SFWRENG 4G06 - Verification & Validation

Group: NextStep (Group 10)

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1 Revisions

Revision Number	**Date**	**Reason for Change**
Revision 0	February 4, 2022	N/A
Revision 1	March 25, 2022	Updating tests for system modifications

Table 1: Revision History

2 Purpose

The purpose of this document is to show what tests are necessary and sufficient for all functional software components and overall system of the NextStep product. This document will help the NextStep team in the development of the product in order to fine tune and mitigate all hazards and point of failures, such that the final product works based on the requirements.

3 Scope

The scope of this document will focus on the software components of the NextStep device that where described in detail within the system design document. The tests within this document pertain to the unit tests that are injective to each software module. Note each software module may have multiple tests that attack each corner case as well as test cases seen in a typical real world implementation. These test will define the input and output requirements for each sub module. Secondly, this document will contain the integration testing between modules that have dependencies with one another. Lastly, we include a system wide test that covers the system as a whole, making sure the functional and nonfunctional requirements are met as well as the error handling for failures. Hence, verifying and validating the system as a whole.

4 Background

The NextStep device is designed with various software modules to interface with hardware for I/O operations, as well as object detection and guidance. All these modules work together in order to detect objects and direct the user of NextStep such that they avoid static and slow moving obstacles within an indoor environment.

NextStep starts off by receiving user input which will be their height; this data will be utilized to calibrate the sensors. The device will then begin to utilize Lidar and ultrasonic sensors in order to collect data on objects and obstacles around the user. This data will be sanitized and processed by our Sensor Fusion module. Next, this data will be sent to the Object Avoidance module to determine a path through the obstacles. Finally, this path will be relayed to the user through the User Guidance module which interfaces with the haptic motors in order to guide the user of our NextStep device.

Additionally, there is a System Diagnostic module which will interface with all sensors to make sure they are working correctly. The Diagnostic module will also notify the user of NextStep when the battery percent is low.

5 Test Cases

5.1 Testing Plan and Testing Factors

The following section describes a testing methodology where we start by testing the functionality of the individual modules using unit tests. These unit tests consist of both white-box and black-box tests, where the white-box test cases are derived from the percentage of code coverage obtained from the unit tests. From here, we then test the functionality of the modules working together using black-box tests.

There are three categories of undesired events within the system: edge cases, passing incorrect parameter types and receiving incorrect sensor data format. Edge cases are tested within the respective component, which are listed below. For parameter passing, only primitive data types are being passed between functions and modules. All non-primitive data types are global, thus each component access it directly instead of passing it, and it is also sanitized and used within spec each time it is being modified. Therefore, it is unnecessary to test for passing incorrect parameter types as it is not beneficial to do so. Lastly, the sensor will always return data that matches within spec according to its data sheet provided by manufacturer, unless there is a connection issue, which is captured by the system diagnostic module and the corresponding test are listed below. Hence, it is not necessary to test for incorrect sensor data format when there is no connection issues.

Component	**Test Plan** Factors
Data Collection Module	The main goal for testing the Data Collection Module was to ensure that the various sensors used in NextStep (ultrasonic sensors, Lidar, accelerometer) are reliably able to collect data points. Tests 1-3 focus on making sure the the ultrasonic sensors are able to detect multiple objects placed at varying distances away from the sensors. Tests 4-8 and 10 focus on the Lidar and making sure that it able to accurately collect data points from a range of distances and angles. Test 9 checks for the correctness of the accelerometer reading.
Object Avoidance System	The main goal for testing the Object Avoidance Module was to ensure that NextStep can adequately guide a user around obstacles in their path. Test 1-3 cover how the system determines the rebound angle necessary to avoid the objects that are within the current frame that the device has to consider objects. Tests 4 and 5 deal with the creation and updating of the bubble band or frame that the device will consider objects to create a safe path.
User Guidance Mechanism	The main goal for testing the User Guidance module was to ensure that NextStep can effectively deliver the information about the calculated path the user must take to avoid the objects in their path. Tests 1-5 cover the function of each haptic motor's ability to convey a path based on the obstacles in the user's path. Tests 6 and 7 ensure that NextStep is able to deliver information in time to avoid a collision with either a static object or a moving object.
User Inputs	The main goal for testing the User Inputs Module was to make sure that the system is able to correctly receive inputs from the user that are needed to update the system state. Tests 1 and 2 cover the functionality of the user inputting their height into NextStep. These tests also accounted for instances where the user would make a mistake and have to redo an input value. Tests 3 and 4 had to do with the user being able to adjust the volume (turn up or down by a specified number of levels) of the speaker that the system uses.
Sensor Fusion	The main goal for testing the Sensor Fusion Module was to certify that the system could accurately detect distances and locations of both stationary and slow moving object using a fused picture of data from the ultrasonic sensors and Lidar. Tests 1-4 test the ability of the system to detect stationary objects. Tests 5-10 test the ability of the system to default to the Lidar's data points. Tests 11 and 12 test the ability of the system to detect objects in the ultrasonic sensor's blind-spots. Tests 13-15 test the data filtering algorithm on both the Lidar and ultrasonic sensor data. Tests 16-18 tests the detection of a larger stationary object. Test 19 certifies that objects below the $S_{min\_detection}$ aren't treated as obstacles. Tests 20-24 test the systems ability to detect moving obstacles and stationary obstacles. Tests 25-32 test the systems ability to detect stationary, moving, and stationary and moving obstacles while moving forwards.
Systems Diagnostics Module	The main goal for testing the Systems Diagnostics Module was to make sure the system is able to detect a hardware issue with its sensors or Lidar, report the issue to user and suggest that the user stops using the device to prevent providing false information of surrounding obstacles.

5.2 Data Collection Module

The ultrasonic sensors are capable of detecting objects in the range of 0cm to 500cm. The Lidar is capable of detecting objects in the range of 0cm to 1200 cm.

