

# Verification and Validation Report: Mechatronics

Team #20, OpenASL  
Robert Zhu zhul49  
Zifan Meng mengz17  
Jiahui Chen chenj194  
Kelvin Huynh huynhk12  
Runze Zhu zhur25  
Mirza Nafi Hasan hasanm21

March 9, 2023

# 1 Revision History

Date	Version	Notes
March 8, 2023	1.0	Everyone - Initial VnV Report Draft

## 2 Symbols, Abbreviations and Acronyms

---

symbol	description
Req	Requirements
Ref	References

---

For others please refer to SRS Documentation at <https://github.com/kelhuynh/OpenASL/blob/main/docs/SRS/SRS.pdf>

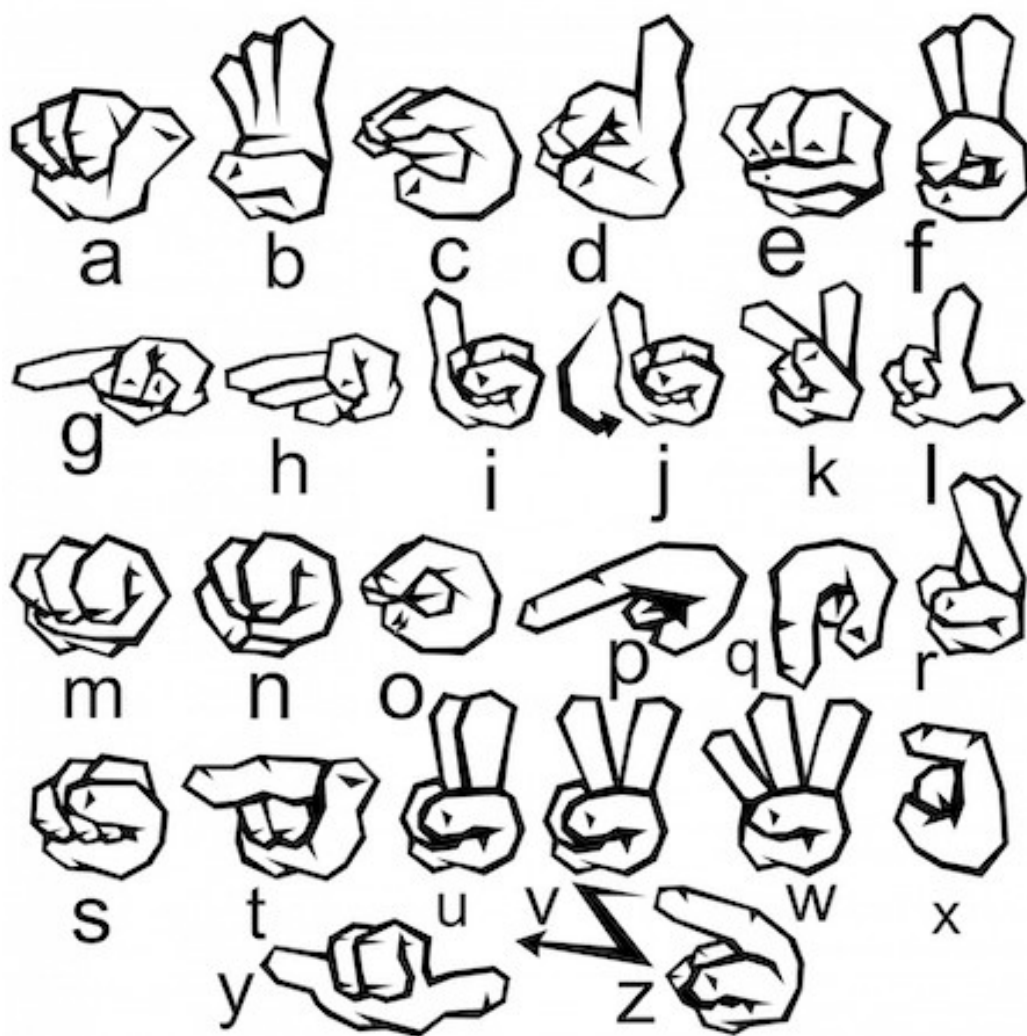


Figure 1: Lower Case



Figure 2: Upper Case

# Contents

<b>1</b>	<b>Revision History</b>	<b>i</b>
<b>2</b>	<b>Symbols, Abbreviations and Acronyms</b>	<b>ii</b>
<b>3</b>	<b>Purpose</b>	<b>1</b>
<b>4</b>	<b>Test Cases</b>	<b>2</b>
<b>5</b>	<b>Trace to Requirements</b>	<b>18</b>
<b>6</b>	<b>Non-Functional Quality 1</b>	<b>20</b>
<b>7</b>	<b>Non-Functional Quality 2</b>	<b>21</b>
<b>8</b>	<b>Changes due to Testing</b>	<b>22</b>
<b>9</b>	<b>Code Coverage Metrics</b>	<b>23</b>

## List of Tables

1	Tests for Motion Tracking Module . . . . .	4
2	Tests for Coordinate Normalization Module . . . . .	6
3	Tests for Coordinate Export Module . . . . .	8
4	Tests for Machine Learning Module . . . . .	10
5	Tests for Training Module . . . . .	11
6	Tests for Text to Speech Module . . . . .	13
7	Tests for Hardware . . . . .	14
8	Text and String Display . . . . .	17
9	Tests for Nonfunctional Requirements accuracy, usability, portability, cultural . . . . .	18
10	Trace to Requirements . . . . .	19

## List of Figures

1	Lower Case . . . . .	iii
2	Upper Case . . . . .	iv

3	Correlation Graph . . . . .	20
4	Angled y . . . . .	21
5	Low Light y . . . . .	21
6	Normal y . . . . .	21
7	Tilted Left . . . . .	21
8	Tilted Right . . . . .	22
9	HTML Output . . . . .	23
10	Terminal Output . . . . .	23

### **3 Purpose**

The purpose of this document is to outline the testing that was done during the development of the ASL translator. These tests were conducted to ensure that the ASL translator is able to perform as expected and is usable in a real-life setting. This document summarizes the results of those tests.



