

Verification and Validation Report: 2D Localizer

Aliyah Jimoh

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1 Revision History

Date	Version	Notes
2024/04/18	1.0	Initial Release

2 Symbols, Abbreviations and Acronyms

symbol	description
CRLB	Cramér-Rao Lower Bound
FM	Fiducial Marker
FIM	Fisher Information Matrix
T	Test
SRS	Software Requirement Specification
VnV	Verification and Validation

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This document shows the results of the system and unit tests done on the 2D Localizer software. More detailed information of the tests cases performed are documented in this system's [VnV Plan](#).

3 Functional Requirements Evaluation

3.1 Validate and Verify Inputs

- **Test Case(s):** `test_map_image`, `test_coordinates`, `test_range_measurements`, `test_invalid_input`
- **Requirement(s) Met:**
 - R1: Accept a map/image as an input
 - R2: Accept sensor and fiducial marker (FM) coordinates as an input
 - R3: Accept sensor measurements as an input
 - R4: Verify that inputs provided are within their constraints
- **Type:** Automatic
- **Testing Method:** `pytest`
- **Result Summary:** All 5 successfully passed
- **Result Location:** Unit tests from `test_inputs_results.txt` and `test_input_file_results.txt` are located in the timestamp folder of [test/results](#).

3.2 Verify Localization

- **Test Case(s):** `test_range_only`, `test_fiducials`, `test_sensor_fusion`
- **Requirement(s) Met:**
 - R5: Compute estimated pose from provided inputs
- **Type:** Automatic
- **Testing Method:** `pytest`

- **Result Summary:** All 3 successfully passed
- **Result Location:** Can all be found in `test_pose_estimation_results.txt` located in the timestamp folder of [test/results](#).

3.3 Accuracy Evaluation

- **Test Case(s):** `test_accuracy`
- **Requirement(s) Met:**
 - R6: Evaluate the accuracy of the estimated pose with statistical models (found in [SRS](#))
- **Type:** Automatic
- **Testing Method:** `pytest`
- **Result Summary:** Successfully passed
- **Result Location:** Can all be found in `test_accuracy_results.txt` located in the timestamp folder of the [test/results](#) folder.

3.4 Validate Visualization

- **Test Case(s):** `test_visualization`
- **Requirement(s) Met:**
 - R7: Display visual representation (plot) of pose estimate
 - R8: Display real-time coordinate updates of the robot
 - R9: Display the robot's trajectory path
- **Type:** Automatic
- **Testing Method:** `pytest`
- **Result Summary:** Successfully passed. There are warnings that come up since the plot is being tested that it can display rather than actually displaying it.
- **Result Location:** Can all be found in `test_visuals_results.txt` located in the timestamp folder of [test/results](#).

4 Nonfunctional Requirements Evaluation

4.1 Accuracy

- **Test Case(s):** `test_accuracy`
- **Requirement(s) Met:**
 - NFR1: Ensure that the accuracy metric output by the system is numerically sound.
- **Type:** Automatic
- **Testing Method:** `pytest`
- **Result Summary:** Successfully passed
- **Result Location:** Can all be found in `test_accuracy_results.txt` located in the timestamp folder of the [test/results](#) folder.

4.2 Maintainability

- **Requirement(s) Met:**
 - NRF2: Software should be simple to modify some components when needed.
- **Type:** Manual
- **Testing Method:** Modifying components in modules and rerunning the unit tests in `pytest` to see if 2D Localizer still works.
- **Result Summary:** Software still operational.

4.3 Usability

- **Requirement(s) Met:**
 - NFR3: Software should be able to run on Linux operating systems and macOS.
- **Type:** Manual

- **Testing Method:** Running the `make install` command from the Makefile found in the `src` folder using two laptops (one with Linux and the other with macOS)
- **Result Summary:** Both laptops were successfully able to install the virtual environment and run the software.

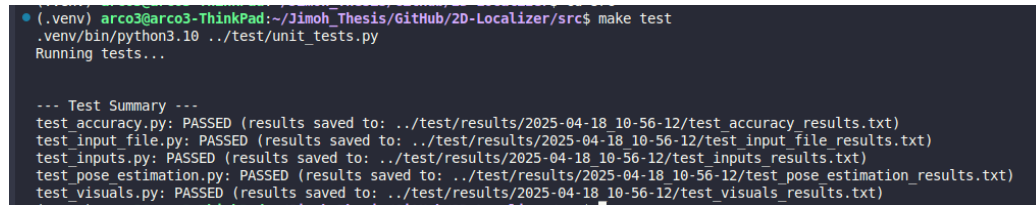
5 Comparison to Existing Implementation

This section is not applicable.

6 Unit Testing

The unit tests for 2D Localizer are run using the command `make test` which executes the program `unit_tests.py` located in the `test` folder. The script looks through all the programs that start with `'test_'` and end with `'py'` as that is the naming convention that was chosen for all test cases.

After all the tests finish running, the program generates a `.txt` summary file each module tested. This file records whether the test passed or failed and indicates the location where the result is stored. A combined terminal output also provides a quick summary of the results.