Test Number	**Description**	**Requirement Reference**	**Inputs**	**Expected Outputs**	**Actual Outputs**	**Results**
5.2.01	Testing the ability of the ultrasonic sensors to detect objects that are close by (less than 20cm away)	FR1, FR7	Objects placed at a distance of 15cm away from each of the sensors	Sensor Readings = [15cm, 15cm, 15cm, 15cm, 15cm]	Sensor Readings = [17cm, 15cm, 16cm, 14cm, 15cm]. Note that because of sensor variance any value within +- 5 cm of the expected outputs is correct.	Pass
5.2.02	Testing the ability of the ultrasonic sensors to detect objects that are less than a meter away	FR1, FR7	Objects placed at a distance of 75cm away from each of the sensors	Sensor Readings = [75cm, 75cm, 75cm, 75cm, 75cm]	Sensor Readings = [72cm, 74cm, 75cm, 77cm, 75cm]. Note that because of sensor variance any value within +- 5 cm of the expected outputs is correct.	Pass

5.2.03	Testing the ability of the ultrasonic sensors to detect objects that are 5 meters away	FR1, FR7	Objects placed at a distance of 500cm away from each of the sensors	Sensor Readings = [500cm, 500cm, 500cm, 500cm, 500cm]	Sensor Readings = [499cm, 497cm, 497cm, 498cm, 500cm]. Note that because of sensor variance any value within +- 5 cm of the expected outputs is correct.	Pass
5.2.04	Test that the Lidar is able to detect objects within a 180°field of view, up to a distance of 12 meters away	FR1	An object placed 30cm and 30°away from the left side of the Lidar (the reference point used for 0 °)	Lidar Reading of 30cm for distance and 30°for the detected angle	Lidar Reading of 30cm for distance and 30°for the detected angle	Pass
5.2.05	Test that the Lidar is able to detect objects within a 180°field of view, up to a distance of 12 meters away	FR1	An object placed 100cm and 50°away from the left side of the Lidar (the reference point used for 0 °)	Lidar Reading of 100cm for distance and 50°for the detected angle	Lidar Reading of 100cm for distance and 50°for the detected angle	Pass

5.2.06	Test that the Lidar is able to detect objects within a 180°field of view, up to a distance of 12 meters away	FR1	An object placed 300cm and 90°away from the left side of the Lidar (the reference point used for 0 °)	Lidar Reading of 300cm for distance and 90°for the detected angle	Lidar Reading of 300cm for distance and 90°for the detected angle	Pass
5.2.07	Test that the Lidar is able to detect objects within a 180°field of view, up to a distance of 12 meters away	FR1	An object placed 600cm and 120°away from the left side of the Lidar (the reference point used for 0 °)	Lidar Reading of 600cm for distance and 120°for the detected angle	Lidar Reading of 600cm for distance and 120°for the detected angle	Pass
5.2.08	Test that the Lidar is able to detect objects within a 180°field of view, up to a distance of 12 meters away	FR1	An object placed 1200cm and 180°away from the left side of the Lidar (the reference point used for 0 °)	Lidar Reading of 1200cm for distance and 180°for the detected angle	Lidar Reading of 1200cm for distance and 180°for the detected angle	Pass
5.2.09	Testing the ability to get the current velocity of the user	FR22	User is walking at $1m/s$ in a straight line	Reading of $1m/s$ in the forward direction	Reading of $1m/s$ in the forward direction	Pass

5.2.10	Testing the ability for the Lidar to detect multiple objects at once when all of the objects fall into the 180°field of view and are up to a distance of 12 meters away.	FR7	Objects placed at the following locations: (15cm, 3°), (30cm, 15°), (50cm, 45°), (100cm, 90°), (7000cm, 135°). Each distance, angle pair corresponds to the distance away from the Lidar and the angle in reference to the left side of the Lidar (the reference point used for 0 °)	List of detected distances [15cm, 30cm, 50cm, 100cm, 7000cm] and list of detected angles [3°, 15°, 45°, 90°, 135°] with index i in each of the lists corresponding to object i	List of detected distances [15cm, 30cm, 50cm, 100cm, 7000cm] and list of detected angles [3°, 15°, 45°, 90°, 135°] with index i in each of the lists corresponding to object i	Pass
5.2.11	Testing the left ultra sonic sensor is operational	FR1, FR7	Person standing 150cm in front of the left sensor	Sensor Reading = 150cm	Sensor Reading = 152cm. Note that because of sensor variance any value within +- 5cm of the expected outputs is correct	Pass

5.2.12	Testing the center-left ultra sonic sensor is operational	FR1, FR7	Person standing 150cm in front of the center-left sensor	Sensor Reading = 150cm	Sensor Reading = 149cm. Note that because of sensor variance any value within +- 5cm of the expected outputs is correct	Pass
5.2.13	Testing the center ultra sonic sensor is operational	FR1, FR7	Person standing 150cm in front of the center sensor	Sensor Reading = 150cm	Sensor Reading = 147cm. Note that because of sensor variance any value within +- 5cm of the expected outputs is correct	Pass
5.2.13	Testing the center-right ultra sonic sensor is operational	FR1, FR7	Person standing 150cm in front of the center-right sensor	Sensor Reading = 150cm	Sensor Reading = 153cm. Note that because of sensor variance any value within +- 5cm of the expected outputs is correct	Pass

5.2.14	Testing the right ultra sonic sensor is operational	FR1, FR7	Person standing 150cm in front of the right sensor	Sensor Reading = 150cm	Sensor Reading = 151cm. Note that because of sensor variance any value within +- 5cm of the expected outputs is correct	Pass

Table 3: Data Collection Module Tests

5.3 Object Avoidance System

For this module please note that if there are any sensor readings equal to 1200cm used as an input, this is referring to the max distance reading that can be obtained from the Sensor Fusion algorithm. Typically this correlates to no object being detected.