## 4 Test Cases

### Tests for Motion Tracking Module

ID	Description	Req Ref	Input	Expected Output	Actual Output	Result
A1	Testing for joint tracking when hiding joints	MLFR1, MLFR5, NFR2	Hand Gesture for “m” and “n” (covering thumb)	Able to recognize hidden joints	Able to recognize hidden joints	Pass
A2	Testing hand detection for hand at the edges of the camera detection area	CFR1	Hand gesture for “a”, “b”, “c”	a b c	a b c	Pass
A3	Testing if joint lines are properly aligned with the user’s joints and move accordingly at the center	MLFR1, MLFR6, NFR2	Moving hand from one side of the screen to the other in rapid succession	Able to overlay joint lines on user’s hand continually and is centered on the hand	Able to overlay joint lines on user’s hand continually and is centered on the hand	Pass
A4	Testing if a joint overlay will be placed on more than two hands	MLFR1, MLFR3, NFR2	Having a third hand in the frame after the initial two	Unable to detect the third hand	Unable to detect the third hand	Pass

A5	Testing if detected joints are from one individual (the user)	MLFR1, NFR1, NFR3	Have two people with one hand each in the frame	Detects the hand from one person as opposed to two	Detects both the hands of both people	Fail
A6	Testing hand detection at a distance of 2 m	CFR1	Hand gesture for “a”, “b”, “c”	a b c	a b c	Pass
A7	Testing hand detection with multiple hands	CFR1	Hand gestures for “z”, “x”, “y”	z x y	z x y	Pass
A8	Testing for joint tracking when overlapping hands	MLFR1, MLFR3, MLFR5	Hand Gesture for “S”, “M”, “N”, “R”	Able to separate different hand joints from each other	Able to separate different hand joints from each other	Pass
A9	Switching from translating mode to training mode stop detecting hand gestures	N/A	Pressing either 2 or 3	The interface no longer tries to record hand motion	The interface no longer tries to record hand motion	Pass
A10	Testing for precision tracking	MLFR1	Making small rotations and tremors	The joint overlay makes small movements	The joint overlay makes small movements	Pass

