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A-Maze-Eng MARV

Qualification Test Procedures for Subsystem Specifications

ELO320 / ERD320 / EWE320

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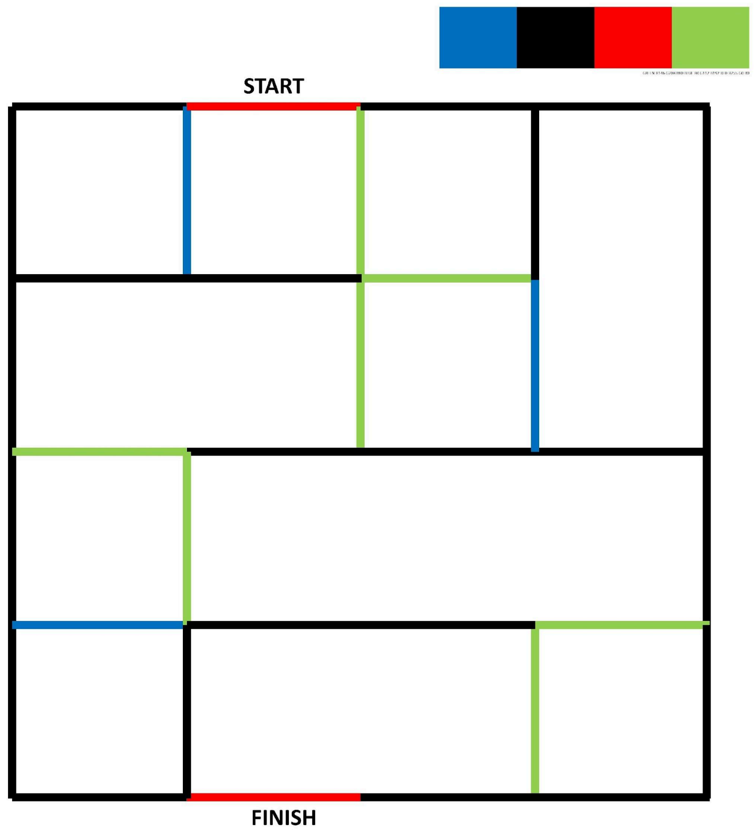

Contents

1. Introduction

The Qualification Test Procedures (QTPs) for each subsystem's specifications are set out in this document and must be read in conjunction with the Project Guide to an AMazeEng MARV. Each subsystem has a table listing the test equipment required, the test environment and the test setup. This is followed by the QTP table stating for each test the specifications tested, the test procedure and the pass requirements. The QTPs are designed so that each subsystem is evaluated independently of the other two subsystems by connecting the subsystem to be tested to the HUB which will then emulate the other two subsystems according to the SCS state diagram and control command library within the project guide. The QTPs will be conducted during the individual demonstrations of project phases 2 and 3. However, because of time constraints, each subsystem will most probably only be evaluated on selected QTPs. The evaluator will decide which tests to complete.

The QTPs have been designed such that the HUB will automatically give error messages at, for example, points within the state diagram where the subsystem being tested does not transmit the expected or correct data packets. This will assist students in debugging their subsystems and provide the evaluators with the means to determine which functions within the subsystem are operating to what extent. It is therefore imperative that students ensure that their subsystems are designed and implemented according to the specifications so that it can be tested as described in this document. Students will be expected to test their subsystems without the HUB by transmitting the other subsystems' data packets via a terminal, or even by writing small python scripts that send data packets in accordance with the SCS state diagram and control library. This is effectively the principle on which the HUB has been developed.

If a group delivers a complete integrated system capable of successfully navigating a maze at the final demonstration, it will of course imply that the subsystems are functional and hence rigorous qualification testing will not be required. However, after having demonstrated the integrated system on a maze, at least one QTP might be conducted per subsystem via the HUB to ensure the system adheres to the SCS design specifications. It is therefore very important that the USB communication ports of the subsystems are easily accessible to quickly connect the individual subsystems to the HUB.

2. State-and-Navigation Control (SNC) subsystem qualification tests

Table 1 provides the test equipment, environment and setup for all the tests and Tables 2 and 3 the qualification tests and procedures that need to be performed to demonstrate that the SNC adheres to the relevant design specifications as mentioned in Sections 6b and 9b of the project guide. The relevant design specifications must be met to ensure the SNC functions as intended within the system.