Test Number	Description	Requirement Reference	Inputs	Expected Outputs	Actual Outputs	Results
5.3.01	Test that the rebound angle calculated by the Object Avoidance algorithm is accurate when there are multiple objects placed in the path of the user	FR19	Sensor readings from Sensor Fusion algorithm = [1200cm, 200cm, 100cm, 1200cm, 1200cm] (this corresponds to objects placed 2m and 1m away in the center-left and center sectors respectively)	Rebound angle = 1.99, Sector = a_3, 'Center-right'	Rebound angle = 1.99, Sector = a_3, 'Center-right'	Pass
5.3.02	Test that the object avoidance algorithm does not output a direction change when no objects are present in front of the user	FR19	Sensor readings from Sensor Fusion algorithm = [1200cm, 1200cm, 1200cm, 1200cm, 1200cm]	Null	Null	Pass

5.3.03	Test rebound angle calculated by the Object Avoidance algorithm for the edge case when the user is nearing a wall	FR9, FR19	Sensor readings from Sensor Fusion algorithm = [1200cm, 200cm, 200cm, 200cm, 1200cm]*	sector a_5, 'right' or sector a_1, 'left'	sector a_5, 'right'	Pass
5.3.04	Testing that the bubble boundary (area in which we start to direct users away from objects) used in the Object Avoidance algorithm grows larger as the user's velocity increases	FR19	A user is walking at a speed of 0.5m/s and then starts walking at a pace of 1m/s.	bubble boundary = [200cm, 200cm, 200cm, 200cm, 200cm]	bubble boundary = [200cm, 200cm, 200cm, 200cm, 200cm]	Pass
5.3.05	Testing that the bubble boundary (area in which we start to direct users away from objects) used in the Object Avoidance algorithm is at least 100cm when the user is standing still	FR19	A user is standing stationary	bubble boundary = [100cm, 100cm, 100cm, 100cm, 100cm]	bubble boundary = [100cm, 100cm, 100cm, 100cm, 100cm]	Pass
5.3.06	Testing that the bubble boundary (area in which we start to direct users away from objects) used in the Object Avoidance algorithm grows to a maximum of 5 meters when the user is walking at 1.5m/s (upper bound of user speed assumption)	FR19	A user is walking at a speed of 1m/s and then starts walking at a pace of 1.5m/s.	bubble boundary = [500cm, 500cm, 500cm, 500cm, 500cm]	bubble boundary = [500cm, 500cm, 500cm, 500cm, 500cm]	Pass

Table 5: Object Avoidance System Tests

5.4 User Guidance Mechanism

Test Number	Description	Requirement Reference	Inputs	Expected Outputs	Actual Outputs	Results
5.4.01	Testing the ability of the left haptic motor to provide guidance to the user (check if the left haptic motor is operational)	FR3, FR9, FR19	A high signal sent from the Arduino to the left haptic motor for 2 seconds, followed by a low signal	Left Haptic motor physically buzzing for 2 seconds	Left Haptic motor physically buzzing for 2 seconds	Pass
5.4.02	Testing the ability of the center-left haptic motor to provide guidance to the user (check if the center-left haptic motor is operational)	FR3, FR9, FR19	A high signal sent from the Arduino to the center-left haptic motor for 2 seconds, followed by a low signal	Center-left Haptic motor physically buzzing for 2 seconds	Center-left Haptic motor physically buzzing for 2 seconds	Pass
5.4.03	Testing the ability of the center haptic motor to provide guidance to the user (check if the center haptic motor is operational)	FR3, FR9, FR19	A high signal sent from the Arduino to the center haptic motor for 2 seconds, followed by a low signal	Center Haptic motor physically buzzing for 2 seconds	Center Haptic motor physically buzzing for 2 seconds	Pass

5.4.04	Testing the ability of the center-right haptic motor to provide guidance to the user (check if the center-right haptic motor is operational)	FR3, FR9, FR19	A high signal sent from the Arduino to the center-right haptic motor for 2 seconds, followed by a low signal	Center-right Haptic motor physically buzzing for 2 seconds	Center-right Haptic motor physically buzzing for 2 seconds	Pass
5.4.05	Testing the ability of the right haptic motor to provide guidance to the user (check if the right haptic motor is operational)	FR3, FR9, FR19	A high signal sent from the Arduino to the right haptic motor for 2 seconds, followed by a low signal	Right Haptic motor physically buzzing for 2 seconds	Right Haptic motor physically buzzing for 2 seconds	Pass
5.4.06	Testing the response time of the user guidance system (from detection of an object to relaying information to the user) so the user avoids a collision with a static object	FR24	User walking at $1m/s$ in a straight line with a box directly in front of them 5000cm away	Haptic motor begins buzzing before the user is 2000cm away from the box	Haptic motor begins buzzing before the user is 2000cm away from the box	Pass

5.4.07	Testing the response time of the user guidance system (from detection of an object to relaying information to the user) so the user avoids a collision with a moving object	FR24	User walking at $1m/s$ in a straight line with a person walking towards them at $1m/s$ from the front and 1000cm away	Haptic motor begins buzzing before the user is less than 4000cm away from the person	Haptic motor begins buzzing before the user is less than 4000cm away from the person	Pass
5.4.08	Test that the speaker is operational	FR13	NextStep relays a message to the user over the speaker	msg_rec = True	msg_rec = True	Pass

Table 7: User Guidance Mechanism Tests

5.5 User Inputs

Test Number	Description	Requirement Reference	Inputs	Expected Outputs	Actual Outputs	Results
5.5.01	Testing that the user can properly enter their height into NextStep using the button on the brim of the hat	FR12, UH2, UH5, UH6	A list, I, of button presses and the pauses between the presses. I = [1, pause, 1, 1, pause, 1, 1, 1, 1, 1, 1, 1, 1, pause, 1, 1, pause, 1, 1, 1, 1, pause, 1, 1]	User height is 182cm	User height is 182cm	Pass

5.5.02	Testing that when the user inputs the wrong height, the system allows for them to correct this by entering in a new height value	FR12	A list, I, of button presses and the pauses between the presses. I = [1, 1, pause, 1, pause, 1, pause, 1,1, pause, 1, 1, 1, 1, 1, 1, 1, pause, 1, 1, pause, 1, 1, pause, 1, 1]	User height is 172cm	User height is 172cm	Pass
5.5.03	Test that the user is able to turn the volume of the speaker down	FR 13	User turns the volume, vol, down two levels given that it starts at level 6	vol = 4	vol = 4	Pass
5.5.04	Test that the user is able to turn the volume of the speaker up	FR 13	User turns the volume, vol, up two levels given that it starts at level 4	vol = 6	vol = 6	Pass
5.5.05	Test the the button is operational and that clicks are registered	FR12	User presses the button	b_press = True	b_press = True	Pass

Table 9: User Input Tests

5.6 Sensor Fusion

For this module please note that if there are any sensor readings equal to 1200cm used as an input, this is referring to the max distance reading that can be obtained from the Sensor Fusion algorithm. Typically this correlates to no object being detected. The ultrasonic sensors are capable of detecting objects in the range of 0cm to 500cm. The Lidar is capable of detecting objects in the range of 0cm to 1200 cm.