A11	Testing for gesture recognition if the hands hand in placing with different angles	CFR1	Hand gestures for “a”, “b”, “c” with different angles for the position of the hand	“a”, “b”, “c”	“a”, “b”, “c”	Pass
A12	Testing for occlusion handling	MLFR1	Partially hiding half of the hand behind a desk	The joint overlay is able to predict the rest of the hand	Joints overlay becomes disjointed and stretches	Fail
A13	Testing the durability for accuracy and reliability	NFR1, MLFR1	Keeping the program open for over an hour and testing for similar results	The joint overlay works as intended	The frame rate decreased leading to poor performance	Fail
A14	User testing for different hand sizes and shapes	MLF1, NFR4	Using different people’s hands to test the accuracy of the string “a”, “b”, “c”, “d”	Able to translate a b c d everytime	Able to translate a b c d everytime	Pass

Table 1: Tests for Motion Tracking Module

Tests for Coordinate Normalization Module

ID	Description	Req Ref	Input	Expected Output	Actual Output	Result
B1	Testing if different webcams or cameras impact coordinates at the same position	CFR1, CFR2	Sign the sentence "how do you do" alphabet-ically through 5 different cameras	The same set of coordinates for all 5	The same set of coordinates for all 5	Pass
B2	Testing if the coordinates (x,y) of each joint is accurately recorded	MLFR2	Repeatedly recording the gesture "a" at the center of the screen	The same set of coordinates should be written to CSV file every time the gesture is recorded	The same set of coordinates should be written to CSV file every time the gesture is recorded	Pass
B3	Testing if the coordinates (x,y) of each joint is accurately recorded for two handed gestures	MLFR3, MLFR2	Repeatedly recording the gesture "F" at the center of the screen	The same set of coordinates should be written to CSV file every time the gesture is recorded	The same set of coordinates should be written to CSV file every time the gesture is recorded	Pass
B4	Testing for range normalization between [-1,1]	MLFR2	Testing the joints at the edge of the frame	No coordinate recorded exceeds [-1, 1]	No coordinate recorded exceeds [-1, 1]	Pass

B5	Testing for scaling normalization for hand size to be consistent	MLFR2	Testing using different sizes to hands	All coordinates recorded from each set of hands are generally the same	All coordinates recorded from each set of hands are generally the same	Pass
----	---	-------	--	---	---	------

Table 2: Tests for Coordinate Normalization Module

Tests for Coordinate Export Module

<b>ID</b>	<b>Description</b>	<b>Req Ref</b>	<b>Input</b>	<b>Expected Output</b>	<b>Actual Output</b>	<b>Result</b>
C1	Testing if the relative coordinates (x,y) is written to the CSV file	RDP1, NFR5	Hand gesture for "a"	Coordinates with identifier "0" (identifier for the letter "a") are written to the CSV file	Coordinates with identifier "0" were written to the CSV file	Pass
C2	Testing if the point history coordinates (x,y) is written to the CSV file	RDP1, NFR5	Hand gesture for "j"	Multiple coordinates with identifier "9" (identifier for the letter "j") are written to the CSV file	Multiple coordinates with identifier "9" get written to the CSV file	Pass

C3	Testing to see if a coordinate for each hand joint is written to the CSV file	RDP1	Hand gesture for “b”	43 coordinates are written to the CSV file, first the identifier (for the gesture, ie ‘a’, ‘b’, etc.) followed by an x,y coordinate for each joint (21 * 2 + 1 = 43)	43 coordinates are written to the CSV file every time a gesture is recorded	Pass
----	---	------	----------------------	--	---	------

Table 3: Tests for Coordinate Export Module

Tests for Machine Learning Module

ID	Description	Req Ref	Input	Expected Output	Actual Output	Result
D1	Testing hand detection for similar looking gestures	CFR1, RDP1	Hand gesture for “m”	m	n	Fail
D2	Testing hand detection for motion (no input)	CFR1, RDP1	Static hand gestures (no motions)	no output	z/d	Fail
D3	Testing hand detection for motion	CFR1, RDP1	Hand motion for “z”	z	z	Pass
D4	Testing if gestures that require movement are able to be recognized (motion gestures)	MLFR4, MLFR6, RDP1	Signing “j” and “z”	j z	j z	Pass
D5	Test model accuracy by signing different sequences of gestures / introducing variance into the system	MLFR4, NFR1, RDP1	Sign letters in sequence of a,b,c,d then sign with d, f, z, j	a,b,c,d d,f,z,j with 100% accuracy	a,b,c,d d,f,z,j	Pass