Table 1: Test equipment, environment and setup for all QTPs

Test Equipment	1. The SNC subsystem. 2. DC measuring equipment, such as a multi-meter. 3. Smartphone with "dB Sound Meter and Noise Detector – Decibel Level" app from Micro Inc installed to measure dB levels. 4. Personal computer or laptop with the HUB software installed.
Test Environment	1. Laboratory conditions (ABC or Heavy Machines lab).
Test Setup	1. Connect the power supply to the subsystem circuitry 2. Switch the system on and wait for the subsystem to complete its start-up sequence. 3. Connect the subsystem to the HUB through serial communication as will be outlined in the HUB user manual. 4. Enter the following design parameters into the HUB GUI as defined in Appendix B of the project guide: a. Inter sensor distances sd1, sd2, sd3 and sd4. b. Distance between the sensor array and wheel axis "A"

Table 2: Qualification tests for the SNC excluding Specification 6 - Navigation Control.

QT Number	Specification The SNC must…	Test Procedure	Pass criteria
1 Power Supply	1. The subsystem must be able to function using one, or a combination of, the following input voltages, with a tolerable variation of 5 %: a. 3.3 V b. 5 V c. 9 V	1. Connect Test Setup. 2. Verify the supply rail voltage of the subsystem to be 3.3V, 5V or 9V by measurement or inspection. 3. Activate the touch sensor (1st Touch) to transition into CAL state. 4. Measure the current drawn from the supply rail. 5. Repeat the test for all supply rails used by the subsystem.	1. The supply rail values are 3.3V, 5V or 9V, to within 5% tolerance.
2 Touch sensor state transition and critical diagnostic display	2. Adhere to the standard communications protocol as stipulated in the SCS. 3. Manage and communicate all state transitions as indicated in the project guide Figure 3 and Table 1. 4. Await end-of-calibration (EoC) signals from the SS and MDPS within the CAL state before displaying all the critical system diagnostics and allowing a 2nd touch of the touch sensor to transition the system from the CAL to the MAZE state. 7. Receive and then display the following critical system diagnostic data using a web or smartphone application, an LCD screen or seven-segment displays (SSD), according to the display requirements as set out in the PEC documentation.	1. Connect the test setup. 2. On the HUB GUI, select SNC and execute QTP2. 3. Verify that the onboard display and HUB GUI indicates IDLE state. 4. Activate the touch sensor (1st Touch) to transition into CAL state. 5. Verify that the onboard display and HUB GUI indicates CAL state. 6. Verify that the SNC displays the Sensor Colours as transmitted from the HUB. 7. Activate 2nd Touch for transition into MAZE state. 8. Verify that the SNC displays all the critical diagnostics as transmitted from the HUB including MAZE state[1]. 9. Activate 3rd Touch to transition back into IDLE state. 10. Verify that the onboard display and HUB GUI indicates IDLE state. **When a touch is required, the HUB will indicate '*Click 'Touch' to manually bypass.*' This will only work if the SNC is not transmitting. It is not meant to bypass the touch sensor.**	1. The SNC must display only IDLE at startup. 2. The SNC correctly transitions to and indicates the CAL state after the 1st touch sensor activation. 3. The display correctly indicates the CAL state and correctly displays the following critical system diagnostics after calibration completion: i. Present system state. ii. Colour detected by each sensor. 4. The SNC correctly transitions to MAZE state after the 2nd touch activation and correctly displays all critical system diagnostics: i. Colour detected by each sensor. ii. Present system state. iii. MARV last executed rotation angle [degrees]. iv. Tangential wheel speeds in [mm/s]. v. MARV distance covered in [mm]. vi. Incidence angle in degrees [degrees]. 5. The SNC transitions to and indicates only IDLE state after the 3rd touch activation.

[1] During tests, compare all HUB and SNC communication on the Hub GUI with the relevant QTP flow diagram to monitor the test execution. Appropriate error messages will be shown in the Hub GUI status window to indicate where in the process errors might have occurred. The Hub will also indicate when a test is complete.

