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

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.

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

Test Number	Description	Requirement Reference	Inputs	Expected Outputs	Actual Outputs	Results
01	Testing the detection of objects placed 15cm in front of each of the five ultrasonic sensors	FR1, FR7	Books placed at the specified distance in front of each sensor	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
02	Testing the detection of objects placed 5cm in front of each of the five ultrasonic sensors	FR1, FR7	Books placed at the specified distance in front of each sensor	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

03	Testing the detection of objects placed 175cm in front of each of the five ultrasonic sensors	FR1, FR7	Books placed at the specified distance in front of each sensor	Sensor Readings = [175cm, 175cm, 175cm, 175cm, 175cm]	Sensor Readings = [171cm, 174cm, 176cm, 175cm, 175cm]. Note that because of sensor variance any value within +- 5 cm of the expected outputs is correct.	Pass
04	Testing the detection of an object placed 30cm and 30°in front of the Lidar	FR1	Book placed at the specified distance in front of the Lidar	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
05	Testing the detection of an object placed 100cm and 50°in front of the Lidar	FR1	Book placed at the specified distance in front of the Lidar	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
06	Testing the detection of an object placed 300cm and 90°in front of the Lidar	FR1	Book placed at the specified distance in front of the Lidar	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
07	Testing the detection of an object placed 600cm and 120°in front of the Lidar	FR1	Book placed at the specified distance in front of the Lidar	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

08	Testing the detection of an object placed 1000cm and 180°in front of the Lidar	FR1	Book placed at the specified distance in front of the Lidar	Lidar Reading of 1000cm for distance and 180°for the detected angle	Lidar Reading of 1000cm for distance and 180°for the detected angle	Pass
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
10	Testing the ability for the Lidar to detect multiple objects at once	FR7	Objects placed at	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

Table 3: Data Collection Module Tests

5.3 Object Avoidance System

Test Number	Description	Requirement Reference	Inputs	Expected Outputs	Actual Outputs	Results
01	Test rebound angle for multiple detected objects	FR19	Object readings = [500cm, 200cm, 100cm, 500cm, 500cm]*, 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
02	Test object avoidance when no objects are present within the bubble boundary	FR19	Object readings = [500cm, 500cm, 500cm, 500cm, 500cm]*	Nothing	Nothing	Pass
03	Test rebound angle nearing a wall of objects	FR9, FR19	Object reading = [500cm, 200cm, 200cm, 200cm, 500cm]*	sector a_5, 'right'	sector a_5, 'right'	Pass
04	Testing the update of the bubble boundary while a user is moving	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

05	Testing the ability to narrow object readings based on current bubble boundary	FR19	User is walking with speed of 1m/s and object readings = [500cm, 500cm, 100cm, 300cm, 500cm]	Filtered objects = [200cm, 200cm, 100cm, 200cm, 200cm]	Filtered objects = [200cm, 200cm, 100cm, 200cm, 200cm]	Pass

Table 5: Object Avoidance System Tests

5.4 User Guidance Mechanism

Test Number	**Description**	**Requirement Reference**	**Inputs**	**Expected Outputs**	**Actual Outputs**	**Results**
01	Testing the ability of the left haptic motor to provide guidance to the user	FR3, FR9, FR19	Books placed in front of the center-left, center, right-center and right ultrasonic sensors	Left Haptic motor physically buzzing	Left Haptic motor physically buzzing	Pass
02	Testing the ability of the center-left haptic motor to provide guidance to the user	FR3, FR9, FR19	Books placed in front of the left, center, right-center and right ultrasonic sensors	Center-left Haptic motor physically buzzing	Center-left Haptic motor physically buzzing	Pass

03	Testing the ability of the center haptic motor to provide guidance to the user	FR3, FR9, FR19	Books placed in front of the left, center-left, right-center and right ultrasonic sensors	Center Haptic motor physically buzzing	Center Haptic motor physically buzzing	Pass
04	Testing the ability of the center-right haptic motor to provide guidance to the user	FR3, FR9, FR19	Books placed in front of the left, center-left, center and right ultrasonic sensors	Center-right Haptic motor physically buzzing	Center-right Haptic motor physically buzzing	Pass
05	Testing the ability of the right haptic motor to provide guidance to the user	FR3, FR9, FR19	Books placed in front of the left, center-left, center, and center-right ultrasonic sensors	Right Haptic motor physically buzzing	Right Haptic motor physically buzzing	Pass
06	Testing the response time of the user guidance system to avoid collision with a static object	FR24	User walking at $1m/s$ in a straight line with a box directly in front of them 5mes away	Haptic motor buzzing before the user is 2m away from the box	Haptic motor buzzing before the user is 5m away from the box	Pass

07	Testing the response time of the user guidance system to avoid 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 10m away	Haptic motor buzzing before the user is 4m away from the box	Haptic motor buzzing before the user is 5m away from the box	Pass

Table 7: User Guidance Mechanism Tests

5.5 User Inputs

Test Number	**Description**	**Requirement Reference**	**Inputs**	**Expected Outputs**	**Actual Outputs**	**Results**
01	Testing that the user can enter a correct height	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