D6	Testing gesture recognition between point history (movement gestures) and keypoint history (static gestures)	MLFR4	Sign letters in sequence “a”, “b”, “j”, “c”, “z”	a b j c z	j a j z b c z	Fail
----	--	-------	--	-----------	---------------	------

Table 4: Tests for Machine Learning Module

Tests for Training Module

<b>ID</b>	<b>Description</b>	<b>Req Ref</b>	<b>Input</b>	<b>Expected Output</b>	<b>Actual Output</b>	<b>Result</b>
E1	Mode Selection	N/A	Program is in “Normal Mode”, press number “2” on keyboard	Program goes into “Training Mode”	Program goes into “Training Mode”	Pass
E2	Test if a .tflite file can be generated from the CSV files	MLFR5, NFR5	A CSV file with data points from different ASL gestures	A .tflite file that can be used to recognize the gestures that were recorded	A .tflite file that can be used to recognize the gestures that were recorded	Pass
E3	Testing if retraining by adding new data points can change recognition	MLFR7, NFR1, NFR5	Adding 50 accurate data points to the gesture “Hello”	The accuracy prediction increases	The accuracy prediction decrease from 60% to 80%	Pass
E4	Testing for gesture variation based on user habits through retraining	MLFR7, NFR1, NFR3, NFR7	Retraining the model with a different method of signing “Hello”	Hello	Hello	Pass

Table 5: Tests for Training Module

### Tests for Text to Speech Module

ID	Description	Req Ref	Input	Expected Output	Actual Output	Result
F1	Text-to-speech in real-time for individual letters	RDP1, RDP2	Hand gestures for “a”, “b” and “c”, then hand gesture for “Speak”	Audio output for letters “a”, “b” and “c”	Audio output for letters “a”, “b” and “c”	Pass
F2	Text-to-speech in real-time for sentence	RDP1, RDP2	Hand gesture for “I love you”, then hand gesture for “Speak”	Audio output for “I love you”	Audio output for “I love you”	Pass
F3	Testing hand detection for a series of hand gestures (fast)	CFR1, RDP1, MLFR4	A series of hand gestures performed in a very fast speed	Letters for correspond-ing hand gestures	Some letters are missing	Fail (need to increase fps)

F4	Test if gesture for “Speak” does not work when in training mode	RDP2	Program is started, in training mode, and gestures are performed, then gesture “Speak” is performed	No audio output	No audio output	Pass
----	---	------	---	-----------------	-----------------	------

Table 6: Tests for Text to Speech Module

Tests for Hardware

<b>ID</b>	<b>Description</b>	<b>Req Ref</b>	<b>Input</b>	<b>Expected Output</b>	<b>Actual Output</b>	<b>Result</b>
G1	Camera is set up on the Raspberry Pi	CFR1	Raspistill command to take a picture	A picture	A picture	Pass
G2	Test if the Raspberry Pi can capture the input from the camera and translate ASL in real time	NFR6	Program is started on the Raspberry Pi	The Raspberry Pi should be able to use the camera to detect and translate ASL in real time	The Raspberry Pi camera does not display the video with an adequate frame rate, making translation undoable	Fail
G3	Real-time video is captured and displayed on screen	CFR1, CFR2	Views in front of the camera	Views in front of the camera are displayed	Views in front of the camera are displayed	Pass

Table 7: Tests for Hardware

### Text and String Display

ID	Description	Req Ref	Input	Expected Output	Actual Output	Result
H1	Real-time text display for hand gestures (normal speed)	RDP1	Hand gestures for “d” and “a” performed in a reasonable speed	Output the correspond -ing letters “d” and “a” besides user’s hand	Output the correspond -ing letters “d” and “a” besides user’s hand	Pass
H2	Real-time text display for hand gestures (super fast)	RDP1, MLFR4	Hand gestures performed in a super fast speed	Letters for correspond -ing hand gestures	Some letters output are missing	Fail (need to increase fps)
H3	String display for one hand gesture	MLFR6, MLFR4, NFR1	Hand gestures for “d”	“d” is displayed as string at the bottom of the screen	“d” is displayed as string at the bottom of the screen	Pass
H4	String display for a series of hand gestures (slow speed)	MLFR6, MLFR4, NFR1	Hand gestures for “d” and “a” and “I love you” with a pause of 4 seconds	“d a I love you” is displayed as string at the bottom of the screen	“d d a a I love you I love you” is displayed as string at the bottom of the screen	Fail

