the corresponding state within 0.5 s of the actual state transition. 9. When an obstacle is placed on the planned path, the Husky shall come to a complete stop at least 1 m before the obstacle. 10. The Husky shall reach every predefined patrol waypoint within 0.5 m of its target position and complete 100% of the assigned patrol route. 11. The Husky shall stop within 0.5 s after the emergency stop is activated and remain stationary until re-enabled.	

Table 6: Husky Autonomous Patrol Navigation

T.P.06 - Skeleton Detection and Person Tracking V2	
Objectives	
Verify that the IoT subsystem detects human skeletons and maintains persistent tracking IDs as people move through or are temporarily occluded within the monitored area.	
Equipment	DGX Spark, Intel RealSense D456 camera, tripod, monitor, and power bank.
Elements	IoT Subsystem
Personnel	Sam Dong
Location	• Indoor: Newell-Simon Hall, Level B. • Outdoor: Area between Newell-Simon Hall and Smith Hall.
Procedure	
1. Mount the Intel RealSense D456 camera on the tripod and position it to observe the desired monitoring area. 2. Connect the RealSense camera to the DGX Spark. Connect the DGX Spark to the power source and monitor, and verify that all required cables and devices are connected. 3. Power on the DGX Spark, enter the skeleton-detection Docker environment, and launch the ROS 2 skeleton-detection and person-tracking nodes. 4. Verify that the live camera stream and skeleton visualization are being displayed correctly on the monitor. 5. Skeleton Detection Test: Position one participant approximately 5 m from the camera. Have the participant perform a variety of normal body motions for approximately 30–60 seconds, including movements of the arms, legs, and torso. 6. Repeat the skeleton-detection test with the participant positioned approximately 10 m from the camera. 7. Repeat the skeleton-detection test with the participant positioned more than 20 m from the camera. 8. Record the camera frame rate, image resolution, person detections, and visualized skeleton keypoints during each distance condition. 9. Person Tracking Test: Position one participant seated in a chair approximately 5 m from the camera. Allow the tracker to detect the participant and assign a stable tracking ID. 10. Have a second participant walk between the camera and the seated participant such that the seated participant is temporarily occluded for no more than 3 seconds. 11. After the seated participant becomes visible again, record whether the tracker preserves or successfully recovers the participant’s original tracking ID. 12. Repeat the occlusion test ten times, using both left-to-right and right-to-left crossings where practical, and record the assigned tracking ID before and after each occlusion.	
Verification Criteria	
1. The system maintains a stable live camera stream of at least 50 FPS at a resolution of at least 640×480. 2. The participant is successfully detected and a skeleton is generated consistently at approximately 5 m, approximately 10 m, and greater than 20 m from the camera. 3. For sampled frames in which the participant is detected, at least 80% of the ground-truth visible and non-occluded COCO body keypoints are successfully detected and visualized. 4. While the seated participant remains continuously visible, the tracker maintains the same tracking ID without an ID switch for at least 90% of the visible tracking duration. 5. Following an occlusion lasting no more than 3 seconds, the seated participant is reassigned the same tracking ID that was present before the occlusion in at least 90% of the test trials.	