Test Number	**Description**	**Requirement Reference**	**Inputs**	**Expected Outputs**	**Actual Outputs**	**Results**
5.6.01	Testing an object placed in front of each ultrasonic sensor at the edge case of less than 20cm is calculated to be in the correct position after fusion.	FR1	Water-bottle placed at 15cm in front of left most ultrasonic sensor (Repeat for all 5 ultrasonic sensors)	Object readings at [15cm, 1200cm, 1200cm, 1200cm, 1200cm]	Object readings at [18cm, 1200cm, 1200cm, 1200cm, 1200cm]	Pass
5.6.02	Testing an object placed in front of each ultrasonic sensor at the edge case of 500cm is calculated to be in the correct position after fusion.	FR1	Water-bottle placed at 500cm in front of left most ultrasonic sensor (Repeat for all 5 ultrasonic sensors)	Object readings at [500cm, 1200cm, 1200cm, 1200cm, 1200cm]	Object readings at [502cm, 500cm, 1200cm, 1200cm, 1200cm]	Pass
5.6.03	Testing that a wall is correctly detected after the distance vector is calculated.	FR9	Aim device at a wall that is 200 cm away.	Object reading at [1200cm, 250cm, 200cm, 250cm, 1200cm] away	Object reading at [1200cm, 246cm, 203cm, 247cm, 1200cm]	Pass

5.6.04	Testing the ability of the system to detect multiple objects at once, with each of the objects at varying distances	FR1, FR7	Objects placed at (150cm, 25°), (30cm, 60°) and (300cm, 100°) in front of device	Object readings at [1200cm, 1200cm, 300cm, 30cm, 150cm]	Object readings at [1200cm, 1200cm, 302cm, 26cm, 151cm]	Pass
5.6.05	Test that when the ultrasonic sensors return faulty data that the Sensor Fusion algorithm will revert to relying solely on the Lidar data	FR1	Aim Lidar at the wrong angle to synthesize only the ultrasonic sensors detecting objects. Place a book at (150cm, 90°)	Object readings at [1200cm, 1200cm, 1200cm, 1200cm, 1200cm]	Object readings at [1200cm, 1200cm, 1200cm, 1200cm, 1200cm]	Pass
5.6.06	Test that when the ultrasonic sensors return faulty data that the Sensor Fusion algorithm will revert to relying solely on the Lidar data	FR1	Aim ultrasonic sensors at the wrong angle to synthesize only the Lidar detecting objects. Place a computer screen at (150cm, 145°)	Object readings at [1200cm, 1200cm, 1200cm, 1200cm, 150cm]	Object readings at [1200cm, 1200cm, 1200cm, 1200cm, 153cm]	Pass

5.6.07	Test that when the ultrasonic sensors return faulty data that the Sensor Fusion algorithm will revert to relying solely on the Lidar data	FR1	Aim ultrasonic sensors at the wrong angle to synthesize only the Lidar detecting objects. Place a computer screen at (150cm, 45°)	Object readings at [1200cm, 150cm, 1200cm, 1200cm, 1200cm]	Object readings at [1200cm, 151cm, 1200cm, 1200cm, 1200cm]	Pass
5.6.08	Test that when the Lidar returns faulty data that the Sensor Fusion algorithm will revert to relying solely on the ultrasonic sensor data	FR1	Aim Lidar at the wrong angle to synthesize only the ultrasonic sensor detecting objects. Place a book at (150cm, 90°)	Object readings at [1200cm, 1200cm, 150cm, 1200cm, 1200cm]	Object readings at [1200cm, 1200cm, 149cm, 1200cm, 1200cm]	Pass
5.6.09	Test that when the Lidar returns faulty data that the Sensor Fusion algorithm will revert to relying solely on the ultrasonic sensor data	FR1	Aim Lidar at the wrong angle to synthesize only the ultrasonic sensor detecting objects. Place a book at (150cm, 145°)	Object readings at [150cm, 150cm, 1200cm, 1200cm, 1200cm]	Object readings at [150cm, 146cm, 1200cm, 1200cm, 1200cm]	Pass

5.6.10	Test that when the Lidar returns faulty data that the Sensor Fusion algorithm will revert to relying solely on the ultrasonic sensor data	FR1	Aim Lidar at the wrong angle to synthesize only the ultrasonic sensor detecting objects. Place a book at (150cm, 45°)	Object readings at [1200cm, 1200cm, 1200cm, 150cm, 150cm]	Object readings at [1200cm, 1200cm, 1200cm, 154cm, 147cm]	Pass
5.6.11	Testing object detection in ultrasonic sensor blind-spots where only Lidar will pick up objects	FR1	Place cup at (20cm, 36°)	Object readings at [1200cm, 1200cm, 20cm, 1200cm, 1200cm]	Object readings at [1200cm, 1200cm, 22cm, 1200cm, 1200cm]	Pass
5.6.12	Testing object detection in ultrasonic sensor blind-spots where only Lidar will pick up objects	FR1	Place cup at (25cm, 108°)	Object readings at [1200cm, 1200cm, 25cm, 1200cm, 1200cm]	Object readings at [1200cm, 1200cm, 23cm, 1200cm, 1200cm]	Pass
5.6.13	Testing data filtering of Lidar garnered data	FR1	Place book at (230cm, 90°)	Lidar data reading is [1200cm, 1200cm, 230cm, 1200cm, 1200cm]	Lidar data reading is [1200cm, 1200cm, 234cm, 1200cm, 1200cm]	Pass
5.6.14	Testing data filtering of Lidar garnered data	FR1	Place book at (150cm, 10°)	Lidar data reading is [1200cm, 1200cm, 1200cm, 1200cm, 150cm]	[1200cm, 1200cm, 1200cm, 1200cm, 149cm]	Pass