H5	String display for a series of hand gestures (normal speed)	MLFR6, MLFR4, NFR1	Hand gestures for “d” and “a” and “I love you” with a pause of 1 to 2 seconds	“d a I love you” is displayed as string at the bottom of the screen	“d a I love you” is displayed as string at the bottom of the screen	Pass
H6	String display for a series of hand gestures (fast speed)	MLFR6, MLFR4, NFR1	Hand gestures for “d” and “a” and “I love you” without pause	“d a I love you” is displayed as string at the bottom of the screen	“d I love you” is displayed as string at the bottom of the screen	Fail
H7	Modifying string display	N/A	Pressing “Backspace” or “Space”	“Backspace” deletes a character in string, “Space” adds a space in string	“Backspace” deletes a character in string, “Space” adds a space in string	Pass
H8	String display is cleared after audio output	RDP1, RDP2	Hand gestures are performed, and then perform hand gesture for “Speak”	Current string is cleared	Current string is cleared	Pass

H9	Test if gestures are not written to string when in training mode	N/A	Program is started, in training mode, and gestures are being performed	Nothing is being added to the string and nothing is displayed at the bottom	Nothing is added to the string and nothing is displayed at the bottom	Pass
----	--	-----	--	---	---	------

Table 8: Text and String Display



Tests for Nonfunctional Requirements accuracy, usability, portability, cultural

<b>ID</b>	<b>Description</b>	<b>Req Ref</b>	<b>Input</b>	<b>Expected Output</b>	<b>Actual Output</b>	<b>Result</b>
I1	Test if GUI is displayed on screen	N/A	Program is started and camera is turned on	The resolution, FPS, mode, and current text are displayed on screen	The resolution, FPS, mode, and current text are displayed on screen	Pass
I2	Test if output is accurate for variations in user gestures	NFR7	Trying three variations of “Hello”	Hello	Hello	Pass
I3	Usability: the ease of use of a user without the knowledge of ASL	N/A	Instructions and example hand gestures are provided to the user	The user should know how to use the ASL device and can input some sample ASL words after reading the instructions.	The user is able to use the ASL device and input some sample ASL words after reading the instructions	Pass

Table 9: Tests for Nonfunctional Requirements accuracy, usability, portability, cultural

## 5 Trace to Requirements

Requirements	ID
CFR1	A2 A6 A7 A11 B1 D1 D2 D3 G1 G3
CFR2	B1 G3
MLFR1	A1 A3 A4 A5 A8 A10 A12 A13
MLFR2	B2 B3 B4 B5
MLFR3	A2 A4 A8 B3
MLFR4	D4 D5 D6
MLFR5	A1 A8 E2
MLFR6	A3 D4
MLFR7	E3 E4
NFR1	A5 A13 D5 E3 E4
NFR2	A1 A2 A4
NFR3	A5 E4
NFR4	A14 B 5
NFR5	C1 C2 E2 E3
NFR6	G2
NFR7	E4
RDP1	C1 C2 C3 D1 D2 D3 D4 D5
RDP2	H8