Table 7: Skeleton Detection and Person Tracking Version 2

T.P.07 - Anomaly Detection V2	
Objectives	
Verify that the Anomaly Detection Subsystem recognizes lying down, trespassing, and loitering events and reports the correct person and location.	
Equipment	All equipment used in T.P.06, including the DGX Spark, Intel RealSense D456 camera, tripod, monitor, and power bank, plus the lab machine and lab-machine monitor.
Elements	IoT Subsystem, Anomaly Detection Subsystem
Personnel	Sam Dong, Po-Ting Ko
Location	• Indoor: Newell-Simon Hall, Level B. • Outdoor: Area between Newell-Simon Hall and Smith Hall.
Preconditions	T.P.06 – Skeleton Detection and Person Tracking V2 has been successfully completed.
Procedure	
1. Assemble and power the IoT subsystem using the same hardware configuration validated in T.P.06. 2. On the DGX Spark, launch the ROS 2 skeleton-detection and person-tracking nodes. 3. Launch the Zenoh communication process on both the DGX Spark and the lab machine and verify that communication between the two computers is active. 4. On the lab machine, launch the anomaly-detection node and verify that tracked-person information is received by the anomaly-detection subsystem. 5. Lying-Down Detection Test: Position one participant approximately 10 m from the camera and have the participant transition from a normal standing or walking posture to a lying-down posture. 6. Repeat the lying-down test with the participant positioned approximately 45° to the left and 45° to the right of the camera optical axis while maintaining an approximate distance of 10 m. 7. Trespassing Detection Test: Configure an approximately 10 m × 10 m region in the anomaly-detection system as a protected geofence. 8. Have one participant begin outside the protected region and walk across the configured geofence boundary into the protected region. Record whether a trespassing anomaly is generated after the participant crosses the boundary. 9. Loitering Detection Test: Have one participant remain within the 5 m × 5 m configured loitering area for more than 60 seconds while standing, walking slowly, or moving naturally within the region. 10. Perform control trials in which the participant remains within the region for less than 60 seconds and then exits.	
Verification Criteria	
1. Lying-down anomaly detection achieves an F1 score of at least 90% across all tested viewing angles. 2. Trespassing anomaly detection achieves an F1 score of at least 90% when distinguishing protected-region entry from legal movement outside the geofence. 3. Loitering anomaly detection achieves an F1 score of at least 90% when distinguishing stays longer than the configured 60-second threshold from short-duration stays. 4. At least 90% of correctly detected anomaly events are associated with the correct persistent tracking ID. 5. At least 90% of reported anomaly locations are within 1.5 m of the measured ground-truth participant location. 6. For lying-down and trespassing events, at least 90% of correctly detected anomalies are reported within 5 seconds after the anomaly condition is satisfied. 7. For loitering events, at least 90% of correctly detected anomalies are reported within 5 seconds after the configured 60-second loitering threshold is reached. 8. Normal activities that do not satisfy the defined lying-down, trespassing, or loitering conditions do not produce persistent false anomaly alerts.	

Table 8: Anomaly Detection Version 2

T.P.08 - Anomaly-Triggered Robot Redirection	
Objectives	
Verify that the Husky robot interrupts its current patrol task after an anomaly is confirmed and redirects to the nearest valid reachable position on the Lanelet2 map.	
Equipment	Husky A200 mobile robot, NVIDIA Jetson Orin NX computer, Velodyne VLP-16 LiDAR, FIXPOSITION Vision-RTK 2 GNSS/IMU, operator laptop, network communication equipment
Elements	Anomaly detection subsystem, patrol scheduler, Lanelet2 map, route planning, localization, vehicle control, and robot status interface.
Personnel	Sam Dong, Joshua Tsai, Po-Ting Ko
Location	In front of Newell-Simon Hall and around Smith Hall.
Preconditions	• The Husky is localized and executing an autonomous patrol route. • The Lanelet2 map is loaded and available to the navigation system. • Anomaly detection has successfully detected and reported a valid anomaly location. • Required Autoware and ROS 2 modules are active.
Procedure	
1. Start the Husky autonomous patrol using a predefined patrol route and confirm that the navigation system enters the patrol state. 2. Trigger or provide a confirmed anomaly with a valid location referenced to the current map. 3. Verify that the anomaly information is received and that the current patrol task is interrupted accordingly. 4. Verify that the robot state changes from PATROLLING to the defined anomaly-response state after the anomaly is confirmed. 5. Identify and set the nearest valid and reachable Lanelet2 position corresponding to the reported anomaly location. 6. Verify that a new collision-free route is generated from the robot's current position to the selected anomaly destination. 7. Verify that the Husky leaves the original patrol route and follows the newly generated route toward the anomaly location. 8. Verify that the Husky reaches the selected Lanelet2 position near the reported anomaly and completes the redirection task.	
Verification Criteria	
1. The Husky shall enter the PATROLLING state and begin following the predefined patrol route. 2. The reported anomaly shall include a valid location referenced to the current map. 3. The anomaly message shall be received without error, and the current patrol task shall be interrupted within 1 s after confirmation. 4. The robot state shall change from PATROLLING to the defined anomaly-response state within 1 s after the anomaly is confirmed. 5. The selected redirection target shall be the nearest valid and reachable Lanelet2 position to the reported anomaly location, with no planning failure reported. 6. A new collision-free route from the robot's current position to the selected anomaly destination shall be generated within 1 s. 7. The Husky shall stop following the original patrol route and begin following the newly generated redirection route. 8. The Husky shall reach the selected Lanelet2 target within 0.5 m of the commanded destination and complete the redirection task without collision or navigation failure.	