5.6.15	Testing data filtering of ultrasonic sensor garnered data	FR1	Place book at 150cm directly in front of the leftmost ultrasonic sensor (Repeat for all 5 ultrasonic sensors)	ultrasonic sensor data reading is [150cm, 1200cm, 1200cm, 1200cm, 150cm]	ultrasonic sensor data reading is [154cm, 1200cm, 1200cm, 1200cm, 149cm]	Pass
5.6.16	Testing larger objects detected as being in 2 different sectors (from the Obstacle Avoidance Algorithm)	FR1	Place chair at (100cm, 36°)	Object readings at [1200cm, 1200cm, 1200cm, 100cm, 100cm]	Object readings at [1200cm, 1200cm, 1200cm, 102cm, 100cm]	Pass
5.6.17	Testing larger objects detected as being in 2 different sectors (from the Obstacle Avoidance Algorithm)	FR1	Place chair at (130cm, 108°)	Object readings at [1200cm, 130cm, 130cm, 1200cm, 1200cm]	Object readings at [1200cm, 130cm, 125cm, 1200cm, 1200cm]	Pass
5.6.18	Testing larger objects detected as being in 2 different sectors (from the Obstacle Avoidance Algorithm)	FR1	Place chair at 160cm, 144°)	Object readings at [160cm, 160cm, 1200cm, 1200cm, 1200cm]	Object readings at [163cm, 156cm, 1200cm, 1200cm, 1200cm]	Pass
5.6.19	Testing that an object smaller than $S_{min\_detection}$ is not considered a detected objected	FR17	Place an object smaller than $S_{min\_detection}$ at (300cm, 90)	Object readings are [1200cm, 1200cm, 1200cm, 1200cm, 1200cm]	Object readings are [1200cm, 1200cm, 1200cm, 1200cm, 1200cm]	Pass

5.6.20	Testing the detection of slow moving obstacle that walks away in a straight line in the same sector	A person stands directly in front of center ultrasonic sensor (at distance 200cm) and slowly walks away from device at a speed of $50cm/sec$ (Repeat for remaining 4 sectors)	FR1	Object readings are initially [500cm, 500cm, 200cm, 500cm, 500cm] and changes to [1200cm, 1200cm, 250cm, 1200cm, 1200cm] after 1 second, [1200cm, 1200cm, 300cm, 1200cm, 1200cm] after 2 seconds, [1200cm, 1200cm, 350cm, 1200cm, 1200cm] after 3 seconds, [1200cm, 1200cm, 400cm, 1200cm, 1200cm] after 4 seconds, [1200cm, 1200cm, 450cm, 1200cm, 1200cm] after 5 seconds and [1200cm, 1200cm, 1200cm, 1200cm, 1200cm] after 6 seconds	Object readings are initially [1200cm, 1200cm, 202cm, 1200cm, 1200cm] and changes to [1200cm, 1200cm, 249cm, 1200cm, 1200cm] after 1 second, [1200cm, 1200cm, 300cm, 1200cm, 1200cm] after 2 seconds, [1200cm, 1200cm, 353cm, 1200cm, 1200cm] after 3 seconds, [1200cm, 1200cm, 397cm, 1200cm, 1200cm] after 4 seconds, [1200cm, 1200cm, 445cm, 1200cm, 1200cm] after 5 seconds and [1200cm, 1200cm, 1200cm, 1200cm, 1200cm] after 6 seconds	Pass

5.6.21	Testing the detection of a slow moving obstacle moving across sectors while maintaining the same distance away from device	FR1	A person stands at (275 cm away from center ultrasonic sensor) and walks left at a pace of 1 sector-width per 2 seconds	Object readings initially are [1200cm, 1200cm, 275cm, 1200cm, 1200cm], [1200cm, 275cm, 1200cm, 1200cm, 1200cm] after 2 seconds, [275cm, 1200cm, 1200cm, 1200cm, 1200cm] after 4 seconds and [1200cm, 1200cm, 1200cm, 1200cm, 1200cm] after 5 seconds	Object readings initially are [1200cm, 1200cm, 276cm, 1200cm, 1200cm], [1200cm, 275cm, 1200cm, 1200cm, 1200cm] after 2 seconds, [277cm, 1200cm, 1200cm, 1200cm, 1200cm] after 4 seconds and [1200cm, 1200cm, 1200cm, 1200cm, 1200cm] after 5 seconds	Pass

5.6.22	Testing the detection of a slow moving obstacle moving across sectors at an angle	FR1	A person stands in the left most sector at a distance of 350 cm and moves across (at a speed of 1 sector-width per 2 seconds) the sectors such that they enter each new sector 50 cm closer than the previous entry	Object reading initially is [350cm, 1200cm, 1200cm, 1200cm, 1200cm], after 2 seconds is [1200cm, 300cm, 1200cm, 1200cm, 1200cm], after 4 seconds is [1200cm, 1200cm, 250cm, 1200cm, 1200cm], after 6 seconds is [1200cm, 1200cm, 1200cm, 200cm, 1200cm] and after 8 seconds is [1200cm, 1200cm, 1200cm, 1200cm, 150cm]	Object reading initially is [351cm, 1200cm, 1200cm, 1200cm, 1200cm], after 2 seconds is [1200cm, 297cm, 1200cm, 1200cm, 1200cm], after 4 seconds is [1200cm, 1200cm, 252cm, 1200cm, 1200cm], after 6 seconds is [1200cm, 1200cm, 1200cm, 200cm, 1200cm] and after 8 seconds is [1200cm, 1200cm, 1200cm, 1200cm, 155cm]	Pass