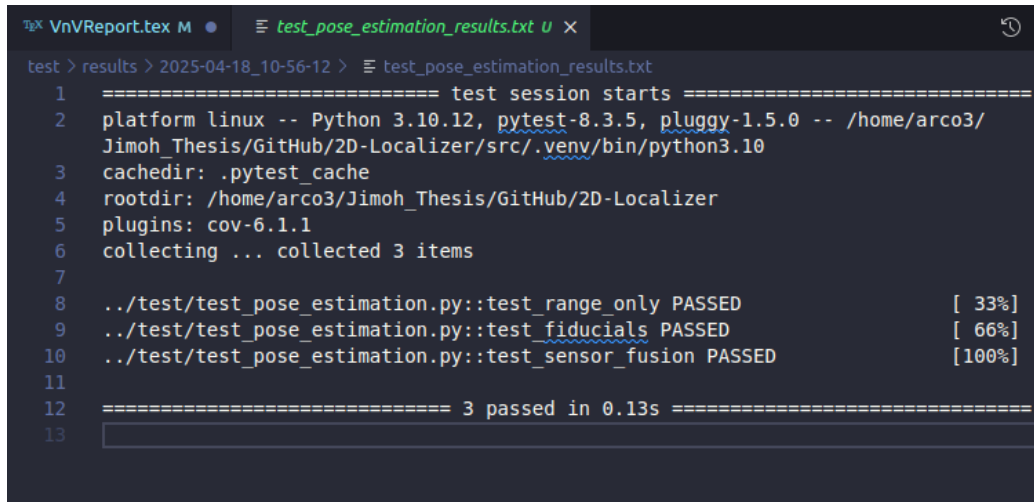
```

• (.venv) arco3@arco3-ThinkPad:~/Jimoh_Thesis/GitHub/2D-Localizer/src$ make test
.venv/bin/python3.10 ../test/unit_tests.py
Running tests...

--- Test Summary ---
test_accuracy.py: PASSED (results saved to: ../test/results/2025-04-18 10-56-12/test_accuracy_results.txt)
test_input_file.py: PASSED (results saved to: ../test/results/2025-04-18 10-56-12/test_input_file_results.txt)
test_inputs.py: PASSED (results saved to: ../test/results/2025-04-18 10-56-12/test_inputs_results.txt)
test_pose_estimation.py: PASSED (results saved to: ../test/results/2025-04-18 10-56-12/test_pose_estimation_results.txt)
test_visuals.py: PASSED (results saved to: ../test/results/2025-04-18 10-56-12/test_visuals_results.txt)

```

Figure 1: Output of the `make test` command



```
test > results > 2025-04-18_10-56-12 > test_pose_estimation_results.txt
1  ===== test session starts =====
2  platform linux -- Python 3.10.12, pytest-8.3.5, pluggy-1.5.0 -- /home/arco3/
   Jimoh_Thesis/GitHub/2D-Localizer/src/.venv/bin/python3.10
3  cachedir: .pytest_cache
4  rootdir: /home/arco3/Jimoh_Thesis/GitHub/2D-Localizer
5  plugins: cov-6.1.1
6  collecting ... collected 3 items
7
8  ../test/test_pose_estimation.py::test_range_only PASSED [ 33%]
9  ../test/test_pose_estimation.py::test_fiducials PASSED [ 66%]
10 ../test/test_pose_estimation.py::test_sensor_fusion PASSED [100%]
11
12 ===== 3 passed in 0.13s =====
13
```

Figure 2: Test Summary for test_pose_estimation.py

7 Changes Due to Testing

- **Improved Accuracy Validation:** The approach for evaluating pose accuracy was expanded. The final version includes explicit tests for Fisher Information Matrix (FIM) and Cramér-Rao Lower Bound (CRLB), validated in `test_accuracy.py`.
- **Expanded Unit Testing and Coverage:** Initial versions of the VnV Plan lacked specific testing for key modules such as plotting and input validation. These were added in `test_visuals.py` and `test_inputs.py`, respectively.
- **Integration with Automation Tools:** To support repeatable testing, automated testing was introduced through an extra command in the Makefile to output summaries. This ensures that changes to the codebase can be quickly validated after updates.

8 Automated Testing

All unit and system tests were written using the `pytest` framework. Test scripts followed a consistent `test_*.py` naming convention and were validated using both standalone runs and automated workflows. This custom Python script, `unit_tests.py`, automatically discovers all test files and records their output in corresponding `.txt` summary files the [test/results](#) folder in the GitHub Repository.

9 Trace to Requirements

Test Case	R1	R2	R3	R4	R5	R6	R7	R8	R9	NFR1
test_invalid_yaml	X	X	X	X						
test_map_image										
test_coordinates										
test_range_measurements										
test_range_only		X	X							
test_fiducials										
test_sensor_fusion										
test_visualization							X	X	X	
test_accuracy						X				X

Table 1: Tracibility Matrix Between the Test Cases & Requirements

10 Trace to Modules

Test Case	localization.py	input_format.py	accuracy.py	plot.py
test_invalid_yaml		X		
test_map_image		X		
test_coordinates		X		
test_range_measurements		X		
test_range_only	X			
test_fiducials	X			
test_sensor_fusion	X			
test_visualization				X
test_accuracy			X	

Table 2: Tracibility Matrix Between the Test Cases & Modules

11 Code Coverage Metrics

As mentioned in the [VnV Plan](#), there were some modules that were justified for not having any unit tests resulting in their coverage being 0%. Due to this, the main focus will be the coverage:

- Input Format Module (M3)
- Localization Module (M6)
- Plotting Module (M8)
- Accuracy Evaluation Module (M9)

Name	Stmts	Miss	Coverage
accuracy.py	15	0	100%
input_format.py	52	2	92%
localization.py	38	0	100%
plot.py	62	20	68%

Table 3: Code Coverage Metric for the Unit Tested Modules

From what is being prioritized, all modules have a with over 60%. The rationale for the Plotting Module being relatively low is due to the unit test not showing the plot but rather confirming that it can display and update itself.