QT Number	Specification The SNC must…	Test Procedure	Pass criteria
3 **Pure tone detection**	6. Detect a pure tone at the frequency as per your group number and react only when the volume is 60 dB_{SPL} or higher at the microphone. Upon detection of two tones, each having a duration of between 0.5 s and 1.0 s, within 2 seconds from each other, the system must transition from MAZE into the SOS state and remain until another set of two tones is detected.	1. Connect the test setup. 2. On the HUB GUI, select SNC and execute QTP3 3. Put the system into MAZE state. 4. Place the smartphone with the sound meter app as close as possible to the Pure Tone sensor to monitor all dB_{SPL} levels. 5. Play two pure tones in succession at 55 dB_{SPL} at the group's specified frequency and verify on the SNC display and HUB GUI that the system remains in MAZE state. 6. Play two pure tones in succession at 65 dB_{SPL} at one of the other specified frequencies and verify on the SNC display and HUB GUI that the system remains in MAZE state. 7. Play two pure tones in succession at 65 dB_{SPL} at the group's specified frequency and verify on the SNC display and HUB GUI that the system transitioned into SOS state. Verify that the system only responds after the second tone. 8. Play two pure tones in succession at 55 dB_{SPL} at the group's specified frequency and at 65 dB_{SPL} at one of the other specified frequencies and verify on the SNC display and HUB GUI that the system remains in SOS state. 9. Play two pure tones in succession at 65 dB_{SPL} at the group's specified frequency and verify on the SNC display and HUB GUI that the system returned to MAZE state. Verify that the system only responds after the second tone.	1. The SNC must remain in MAZE state after two tones below 60 dB_{SPL} at the specified frequency or any other frequency above 60 dB_{SPL}. 2. The SNC must transition into the SOS state after two tones at the specified frequency above 60 dB_{SPL}. 3. The SNC must remain in the SOS state after two tones below 60 dB_{SPL} at the specified frequency or any other frequency above 60 dB_{SPL}. 4. The SNC must transition back into the MAZE state after two tones at the specified frequency above 60 dB_{SPL}.

Table 3: Qualification tests for the SNC – Specification 6 Navigation Control. Specification numbers in the table correspond to the specification numbers in Section 9b of the project guide.

QT Number	Specification	Test Procedure[2]	Pass criteria
1 **Traverse Green/Red at $\theta_i \leq 5°$**	3. The MARV must stop before changing direction or turning (rotating) 4. The MARV may not traverse (cross) a green or red line with an incidence angle of $\theta_i > 5°$. If the MARV encounters a green line at an angle of $5° < \theta_i \leq 45°$, it must reverse, apply steering correction, and re-attempt traversing the line.	1. Connect Test Setup. 2. Continue only if SNC QTP2 was successful. 3. On the HUB GUI, select NAVCON and execute QTP1. 4. Put the SNC into MAZE state with two touches of the touch sensor. 5. The HUB will automatically complete the rest of the QTP first emulating detection of GREEN at $5° < \theta_i \leq 45°$ followed by emulating RED detected at $\theta_i \leq 5°$ and indicate the status of the tests in the HUB GUI status window.	1. The MARV must stop before changing direction or rotating. 2. The MARV must cross RED or GREEN at $\theta_i \leq 5°$ when the line is encountered at $5° < \theta_i \leq 45°$. 3. The MARV must cross RED or GREEN without rotating when the line is encountered at $\theta_i \leq 5°$.
2 **Detecting Green/Red at $\theta_i > 45°$**	5. If in going forward the MARV detects a green or red line at an incidence angle $\theta_i > 45°$, the MARV must reverse and apply steering correction through a single rotation of $\leq 5°$ toward the line. This process (forward, detect, reverse, rotate) must repeat until $\theta_i \leq 45°$ at which point specification 4 must be adhered to.	1. Connect Test Setup. 2. Continue only if SNC QTP2 was successful. 3. On the HUB GUI, select NAVCON and execute QTP2. 4. Put the SNC into MAZE state with two touches. 5. The HUB will automatically complete the rest of the QTP emulating detecting GREEN on one side at $\theta_i > 45°$ such that more than one steering correction is required. 6. The HUB will then automatically repeat step 5 detecting RED on the other side.	1. Upon detecting GREEN or RED on the **left** at $\theta_i > 45°$, the MARV must apply multiple course corrections of ≤ 5° **toward** the line. 2. Upon detecting GREEN or RED on the **right** at $\theta_i > 45°$, the MARV must apply multiple course corrections of ≤ 5° **toward** the line.