5.6.23	Testing detection of a stationary obstacle and a moving obstacle	FR1	Place a book at (200cm, 90°) and have a person start at 100cm in the right most sector and move left at 1 sector-width/2 seconds while maintaining their distance from the device	Object reading initially is [1200cm, 1200cm, 200cm, 1200cm, 100cm], after 2 seconds is [1200cm, 1200cm, 200cm, 100cm, 1200cm], after 4 seconds is [1200cm, 1200cm, 100cm, 1200cm, 1200cm], after 6 seconds is [1200cm, 100cm, 200cm, 1200cm, 1200cm] and after 8 seconds is [100cm, 1200cm, 200cm, 1200cm, 1200cm]	Object reading initially is [1200cm, 1200cm, 201cm, 1200cm, 97cm], after 2 seconds is [1200cm, 1200cm, 202cm, 100cm, 1200cm], after 4 seconds is [1200cm, 1200cm, 99cm, 1200cm, 1200cm], after 6 seconds is [1200cm, 101cm, 1200cm, 1200cm, 1200cm] and after 8 seconds is [105cm, 1200cm, 198cm, 1200cm, 1200cm]	Pass

5.6.24	Testing detection of a stationary obstacle and a moving obstacle	FR1	Place a book at (200cm, 170°) and have a person start at 100cm in the right most sector and move left at 1 sector-width per 2 seconds while maintaining their distance from the device	Object reading initially is [200cm, 1200cm, 1200cm, 1200cm, 100cm], after 2 seconds is [200cm, 1200cm, 1200cm, 100cm, 1200cm], after 4 seconds is [200cm, 1200cm, 100cm, 1200cm, 1200cm], after 6 seconds is [200cm, 100cm, 1200cm, 1200cm, 1200cm] and after 8 seconds is [100cm, 1200cm, 1200cm, 1200cm, 1200cm]	Object reading initially is [201cm, 1200cm, 1200cm, 1200cm, 102cm], after 2 seconds is [203cm, 1200cm, 1200cm, 100cm, 1200cm], after 4 seconds is [204cm, 1200cm, 96cm, 500cm, 500cm], after 6 seconds is [203cm, 101cm, 1200cm, 1200cm, 1200cm] and after 8 seconds is [96cm, 1200cm, 1200cm, 1200cm, 1200cm]	Pass

5.6.25	Testing the detection of an obstacle while the sensors are moving towards it	FR1	Place an obstacle in the center sector at a distance of 300 cm (Repeat for all sectors), move the sensors at a speed of $50 cm/sec$ straight towards the object	Object reading initially is [1200cm, 1200cm, 300cm, 1200cm, 1200cm], after 1 second is [1200cm, 1200cm, 250cm, 1200cm, 1200cm] and after 3 seconds is [1200cm, 1200cm, 150cm, 1200cm, 1200cm]	Object reading initially is [1200cm, 1200cm, 301cm, 1200cm, 1200cm], after 1 second is [1200cm, 1200cm, 252cm, 1200cm, 1200cm] and after 3 seconds is [1200cm, 1200cm, 147cm, 1200cm, 1200cm]	Pass
5.6.26	Testing that a wall is correctly detected while moving towards it	FR9	Aim device at a wall that is 200 cm away and move the sensors at a speed of $50 cm/sec$ straight towards the wall	Object reading initially at [1200cm, 245cm, 200cm, 245cm, 1200cm], after 1 second is [1200cm, 200cm, 150cm, 200cm, 1200cm], and after 3 seconds is [1200cm, 75cm, 50cm, 75cm, 1200cm]	Object reading initially at [1200cm, 245cm, 198cm, 246cm, 1200cm], after 1 second is [1200cm, 199cm, 153cm, 204cm, 1200cm], and after 3 seconds is [120cm, 75cm, 52cm, 77cm, 1200cm]	Pass

5.6.27	Testing the detection of multiple objects at different distances while moving towards them	FR1, FR7	Place books at (150cm, 25°), (30cm, 60°) and (300cm, 100°) in front of device and move the sensors at a speed of $50cm/sec$ straight forward	Object readings initially are [1200cm, 1200cm, 300cm, 30cm, 150cm], after 1 second are [1200cm, 1200cm, 250cm, 1200cm, 100cm] and after 3 seconds are [1200cm, 1200cm, 150cm, 1200cm, 1200cm]	Object readings initially are [1200cm, 1200cm, 302cm, 31cm, 150cm], after 1 second are [1200cm, 1200cm, 250cm, 1200cm, 99cm] and after 3 seconds are [1200cm, 1200cm, 152cm, 1200cm, 1200cm]	Pass
5.6.28	Testing larger objects detected as being in multiple sectors while moving towards them	FR1	Place chair at (350cm, 36°) and move sensors forward at $100cm/sec$	Object readings are initially at [1200cm, 1200cm, 1200cm, 350cm, 350cm], after 1 second are [1200cm, 1200cm, 1200cm, 250cm, 250cm] and after 2 seconds are [1200cm, 1200cm, 1200cm, 150cm, 150cm]	Object readings are initially at [1200cm, 1200cm, 1200cm, 351cm, 351cm], after 1 second are [1200cm, 1200cm, 1200cm, 251cm, 251cm] and after 2 seconds are [1200cm, 1200cm, 1200cm, 149cm, 149cm]	Pass