Table 9: Anomaly-Triggered Robot Redirection

T.P.09 - Live Investigation and Patrol Resumption	
Objectives	
Verify that the Husky robot can orient its front camera toward the anomaly, provide a live video stream to the Mission Manager, process operator investigation decisions, record confirmed anomaly events in the Mission History database, and either remain at the inspection location or resume the interrupted patrol.	
Equipment	Husky A200 mobile robot, NVIDIA Jetson Orin NX computer, Velodyne VLP-16 LiDAR, FIXPOSITION Vision-RTK 2 GNSS/IMU, operator laptop, network communication equipment, Computer, Mission Manager software
Elements	Mission Manager, camera streaming interface, robot control, robot status interface, patrol scheduler, route planning, localization, Mission-history database
Personnel	Po-Ting Ko, Joshua Tsai
Location	In front of Newell-Simon Hall and around Smith Hall.
Preconditions	• The Husky has reached the anomaly inspection location. • The anomaly location and direction are available to the robot. • The camera and video-streaming interface are operational. • The interrupted patrol route and next patrol waypoint are retained.
Procedure	
1. Verify that the Husky has reached the anomaly inspection location and stopped before beginning the investigation. 2. Determine the direction from the robot to the reported anomaly location, then rotate the Husky in place until the front-facing camera is oriented toward the anomaly. 3. Start the camera live stream and verify that the video is displayed in the Mission Manager. 4. Verify that the robot state changes to the defined investigation state while the live investigation is active. 5. From the Mission Manager, classify the detected anomaly as either TRUE or FALSE and verify that the decision is received by the system. 6. Verify that both TRUE and FALSE investigation results are stored in the Mission History database and that TRUE results are marked as confirmed anomalies. 7. Select STAY as the operator action and verify that the Husky remains at the inspection location while continuing the live video stream. 8. Select DISMISS as the operator action and verify that the camera live stream is stopped. 9. Verify that the Husky rotates in place to restore its original heading before the anomaly investigation. 10. Verify that the robot state changes back to the patrol state after the investigation is dismissed. 11. Verify that the Husky navigates to the next waypoint of the interrupted patrol route and continues autonomous patrol.	
Verification Criteria	
1. The Husky shall remain stationary at the anomaly inspection location before the investigation begins. 2. The Husky shall rotate until the front-facing camera is oriented toward the reported anomaly location. 3. The camera live stream shall be displayed in the Mission Manager within 1 s after streaming is activated. 4. The robot state shall change to the defined investigation state within 0.5 s after the live investigation begins. 5. The selected TRUE or FALSE classification shall be received by the system without communication failure. 6. Both TRUE and FALSE investigation results shall be stored in the Mission History database, and TRUE results shall be marked as confirmed anomalies. 7. When STAY is selected, the Husky shall remain stationary at the inspection location and the live video stream shall continue without interruption. 8. When DISMISS is selected, the camera live stream shall stop within 1 s. 9. The Husky shall restore its pre-investigation heading within 5° before patrol resumption. 10. The Husky shall maintain valid localization and map alignment throughout the in-place rotation without localization loss or reset. 11. The robot state shall return to PATROLLING within 2 s after the Husky restores its pre-investigation heading. 12. The Husky shall navigate to the next waypoint of the interrupted patrol route and resume autonomous patrol.	