[2] During all tests, compare all Hub and SNC communication on the Hub GUI with the relevant QTP flow diagram to monitor the test execution. Appropriate error messages will be shown in the Hub GUI status window to indicate where in the process errors might have occurred. The Hub will also indicate when a test is complete.

QT Number	Specification	Test Procedure	Pass criteria
3 **Detecting Blue/Black at** $\theta_i < 45°$	1b) Only two sensors are allowed to cross a black or blue line to determine the angle of incidence. 6. The following sequence must be applied when encountering a black or a blue line at an incidence angle of $\theta_i \leq 45°$ after the MARV has been driving forward. The MARV must: a) Reverse, b) Apply a $90° \pm \theta_i$ RIGHT turn to move forward parallel to the black/blue line on its left, c) Continue moving forward, d) If, after having turned right, the MARV detects a green line OR no line, it must keep on driving forward, e) If, after having turned right, the MARV, detects a blue OR a black line BEFORE detecting a green line, it must: i. Reverse; ii. Apply $180° \pm \theta_i$ turn (LEFT or RIGHT) to move forward parallel to the black/blue line on its right; iii. Drive forward.	1. Connect Test Setup. 2. Continue only if SNC QTP2 was successful. 3. On the HUB GUI, select NAVCON and execute QTP3. 4. Put the SNC into MAZE state with two touches. 5. The HUB will automatically complete the rest of the QTP emulating: a. a RIGHT turn (≤90°) on detecting BLUE/BLACK followed by GREEN and WHITE followed by another RIGHT turn (≤90°) on detecting BLUE/BLACK. b. crossing GREEN followed by a RIGHT turn (≥90°) on detecting BLUE/BLACK followed by a $180° \pm \theta_i$ turn on detecting BLUE/BLACK followed by WHITE as required by specification 6e.	**For part (a) a RIGHT turn ≤ 90°:** 1. Upon detecting BLUE/BLACK, the MARV must turn RIGHT such that the line is parallel to the MARV on the left. 2. The MARV must then drive forward and cross GREEN. 3. After GREEN, the MARV must again turn RIGHT upon detecting BLACK/BLUE and **not** turn 180°. **For part (b) a RIGHT turn ≥ 90°:** 4. Upon detecting BLUE/BLACK after a 2nd GREEN crossing, the MARV must turn RIGHT such that the line is parallel to the MARV on the left. 5. This will be followed by another BLACK/BLUE line where the MARV must turn $180° \pm \theta_i$ and then continue forward.
4 **Detecting Blue/Black at** $\theta_i > 45°$	7. If in going forward the MARV detects a black or blue line at an incidence angle $\theta_i > 45°$ the MARV must reverse and apply steering correction through a single rotation of ≤ 5°. This process (forward, reverse, rotate) must repeat until the MARV steers clear of the wall (black) or closed door (blue).	1. Connect Test Setup. 2. Continue only if SNC QTP2 was successful. 3. On the HUB GUI, select NAVCON and execute QTP4. 4. Put SNC into MAZE state with two touches. 5. The HUB will automatically complete the rest of the QTP emulating detecting BLACK or BLUE on one side at $\theta_i > 45°$ such that more than one steering correction is required. 6. Repeat step 5 detecting BLUE or BLACK on the other side.	1. Upon detecting BLACK/BLUE on the **left** at $\theta_i > 45°$, the MARV must apply multiple course corrections of ≤ 5° **away** from the line. 2. Upon detecting BLUE/BLACK on the **right** at $\theta_i > 45°$, the MARV must apply multiple course corrections of ≤ 5° **away** from the line. 3. The MARV must perform a successful 90° rotation after the 2nd correction sequence when detecting a BLUE/BLACK line.
5 **End-of-Maze**	8. If the MARV crosses red (exit), the maze is solved and the MARV must transition into the IDLE state.	1. Connect Test Setup. 2. Continue only if SNC QTP2 was successful. 3. On the HUB GUI, select NAVCON and execute QTP5. 4. Put SNC into MAZE state with two touches. 5. The HUB will automatically complete the rest of the QTP emulating detecting and crossing RED.	1. Upon detecting RED the MARV must cross the line. 2. On receipt of the EoM from the eSS, the SNC must not transmit or transition into IDLE state.