Table 10: Trace to Requirements

## 6 Non-Functional Quality 1

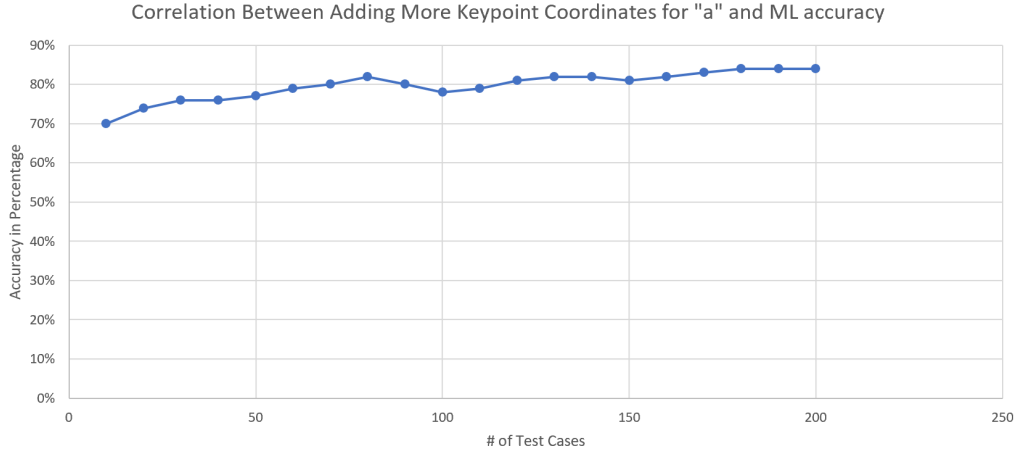


Figure 3: Correlation Graph

The pictures above are some examples of our test for the robustness of the machine learning module following a rigorous evaluation process.. We introduced various types of noise and perturbations as our input for this test. This includes obscuring parts of the hand, changing the lighting, and a different orientation. We measured the robustness using these conditions and fine-tuned the model by retraining it using the perturbed data. Finally, we validated the performance by testing with a different set of users, as seen above in the images, with different hand sizes and gestures to help ensure that the model is robust and reliable for recognizing hand gestures in a wide range of real-world scenarios.