Table 10: Live Investigation and Patrol Resumption

T.P.10 - Fall Validation Demonstration	
Objectives	
Validate the complete system by demonstrating an autonomous security-patrol mission from mission selection through anomaly detection, robot investigation, operator decision, and patrol resumption.	
Equipment	Fully integrated Husky patrol robot (Orin, LiDAR, Camera, IMU/GNSS), One or more IoT towers (DGX Spark, Camera, Power Bank), Mission Manager Computer
Elements	IoT Subsystem, Husky Robot Subsystem, Anomaly Detection Subsystem, Mission Manager Subsystem
Personnel	Pin-Wen (Maddie) Wang, Hongyi (Sam) Dong, Tzu-Cheng(Joshua) Tsai, Chenxi (Leo) Xu, Po-Ting (Koko) Ko
Location	In front of Newell-Simon Hall, around Smith Hall
Preconditions	• The robot and IoT towers are online and their positions are located on the map.. • The patrol map and permitted lanes are loaded. • Network connectivity is verified. • A predefined mission has been saved. • There is mission history in the database.
Procedure	
1. The operator opens the dashboard and loads a saved mission containing multiple patrol waypoints. 2. The operator edits the mission based on AI generated heatmap. 3. The system generates route, and starts the mission after operation confirmation. 4. The robot autonomously follows the route while the dashboard displays robot mission status and all device status. 5. A participant enters the monitored area and performs the selected anomaly scenario. 6. The system detects and tracks the participant, identifies the anomaly and displays an alert. 7. The mission manager redirects the robot to the anomaly location. 8. The robot autonomously reaches the designated observation location and displays the robot's live camera stream for visual verification. 9. The operator verifies the event as either confirmed or false, then, dismisses/resolves the alert. 10. The robot resumes its interrupted patrol and completes the remaining waypoints.	
Verification Criteria	
1. Mission loading and editing: The saved mission loads within 5 seconds, displays 100% of its saved waypoints, and reflects all operator edits based on the AI heatmap within 2 seconds. 2. AI heatmap: The heatmap appears within 10 seconds, covers at least 95% of the designated patrol area, and enables the operator to add, remove, or reposition at least one waypoint. 3. The route is generated within 1s after confirmation, includes 100% of the selected waypoints. 4. The robot reaches 100% of the patrol waypoints with zero collisions and zero safety interventions. 5. The dashboard displays each devices status with refresh rate of 2hz. 6. The participant is detected within 50ms of entering the monitored area, and the same tracking ID is maintained for at least 90% of the participant's visible trajectory. 7. The 3 selected anomaly, including lying down, trespassing, loitering, is correctly classified with f1 score greater than 90, localized within 1.5 m of ground truth, and displayed as an alert greater than 5 seconds of satisfying the defined anomaly condition. 8. The robot begins executing the investigation route within 5 seconds of alert generation and reaches the closest lanelet point next to observation site within 1.0 m. 9. The live stream appears within 5 seconds after arrival and the system records the event within 3 seconds upon operator confirmation.	

Table 11: Fall Validation Demonstration

Appendix A: System Requirements

Table 12: Functional Requirements

ID	Function	Requirement description
F.R.1	Detect anomalies	Identify security anomalies, including lying down, loitering, and trespassing.
F.R.2	Enable robot patrol	Support autonomous robot patrol along predefined routes.
F.R.3	Avoid obstacles	Detect and navigate around static and moving obstacles to avoid collisions.
F.R.4	Generate paths	Generate a collision-free path to specified goals within the lanelet network.
F.R.5	Receive waypoints	Let users enter or select waypoints for the robot.
F.R.6	Suggest waypoints	Recommend waypoints using an AI model and historical data.
F.R.7	Visualize patrol	Show the robot’s current position and patrol progress on the dashboard map in real time.
F.R.8	Redirect robot	Change the robot’s destination in response to an emergency alarm.
F.R.9	Verify alarms	Let users confirm or dismiss detected alarms and anomalies.

Table 13: Mandatory Functional and Performance Requirements

Function ID	Performance ID	Requirement
M.F.1		Build maps.
	M.P.1.1	After loop closure produces at least one loop edge, improve global map consistency without structural misalignment.
	M.P.1.2	Remove 100% of dynamic objects and outliers from the final map, reducing wall misalignment to at most 15%.
M.F.2		Plan a collision-free path within lanelet.
	M.P.2.1	Keep planned paths inside lanelet.
	M.P.2.2	Produce a collision-free path within 5 seconds.
M.F.3		Patrol along the planned path.
	M.P.3.1	Limit lateral overshoot to 10% of the step offset.
	M.P.3.2	At a constant speed of 1.5 m/s, keep steady-state cross-track error below 5 cm.
M.F.4		Support user interaction.
	M.P.4.1	Establish the connection automatically within 30 seconds of robot-system launch.
	M.P.4.2	Send waypoints to the ROS 2 stack within 50 ms of the operator pressing Publish.
	M.P.4.3	Notify the operator within 50 ms of robot-stack shutdown.
M.F.5		Detect anomaly
	M.P.5.1	Detect anomaly actions, lying down, trespassing, loitering with F1 score $\geq 90\%$.

Function ID	Performance ID	Requirement
	M.P.5.2	Notify user with anomaly action alert once detected within 2 seconds.

Table 14: Non-Functional Requirements

ID	Requirement
M.N.1	Allow operators without robotics expertise to configure a patrol.
M.N.2	Display timely warnings and status updates so operators can monitor system conditions.
M.N.3	Colored UI waypoints to show users if the point is AI-suggested or manually added.