3. Sensor (SS) subsystem qualification tests

Table 4 provides the test equipment, environment and setup for all the tests and Table 5 the qualification tests and procedures that need to be performed to demonstrate that the subsystem adheres to the relevant design specifications as mentioned in Section 7b of the project guide. The relevant design specifications must be met to ensure the Sensor subsystem functions as intended within the system.

Table 4: Test equipment, environment and setup for all QTPs

Test Equipment	1. The Sensor subsystem. 2. Stopwatch or timer. 3. DC measuring equipment, such as a multi-meter. 4. Printed A4 sized protractor provided on the last page. 5. Ruler. 6. Personal computer or laptop with the HUB software installed. 7. Long USB cable between the computer and SS
Test Environment	1. Laboratory conditions (ABC or Heavy Machines lab).
Test Setup	1. Apply the required supply rails to the subsystem. 2. Switch the system on and wait for the subsystem to complete its start-up sequence. 3. Connect the subsystem to the HUB through serial communication as will be outlined in the HUB user manual. 4. Enter the following design parameters into the HUB GUI as defined in Appendix B of the project guide: a. Inter-sensor distances sd1, sd2, sd3 and sd4.

Table 5: Qualification tests for the Sensor subsystem

QT Number	Specification	Test Procedure[3]	Pass criteria
1 Power Supply and Sensor Array	1. Be able to function using one, or a combination of, the following input voltages, with a tolerable variation of 5%: a. 3.3 V b. 5 V c. 9 V 3. Have three (3) colour sensors in the sensor array. The sensors must be in a straight array, parallel to the wheel axis.	1. Connect Test Setup. 2. Verify the supply rail voltage of the subsystem to be 3.3V, 5V or 9V by measurement or inspection. 3. On the HUB GUI, select "Sensor" and then execute QTP1. 4. Measure the current drawn from the supply rail. 5. Repeat the test for all supply rails used by the subsystem. 6. Visually inspect the sensor array.	1. The supply rail values are 3.3V, 5V or 9V, to within 5% tolerance. 2. There must be three sensors in a straight line parallel to the wheel axis.
2 Calibration	2. Communicate with the SNC or HUB using the standard communication protocol as stipulated in the SCS. 5. Communicate the colour being detected by each sensor to the SNC or HUB when the calibration is completed. 6. Visually depict the colour of each sensor in the array in real-time. 7. Implement the states and transition between operating states as set out in the SCS. 8. Calibrate within 60 seconds and send an end-of-calibration (EoC) signal to the SNC or HUB.	1. Connect Test Setup. 2. On the HUB GUI, select "Sensor" and then execute QTP2. 3. Verify on the HUB GUI that the SS is not transmitting data. 4. Click "Touch" on the eSNC[4], a timer will be started on the HUB. 5. Verify the timer as soon as all 3 colours have been calibrated and the calibration readings have been received and displayed on the eSNC. 6. Place the sensor array on each of the four lines and on WHITE and visually verify that the SS displays all 3 colours correctly on its on-board display. 7. Click the "Touch" on the HUB GUI to transition from CAL into MAZE state. 8. The HUB will automatically verify that the SS transmitted the two MAZE state packages indicating the result in the status window.	1. The SS does not transmit data at start-up. 2. The SS displays and transmits the correct detected colours to the HUB after calibration. 3. The SS calibrates in under 60 seconds. 4. The SS successfully transitions from IDLE to CAL to MAZE states.

[3] During all tests, compare all Hub and SS communication on the Hub GUI with the relevant QTP flow diagram to monitor the test execution. Appropriate error messages will be shown in the Hub GUI status window to indicate where in the process errors might have occurred. The Hub will also indicate when a test is complete.

[4] eSNC = emulated SNC on the HUB GUI.