## 7 Non-Functional Quality 2

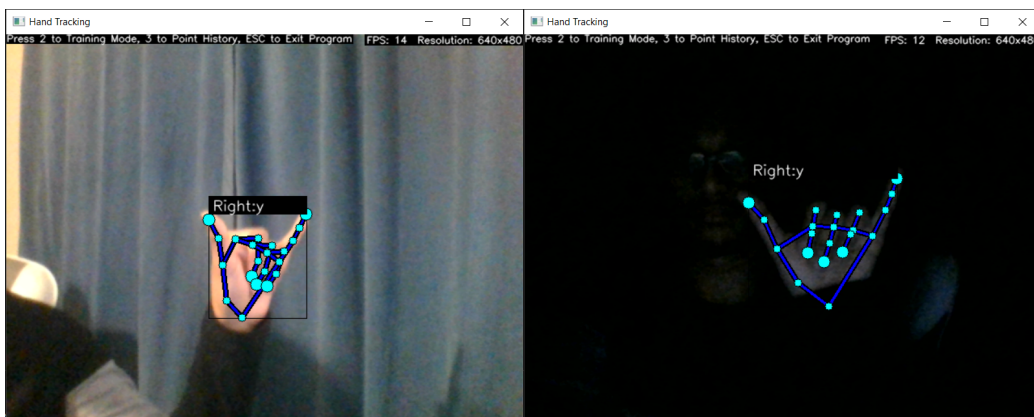


Figure 4: Angled y

Figure 5: Low Light y

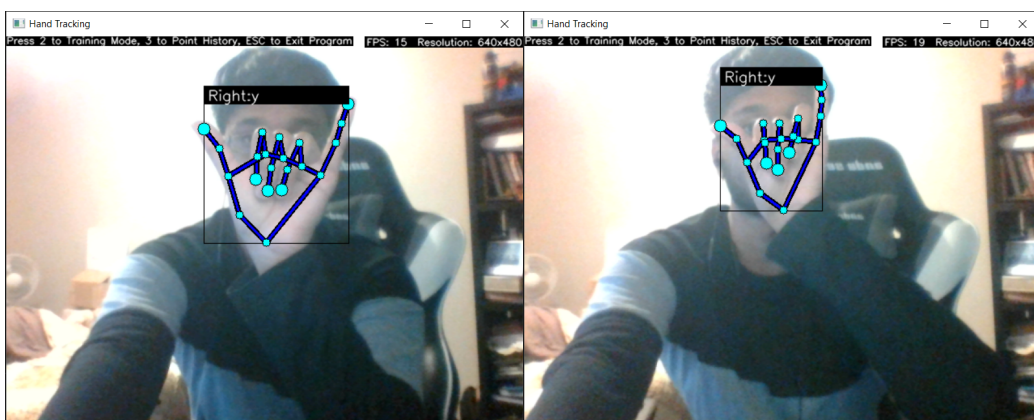


Figure 6: Normal y

Figure 7: Tilted Left

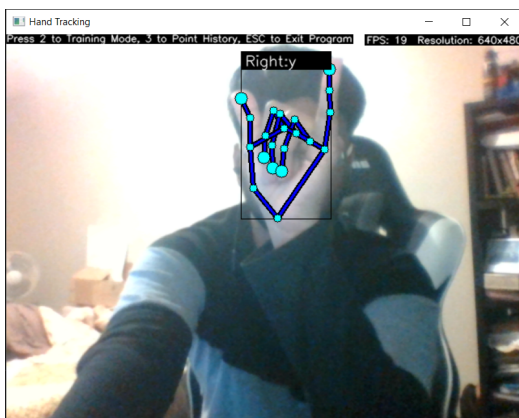


Figure 8: Tilted Right

The pictures above are some examples of our test for the robustness of the machine learning module following a rigorous evaluation process.. We introduced various types of noise and perturbations as our input for this test. This includes obscuring parts of the hand, changing the lighting, and a different orientation. We measured the robustness using these conditions and fine-tuned the model by retraining it using the perturbed data. Finally, we validated the performance by testing with a different set of users, as seen above in the images, with different hand sizes and gestures to help ensure that the model is robust and reliable for recognizing hand gestures in a wide range of real-world scenarios.

## 8 Changes due to Testing

From the failures of test cases G2 and H2, it was determined that the program's performance on a Raspberry Pi is inadequate; likely due to hardware limitations with single core processing. Thus, the approach that we decided to take was to rewrite the program such that the Raspberry Pi is able to utilize Python's multiprocessing library to alleviate performance issues. As of writing this, this solution is still being worked on and is not guaranteed to work. There are also potentially other solutions to use slightly more powerful hardware such as mobile devices or another board, though the main concern would be the portability requirement NFR6.

In addition, from test cases D2 and D6, the program fails to detect the difference between its modes KeypointClassification (regular static gesture), PointHistoryClassification (motion gesture), and idle (where no gestures should be detected). At the moment, both modes operate at the same exact time which may cause confusion for the user and cause issues with the text to speech module. Therefore, changes to the program as a result of the tests would include a method that provides better distinction between the two modes.

Furthermore from the test cases for the training module, we encountered an oversight with how training would occur when signing with both hands. We have it currently set up so that you would press a key to record the coordinates of your hand gestures. But in doing so, we failed to realize how this would work when performing signs that required the use of both hands. As a result of this circumstance, we are now working on implementing a change to the GUI that enables automated recording of these gestures where a keypress will start a timer of 10 seconds then record a data point every 5 seconds. These values are subject to change and will be adjusted as needed.

From test case D1, we can conclude that the accuracy of the model for similar gestures is also one aspect that is inadequate in quality. Therefore the change that would be made based on non-functional quality 1, would be to add more data points such that the machine learning model is able to draw a distinction between similar gestures.

## 9 Code Coverage Metrics

Coverage report: 92%

coverage.py v7.2.1, created at 2023-03-07 21:08:0500

Module	statements	missing	excluded	coverage
HandTrack.py	349	29	0	92%
application.py	3	0	0	100%
model\__init__.py	2	0	0	100%
model\keypoint_classifier\keypoint_classifier.py	17	0	0	100%
model\point_history_classifier\point_history_classifier.py	21	1	0	95%
Total	392	30	0	92%

name	statements	missing	coverage	lines
HandTrack.py	349	29	92%	46-47, 117, 140, 141, 150-155, 160, 170, 201-204, 206-209, 400-403
application.py	3	0	100%	
model\__init__.py	2	0	100%	
model\keypoint_classifier\keypoint_classifier.py	17	0	100%	
model\point_history_classifier\point_history_classifier.py	21	1	95%	35
Total	392	30	92%	

Figure 9: HTML Output

Figure 10: Terminal Output

The images above are code coverage reports generated using Coverage.py which utilizes the PyTest Unit Testing Framework.

While the code coverage is not 100%, it is reasonable enough at 92% as not every single line of code will be hit upon execution.

This is especially true because there are portions of code which would require manual input from the user before they can be executed.