5.6.29	Testing the detection of slow moving obstacle that walks away in a straight line in the same sector while the sensors move forwards	FR1	A person stands directly in front of center ultrasonic sensor (at distance 350cm) and slowly walks away from device at a speed of $50cm/sec$ (Repeat for remaining 4 sectors) while the sensors are moved forward at $100cm/sec$	Object readings are initially [1200cm, 1200cm, 350cm, 1200cm, 1200cm] and changes to [1200cm, 1200cm, 300cm, 1200cm, 1200cm] after 1 second, [1200cm, 1200cm, 250cm, 1200cm, 1200cm] after 2 seconds, [1200cm, 1200cm, 200cm, 1200cm, 1200cm] after 3 seconds, [1200cm, 1200cm, 150cm, 1200cm, 1200cm] after 4 seconds, and [1200cm, 1200cm, 100cm, 1200cm, 1200cm] after 5 seconds	Object readings are initially [1200cm, 1200cm, 347cm, 1200cm, 1200cm] and changes to [1200cm, 1200cm, 299cm, 1200cm, 1200cm] after 1 second, [1200cm, 1200cm, 254cm, 1200cm, 1200cm] after 2 seconds, [1200cm, 1200cm, 200cm, 1200cm, 1200cm] after 3 seconds, [1200cm, 1200cm, 145cm, 1200cm, 1200cm] after 4 seconds, and [1200cm, 1200cm, 98cm, 1200cm, 1200cm] after 5 seconds	Pass

5.6.30	Testing the detection of a slow moving obstacle moving across sectors while maintaining the same distance away from device as the sensors move forward	FR1	A person stands at 275 cm away from center ultrasonic sensor and walks left at a pace of 1 sector-width per 2 seconds while the sensors move forward at 25cm/sec	Object readings initially are [1200cm, 1200cm, 275cm, 1200cm, 1200cm], [1200cm, 225cm, 1200cm, 1200cm, 1200cm] after 2 seconds, [175cm, 1200cm, 1200cm, 1200cm, 1200cm] after 4 seconds and [1200cm, 1200cm, 1200cm, 1200cm, 1200cm] after 5 seconds	Object readings initially are [1200cm, 1200cm, 273cm, 1200cm, 1200cm], [1200cm, 226cm, 1200cm, 1200cm, 1200cm] after 2 seconds, [172cm, 1200cm, 1200cm, 1200cm, 1200cm] after 4 seconds and [1200cm, 1200cm, 1200cm, 1200cm, 1200cm] after 5 seconds	Pass

5.6.31	Testing the detection of a slow moving obstacle moving across sectors at an angle while the sensors are moving	FR1	A person stands in the left most sector at a distance of 450 cm and moves across (at a speed of 1 sector-width per 2 seconds) the sectors such that they enter each new sector 50 cm closer than the previous entry while the sensors move forward at $25cm/sec$	Object reading initially is [450cm, 1200cm, 1200cm, 1200cm, 1200cm], after 2 seconds is [1200cm, 350cm, 1200cm, 1200cm, 1200cm], after 4 seconds is [1200cm, 1200cm, 250cm, 1200cm, 1200cm], after 6 seconds is [12000cm, 1200cm, 1200cm, 150cm, 1200cm] and after 8 seconds is [1200cm, 1200cm, 1200cm, 1200cm, 50cm]	Object reading initially is [446cm, 1200cm, 1200cm, 1200cm, 1200cm], after 2 seconds is [1200cm, 353cm, 1200cm, 1200cm, 1200cm], after 4 seconds is [1200cm, 1200cm, 253cm, 1200cm, 1200cm], after 6 seconds is [12000cm, 1200cm, 1200cm, 154cm, 1200cm] and after 8 seconds is [1200cm, 1200cm, 1200cm, 1200cm, 45cm]	Pass

5.6.32	Testing detection of a stationary obstacle and a moving obstacle while the sensors are moving forward	FR1	Place a book at (200cm, 170°) and have a person start at 400cm in the right most sector and move left at $1 sector-width/sec$ while maintaining their distance from the device while the sensors move forward at $50 cm/sec$	Object reading initially is [200cm, 1200cm, 1200cm, 1200cm, 400cm], after 2 seconds is [100cm, 1200cm, 1200cm, 300cm, 1200cm], after 4 seconds is [1200cm, 1200cm, 200cm, 1200cm, 1200cm], after 6 seconds is [1200cm, 100cm, 1200cm, 1200cm, 1200cm] and after 8 seconds is [1200cm, 1200cm, 1200cm, 1200cm, 1200cm]	Object reading initially is [201cm, 1200cm, 1200cm, 1200cm, 403cm], after 2 seconds is [98cm, 1200cm, 1200cm, 298cm, 1200cm], after 4 seconds is [1200cm, 1200cm, 197cm, 1200cm, 1200cm], after 6 seconds is [1200cm, 96cm, 1200cm, 1200cm, 1200cm] and after 8 seconds is [1200cm, 1200cm, 1200cm, 1200cm, 1200cm]	Pass

Table 11: Sensor Fusion Tests

5.7 System Diagnostics Module/Safety Requirements Tests

Test Number	Description	Requirement Reference	Inputs	Expected Outputs	Actual Outputs	Results
5.7.01	Test that the system is able to detect a connection issue between the Lidar and the Arduino	FR14	Loosen the power connection of Lidar	Informing the user that there is a connection issue with Lidar via the speaker.	Informing the user that there is a connection issue with Lidar via the speaker	Pass
5.7.02	Test that the system is able to detect something blocking the Lidar	FR14	Place your hands at 5cm away from Lidar covering its front, left and right	Informing the user, via the speaker, that the Lidar is blocked and requesting they attempt to unblock the Lidar	Informing the user, via the speaker, that the Lidar is blocked and requesting they attempt to unblock the Lidar	Pass
5.7.03	Test that the system is able to detect a connection issue between any of the ultrasonic sensors and the Arduino	FR14	Loosen the power connection of the front facing ultrasonic sensors (repeat for all ultrasonic sensors)	Inform the user that there is a connection issue with the front facing ultrasonic sensor via the speaker	Inform the user that there is a connection issue with the front facing ultrasonic sensor via the speaker	Pass
5.7.04	Test that the system is able to detect any of the ultrasonic sensors being blocked by a obstacle	FR14	Place hand 5cm in front of the front facing ultrasonic sensor (repeat for all the ultrasonic sensors)	Inform the user that the front facing ultrasonic sensor is being blocked via the speaker	Inform the user that the front facing ultrasonic sensor is being blocked via the speaker	Pass

5.7.05	Test that the system is able to detect a connection issue between the input button and the Arduino	FR14	Loosen the data connection cable between input button and Arduino, and run the procedure for user inputting their height	Inform the user that there is a connection issue with the input button via the speaker	Inform the user that there is a connection issue with the input button via the speaker	Pass
5.7.06	Test that the system is able to detect a connection issue between the accelerometer and the Arduino	FR14	Loosen the power connection of the accelerometer	Inform the user that there is a connection issue with the accelerometer via the speaker	Inform the user that there is a connection issue with the accelerometer via the speaker	Pass

Table 13: System Diagnostics Module/Safety Requirements Tests

5.8 Integration Testing

Since testing for the Sensor Fusion module inherently does integration testing with the Data Collection module and testing for User Guidance module also performs integration testing with the Object Avoidance module, the integration testing will only include testing for the overall system.