QT Number	Specification	Test Procedure	Pass criteria
3 **Colour Detection**	2. Communicate with the SNC or HUB using the standard communication protocol as stipulated in the SCS. 4. Be able to detect and classify the following colours as printed on the maze test block: White, Black, Red, Green, Blue. 6. Visually depict the colour of each sensor in the array in real-time.	1. Complete the execution of QTP2 which puts the SS in MAZE state and then execute QTP3 on the HUB GUI. 2. Place the sensor array in the centre of the test block at approximately 45° toward the blue and red lines facing the corner. 3. Slowly move the sensor array forward while visually confirming the change in colours from white-to-blue/red-to-white on the SS onboard display and HUB GUI as the array crosses the lines. 4. Repeat steps 2 and 3 with the array facing and crossing the red and green lines at 45° 5. Repeat steps 2 and 3 crossing the green and black lines at 45°. 6. Repeat steps 2 and 3 crossing the black and blue lines at 45°. 7. Click "Continue" to terminate the QTP.	1. The SS classifies white, blue, red, green or black correctly on the applicable sensors, both on the SS display and the HUB GUI, for each of the four directions.
4 **Incidence Angle**	2. Communicate with the SNC or HUB using the standard communication protocol as stipulated in the SCS. 4. Be able to detect and classify the following colours as printed on the maze test block: White, Black, Red, Green, Blue. 9. Determine the angle of incidence within a 5° accuracy and communicate the result to the SNC or HUB adhering to the formatting requirements as stipulated in the PEC documentation.	1. Complete the execution of QTP3. 2. On the HUB GUI, select "Sensor" and then execute QTP4. 3. Place sensor S3 in FRONT of (not on) the BLUE, BLACK or GREEN line with the array at an incidence angle of $5° < \theta_i < 45°$. The evaluator will state which colour and at what angle at the evaluation. 4. Click 'Continue' and then start moving the array forward until the HUB indicates that the line has been detected. 5. Measure and enter the distance, in mm, between S2 and the line, in the direction of travel, into the eMDPS[5] and click "Continue" on the HUB GUI. 6. Move the array forward until the HUB indicates that the middle sensor (S2) detected the line. 7. Verify that the correct colours are displayed on the SS and the eSNC. 8. Compare the θ_i communicated to the HUB with the actual θ_i of step 3 9. Repeat from steps 3 with a different colour line on the left of the sensor array thus using the two leftmost sensors (S1 and S2). All instructions are given in the HUB status window. Please just read and follow it.	1. The SS measures and transmits an incidence angle within a 5° accuracy for $5° < \theta_i < 45°$ on the **right**. 2. The SS measures and transmits an incidence angle within a 5° accuracy for $5° < \theta_i < 45°$ on the **left**.

[5] eMDPS = emulated MDPS on the HUB GUI.

QT Number	Specification	Test Procedure	Pass criteria
5 **End-of-Maze, IDLE or SOS**	7. Implement the states and transition between operating states as set out in the SCS. 10. Communicate the end-of-maze condition to the SNC or HUB when all the sensors detect the colour Red as it moves across the RED line. 11. Transmit no data to the SNC or HUB, while in IDLE or SOS state.	1. Complete the execution of QTP3. 2. Position the sensor array inside the test block facing the RED line at an angle of $\theta_i \approx 0°$. 3. On the HUB GUI, select “Sensor” and then execute QTP5. 4. The HUB will emulate a “PureTone” on the eSNC to transition into SOS. Verify on the HUB that the SS does not transmit in the SOS state. 5. Click “Continue” on the HUB GUI to transition back into MAZE. Verify on the HUB that the SS is transmitting again. 6. Move the sensor array across the RED line. 7. Verify on the HUB that the SS communicates the End-of-Maze condition to the HUB when the sensors move over RED. 8. If the SS does not successfully detect the EoM, click the “EOM” button to terminate the QTP on the HUB. 9. Repeat QTP 5 with only 2 of the 3 sensors moving over RED to confirm no EOM is signalled.	1. After the SOS state is communicated, the SS must not transmit data to the HUB. 2. After having transitioned back into the MAZE state, the SS must again transmit COLOUR and INCIDENCE data to the HUB. 3. When the SS detects and displays all 3 sensors as red as it moves over the red line, it must transmit the End-of-Maze control byte to the HUB.

4. Motor Driver and Power Supply (MDPS) subsystem qualification tests

Table 6 provides the test equipment, environment and setup for all the tests and Table 7 the qualification tests and procedures that need to be performed to demonstrate that the subsystem adheres to the relevant design specifications as mentioned in Section 8b of the project guide. The relevant design specifications must be met to ensure the MDPS functions as intended within the system.