The pictures above are some examples of our test for the robustness of the machine learning module following a rigorous evaluation process.. We introduced various types of noise and perturbations as our input for this test. This includes obscuring parts of the hand, changing the lighting, and a different orientation. We measured the robustness using these conditions and fine-tuned the model by retraining it using the perturbed data. Finally, we validated the performance by testing with a different set of users, as seen above in the images, with different hand sizes and gestures to help ensure that the model is robust and reliable for recognizing hand gestures in a wide range of real-world scenarios.

## Appendix — Reflection

The information in this section will be used to evaluate the team members on the graduate attribute of Reflection. Please answer the following question:

1. In what ways was the Verification and Validation (VnV) Plan different from the activities that were actually conducted for VnV? If there were differences, what changes required the modification in the plan? Why did these changes occur? Would you be able to anticipate these changes in future projects? If there weren't any differences, how was your team able to clearly predict a feasible amount of effort and the right tasks needed to build the evidence that demonstrates the required quality? (It is expected that most teams will have had to deviate from their original VnV Plan.)

Robert Zhu: One of the things we didn't consider during the VnV plan was how the GUI would be created and tested. During the VnV planning, the scope of the plan was focused on machine learning and the newly purchased Raspberry Pi that required many test cases to ensure that the gestures would be correctly translated using the new hardware. The GUI requirements were less critical during the development process, however during testing, we needed to think about how the user is about to access the different functions of the code and the issues that occur from it. In future projects this should be anticipated since the user experience is an important requirement especially in this project where providing visual feedback to the user in real-time is necessary for improving their performance and accuracy in hand signs.

Mirza Nafi Hasan: Many things had changed from our VnV Plan. In our VnV plan, a lot of the test cases covered only the basic functionality of our project. Since we have gotten into the development, we have started to realize the details that we would need to focus on. For example, in our VnV plan, we have a test case for detecting hand gestures (TC-MLFR1). However, we failed to consider the edge cases, like what happens if two joints are on top of each other? Or if two hands are on top of each other? We were able to get a better idea of these edge cases once we had started writing the code. We would likely be able to identify some more tests we need to account for before



starting development for future projects.

Kelvin Huynh: When we created our VnV Plan, we mentioned the use of the PyTest framework for the purposes of automated testing. However, at the time we failed to consider how we would create specific unit tests and their pass/fail conditions. Given the time constraint on the creation of the VnV report, we were not able to implement the use of this tool in full capacity. Instead, we opted to just do manual testing while considering as many test cases as possible. In future projects, this issue could easily be circumvented if we actively thought of potential test cases and developed automated testing scripts during the development process as needed.

Jiahui Chen: By cross referencing to the VnV plan, one of the differences is that the test cases written in the VnV plan did not cover all the modules or functionalities that need to be tested. They were too general and did not correspond to the specific modules. Therefore, in the VnV Report, we redesigned the test cases based on modules to make sure all the important testing criteria are covered. This problem happened because at the beginning of the development, we missed out some functionalities of the modules and they were added during the development process. And we also changed some of the functions for the device when we realized the initial ideas or design could not be implemented well. For example, the text-to-speech module was added to replace the external speaker and the testing for the text-to-speech module needs to be conducted. We might still anticipate some changes to testing plans or testing cases in the future with the continuous development and improvement of the device. But this can be easily solved by adding more testing cases for the new functions or modules.

Zifan Meng: One of the differences between the VnV plan and the actual VnV process is that the VnV plan did not account for the differentiation between static hand gestures and motion gestures. However, during the development process, we realized that differentiating static gestures and motion gestures was crucial, due to the fact that American Sign Language involves a large amount of motions. Therefore, the key point history mode was developed and implemented for recognizing and

translating motions. Corresponding test plans are also designed and executed to test whether the program can detect motions. Although it is difficult to anticipate every potential change that could arise, this experience indicates the importance of carefully considering the requirements of the project. We will continue to develop modularized programs so that the program is flexible and adaptable for possible modifications.

Runze Zhu: A difference we encountered was the use of the Raspberry Pi not being able to run our program to the same level as a desktop or laptop computer and it struggles with the demanding application. This can be due to the amount of memory and the speed of the SD card being used. In the future we can learn to anticipate these issues by considering a single-board computer such as the Nvidia Jetson Nano, which was specially designed for computer vision, machine learning and robotics. While they are more expensive, they offer more powerful hardware and better performance for our use cases.