Test Number	**Description**	**Requirement Reference**	**Inputs**	**Expected Outputs**	**Actual Outputs**	**Results**
5.8.01	Test the system's ability to direct the user around a stationary obstacle	FR1, FR7, PR1, PR5	An obstacle placed 2 meters directly ahead	Center-right haptic motor buzzing	Center-right haptic motor buzzing	Pass

5.8.02	Test the system's ability to guide a user past a stationary obstacle while the user is moving at 50cm/s	FR1, FR7, PR1, PR5	Place an obstacle 2 meters directly ahead	Initially center-right haptic motor buzzing, after 2 seconds, user turns to the right and the center haptic motor buzzes, after 3 seconds no buzzing.	Initially center-right haptic motor buzzing, after 2 seconds, user turns to the right and the center haptic motor buzzes, after 3 seconds no buzzing	Pass
5.8.03	Test the system's ability to guide a user past multiple obstacle while the user is moving at 50cm/s	FR1, FR7, PR1, PR5	Place an obstacle at (150cm, -90°), (30cm, -45°) and (300cm, 0°, moving toward user's initial position at 50cm/s) in front of user	Initially center haptic motor buzzing, after 1.5 seconds, center-right haptic motor buzzes and user turns to the right, then the center buzzer buzzes, after 2 seconds no buzzing.	Initially center haptic motor buzzing, after 1.5 seconds, center-right haptic motor buzzes and user turns to the right, then the center buzzer buzzes, after 2 seconds no buzzing	Pass

Table 15: Integration Tests

6 Beyond Testing

In addition to testing, the NextStep development team utilized code reviews. The code reviews served the purpose of ensuring that any code being submitted was clear, concise, and functionally correct. This process worked by assigning each file an "owner" who would be an expert on the contents of that file.

Each time a member of the development team wanted to add some code/functionality to that specific file the owner of the file would be added to the code review where they could leave any comments or suggestions as to how to improve the code before any changes were committed. If multiple files were worked on for a given change then the code review would have the owners from each of those files added to the review. If the file owner made changes to their own file then another developer would be added to the review to step in as the temporary file owner for the purposes of this review (Ideally this temporary owner has prior experience contributing code to that file).

7 Supporting Material

Please refer to the updated REV1 documents for further support in understanding the system.

8 Traceability Matrices

The following traceability matrices map the functional and non-functional requirements to the test cases outlined in previous sections.

Test Cases	**Functional and Non-Functional Requirements**
5.2.01	FR1, FR7, PR5
5.2.02	FR1, FR7, PR5
5.2.03	FR1, FR7, PR5
5.2.04	FR1, PR5
5.2.05	FR1, PR5
5.2.06	FR1, PR5
5.2.07	FR1, PR5
5.2.08	FR1, PR5
5.2.09	FR22
5.2.10	FR7
5.2.11	FR1,FR7
5.2.12	FR1,FR7
5.2.13	FR1,FR7
5.2.14	FR1,FR7

Table 16: Data Collection Module Traceability

Test Cases	**Functional and Non-Functional Requirements**
5.3.01	FR19
5.3.02	FR19
5.3.03	FR9, FR19
5.3.04	FR19
5.3.05	FR19
5.3.06	FR19

Table 17: Object Avoidance System Traceability

Test Cases	Functional and Non-Functional Requirements
5.4.01	FR3, FR9, FR19
5.4.02	FR3, FR9, FR19
5.4.03	FR3, FR9, FR19
5.4.04	FR3, FR9, FR19
5.4.05	FR3, FR9, FR19
5.4.06	FR24, PR1
5.4.07	FR24, PR1
5.4.08	FR13

Table 18: User Guidance Mechanism Traceability

Test Cases	Functional and Non-Functional Requirements
5.5.01	FR12, UH2, UH5, UH6
5.5.02	FR12
5.5.03	FR13
5.5.04	FR13
5.5.05	FR12

Table 19: User Inputs Traceability

Test Cases	Functional and Non-Functional Requirements
5.6.01	FR1
5.6.02	FR1
5.6.03	FR9
5.6.04	FR1, FR7
5.6.05	FR1
5.6.06	FR1
5.6.07	FR1
5.6.08	FR1
5.6.09	FR1
5.6.10	FR1
5.6.11	FR1
5.6.12	FR1
5.6.13	FR1
5.6.14	FR1
5.6.15	FR1
5.6.16	FR1
5.6.17	FR1
5.6.18	FR1
5.6.19	FR17
5.6.20	FR1
5.6.21	FR1
5.6.22	FR1
5.6.23	FR1
5.6.24	FR1
5.6.25	FR1
5.6.26	FR9
5.6.27	FR1, FR7
5.6.28	FR1
5.6.29	FR1
5.6.30	FR1
5.6.31	FR1
5.6.32	FR1

Table 20: Sensor Fusion Traceability

Test Cases	**Functional and Non-Functional Requirements**
5.7.01	FR14
5.7.02	FR14
5.7.03	FR14
5.7.04	FR14
5.7.05	FR14
5.7.06	FR14

Table 21: System Diagnostics Module Traceability

Test Cases	**Functional and Non-Functional Requirements**
5.8.01	FR1, FR7, PR1, PR5
5.8.02	FR1, FR7, PR1, PR5
5.8.03	FR1, FR7, PR1, PR5

Table 22: Integration Testing Traceability