Table 6: Test equipment, environment and setup for all QTPs

Test Equipment	1. The MDPS subsystem. 2. DC measuring equipment, such as a multi-meter. 3. Personal computer or laptop with the HUB software installed. 4. Long USB cable between the computer and MDPS so that it can move freely when connected to the computer. 5. Ruler or measuring tape. 6. Printed A4 sized protractor provided on the last page of this document.
Test Environment	1. Laboratory conditions (ABC or Heavy Machines lab).
Test Setup	1. Apply the required supply rails to the subsystem. Switch the system on and wait for the subsystem to complete its start-up sequence. 2. Connect the subsystem to the HUB through serial communication as will be outlined in the HUB user manual. 3. Enter the following design parameters into the HUB GUI as defined in Appendix B of the project guide: a. Inter-sensor distances sd1, sd2, sd3 and sd4. b. Distance between the sensor array and wheel axis "A" c. Designed v_{op} in mm/s which is the speed at which the MARV is designed to travel in the maze.

Table 7: Qualification tests for the MDPS subsystem

QT Number	Specification. The MDPS must:	Test Procedure	Pass criteria
1 Power supply	1. operate independently of wall socket power when in use. 2. output, externally, voltage levels of 3.3 V, 5 V and/or 9 V to within a 5 % accuracy under all load conditions.	1. Voltage outputs can be measured during any of the other QTPs.	1. Voltages measured must be within 5% of the rated voltage used.
2 Calibration and Communi-cation	3. calibrate the tangential wheel speeds (v_{op}) in the CAL state within 60 seconds. 6. ensure a speed to within 5% of the speed set by the SNC. 10. communicate with the SNC or HUB using the standard communication protocol as stipulated in the SCS. 13. report no data to the SNC or HUB in the IDLE state.	1. Connect the test setup as described. 2. Select a wheel speed of $\leq 0.8 v_{op\_designed}$ OR $\geq 1.5 v_{op\_designed}$ and enter this value into the HUB GUI. The evaluator will decide on the speed value in consultation with the student. $v_{op\_designed}$ refers to the speed at which the MARV is designed to travel in the maze. 3. On the HUB GUI, select "MDPS" and then execute QTP2. 4. Verify that no transmission is received from the MDPS in IDLE before clicking "Touch" to proceed to the CAL state.[6] 5. The HUB will verify that the MDPS calibrates the wheel speeds of both wheels to within 5% of the set v_{op}. 6. Verify that the MDPS continues to transmit a ≥ 0 battery level within the CAL loop as required by the SCS state diagram before clicking "Touch" to proceed to the MAZE state. 7. The HUB will verify that no transmission is received from the MDPS before the SNC speed transmission in the MAZE state. 8. Repeat the test at $v_{op\_designed}$ and confirm visually and/or audibly that the MDPS calibrated at the higher or lower speed.	1. The MDPS must not transmit in IDLE state. 2. The MDPS must calibrate both wheel speeds to $v_{op} \pm 5\%$ in both test runs. 3. The MDPS must function and communicate as stipulated in the SCS state diagram with successful transition from CAL to MAZE state 4. It must be proven that the second test run executed at a higher or lower speed than the first.

[6] During this test, compare all Hub and MDPS communication on the Hub GUI with the relevant QTP flow diagram to monitor the test execution. Appropriate error messages will be shown in the Hub GUI status window to indicate where in the process errors might have occurred. The Hub will also indicate when a test is complete.

QT Number	Specification. The MDPS must:	Test Procedure	Pass criteria
3 **Forward, Stop, Reverse, Communi-cation, SOS**	4. enable all necessary movements of the MARV to adhere to all the navigation specifications in Section 9b. 5. be able to propel the MARV at a speed v_{op} of at least 10 mm/s. 6. ensure a speed to within 5% of the speed set by the SNC. 9. determine the distance travelled since the last stop with an error ≤ 5%. 11. communicate the following to the SNC or HUB, according to the display requirements in the PEC documentation: • Tangential wheel speeds in [mm/s]. • Distance travelled since last stop in [mm]. • Last rotation angle of the MARV in degrees. 12. come to a complete halt in less than 2 seconds upon entering the SOS state.	1. Reset the MDPS after completion of QTP2. 2. On the HUB GUI, select "MDPS" and then execute QTP3 that starts in IDLE. 3. The HUB will execute the following three tests in a random order. a. An elementary Reverse followed by a Stop instruction after a distance of between 60 and 100 mm, randomly chosen by the HUB, has been received from the MDPS. See note below. b. An elementary Forward followed by a Stop instruction after a distance of between 120 and 200 mm, randomly chosen by the HUB, has been received from the MDPS. This test will evaluate the distance and speed accuracy of the MDPS. Measure the actual distance that the MDPS drove forward with a ruler and calculate the actual average speed of the MDPS using the time displayed by the HUB. Compare this to the average speed calculated and displayed by the HUB. c. A "Forward or Reverse – into and out of SOS – Forward" sequence of movements at distances of between 30 and 50 mm, randomly chosen by the HUB. 4. Before the start of each test, the status window will prompt the user to position the MARV accordingly and to then click "Continue". The HUB/SNC does not send a travel distance to the MDPS. The HUB continuously reads the distance sent by the MDPS, compares it to the required distance and when the MDPS distance exceeds the required distance, the HUB sends a STOP to the MDPS. This will inevitably result in an overshoot of which the magnitude is dependent on the speed of the MDPS. The evaluator will compare the physically measured distance the MDPS drove with the last distance transmitted by the MDPS to, and displayed on, the HUB in the MDPS window and not to the required distance at which the HUB gave the stop instruction.	1. The MDPS drives forward at a speed that is within 5% of the set point v_{op}. 2. **QTP3a**: The MDPS must reverse and stop after the distance indicated on the HUB with an error of ≤ 5%. 3. **QTP3b**: The MDPS must drive forward and stop after the distance indicated by the HUB with an error of ≤ 5%. 4. **QTP3b**: The average speed transmitted by the MDPS must be within 5% of the actual speed. 5. **QTP3c:** At the HUB's command, the MDPS must: • Reverse or go forward as instructed • go into SOS and stop within 2sec, • transition back into MAZE, • drive forward and • stop again. 6. The MDPS must communicate all critical system diagnostics to the HUB throughout the process.

<table>
<tr><th>QT Number</th><th>Specification. The MDPS must:</th><th>Test Procedure</th><th>Pass criteria</th></tr>
<tr><td>4
Rotation

and

End-of-Maze</td><td>4. enable all necessary movements of the MARV to adhere to all the navigation specifications in Section 9b.

7. rotate around the midpoint between the two wheels of the MARV (see Figure B.1a).

8. allow rotation of the MARV of between 5° and 360° with an error of ≤ 5% for rotation angles > 100° and a maximum error of 5° for rotation angles ≤ 100°.

14. Stop and rotate 360° on detection of the End-of-Maze transmission from the SS.

NAVCON specification 2:
The MARV must be able to perform the following distinct turn functions:
● turn 90° ± 5° RIGHT
● turn 180° ± 5° LEFT or RIGHT
● turn 360° ± 5° LEFT or RIGHT
● an incremental rotation of ≤ 5° RIGHT AND LEFT.</td><td>1. Reset the MDPS after completion of QTP2.
2. On the HUB GUI, select “MDPS” and then execute QTP4 that starts in IDLE.
3. The HUB will automatically instruct the following rotations in random order with the user required to click “Continue” before each rotation:
● turn 90° RIGHT
● turn 180° LEFT
● turn 180° RIGHT,
● turn 360° LEFT
● turn 360° RIGHT,
● a number of incremental rotations of ≤ 5° RIGHT
● a number of incremental rotations of ≤ 5° LEFT
● a random angle between 45° and 135° LEFT,
● a random angle between 45° and 135° RIGHT.

4. At the end the HUB will instruct the user to click EOM on the HUB GUI to emulate an End-of-Maze transmission by the SS to which the MDPS must stop and rotate 360°.

Each rotation must be measured with the protractor provided on the last page of this document.</td><td>1. The MDPS must execute all rotations listed to within 5% accuracy.

2. The MDPS must stop and rotate 360° after having clicked EOM.

3. The MDPS must rotate around the midpoint on the axis between the two wheels.</td></tr>
</table>

Appendix A: Document revisions

2025-06-05: Version 1 for 2025

Appendix B: Protractor