02	Testing that when the user inputs the wrong height they are able to remedy this	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, pause, 1, 1, pause, 1, 1, pause, 1, 1]	User height is 172cm	User height is 172cm	Pass
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
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

Table 9: User Input Tests

5.6 Sensor Fusion

Test Number	Description	Requirement Reference	Inputs	Expected Outputs	Actual Outputs	Results
01	Testing an object placed in front of each ultrasonic sensor is detected in the same location by both the Lidar and ultrasonic sensor	FR1	Water-bottle placed at 80cm in front of left most ultrasonic sensor (Repeat for all 5 ultrasonic sensors)	Object readings at [80cm, 500cm, 500cm, 500cm, 500cm]	TBD	TBD
02	Testing an object placed in front of each ultrasonic sensor is detected in the same location by both the Lidar and ultrasonic sensor	FR1	Water-bottle placed at 285cm in front of left most ultrasonic sensor (Repeat for all 5 ultrasonic sensors)	Object readings at [285cm, 500cm, 500cm, 500cm, 500cm]	TBD	TBD
03	Testing that a wall is correctly detected	FR9	Aim device at a wall that is 200 cm away.	Object reading at [200cm, 200cm, 200cm, 200cm, 200cm] away	TBD	TBD
04	Testing the detection of multiple objects at different distances	FR1, FR7	Place books at (150cm, 25°), (30cm, 60°) and (300cm, 100°) in front of device	Object readings at [500cm, 500cm, 300cm, 30cm, 150cm]	TBD	TBD

05	Testing the defaulting of the system detection to the Lidar	FR1	Aim Lidar at the wrong angle to synthesize only the ultrasonic sensors detecting objects. Place a book at (150cm, 90°)	Object readings at [500cm, 500cm, 500cm, 500cm, 500cm]	TBD	TBD
06	Testing the defaulting of the system detection to the Lidar	FR1	Aim Lidar at the wrong angle to synthesize only the ultrasonic sensors detecting objects. Place a computer screen at (150cm, 145°)	Object readings at [500cm, 500cm, 500cm, 500cm, 500cm]	TBD	TBD
07	Testing the defaulting of the system detection to the Lidar	FR1	Aim Lidar at the wrong angle to synthesize only the ultrasonic sensors detecting objects. Place a computer screen at (150cm, 45°)	Object readings at [500cm, 500cm, 500cm, 500cm, 500cm]	TBD	TBD

08	Testing the defaulting of the system detection to the Lidar	FR1	Aim ultrasonic sensors at the wrong angle to synthesize only the Lidar detecting objects. Place a book at (150cm, 90°)	Object readings at [500cm, 500cm, 150cm, 500cm, 500cm]	TBD	TBD
09	Testing the defaulting of the system detection to the Lidar	FR1	Aim ultrasonic sensors at the wrong angle to synthesize only the Lidar detecting objects. Place a book at (150cm, 145°)	Object readings at [150cm, 150cm, 500cm, 500cm, 500cm]	TBD	TBD
10	Testing the defaulting of the system detection to the Lidar	FR1	Aim ultrasonic sensors at the wrong angle to synthesize only the Lidar detecting objects. Place a book at (150cm, 45°)	Object readings at [500cm, 500cm, 500cm, 150cm, 150cm]	TBD	TBD
11	Testing object detection in ultrasonic sensor blind-spots	FR1	Place cup at (20cm, 36°)	Object readings at [500cm, 500cm, 20cm, 500cm, 500cm]	TBD	TBD

12	Testing object detection in ultrasonic sensor blind-spots	FR1	Place cup at (25cm, 108°)	Object readings at [500cm, 500cm, 25cm, 500cm, 500cm]	TBD	TBD
13	Testing data filtering of Lidar garnered data	FR1	Place book at (230cm, 90°)	Lidar data reading is [500cm, 500cm, 230cm, 500cm, 500cm]	TBD	TBD
14	Testing data filtering of Lidar garnered data	FR1	Place book at (150cm, 10°)	Lidar data reading is [500cm, 500cm, 500cm, 500cm, 150cm]	TBD	TBD
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, 500cm, 500cm, 500cm, 150cm]	TBD	TBD
16	Testing larger objects detected as being in 2 sectors	FR1	Place chair at (100cm, 36°)	Object readings at [500cm, 500cm, 500cm, 100cm, 100cm]	TBD	TBD

17	Testing larger objects detected as being in 2 sectors	FR1	Place chair at (130cm, 108°)	Object readings at [500cm, 130cm, 130cm, 500cm, 500cm]	TBD	TBD
18	Testing larger objects detected as being in 2 sectors	FR1	Place chair at 160cm, 144°)	Object readings at [160cm, 160cm, 500cm, 500cm, 500cm]	TBD	TBD
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 [500cm, 500cm, 500cm, 500cm, 500cm]	TBD	TBD

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 [500cm, 500cm, 250cm, 500cm, 500cm] after 1 second, [500cm, 500cm, 300cm, 500cm, 500cm] after 2 seconds, [500cm, 500cm, 350cm, 500cm, 500cm] after 3 seconds, [500cm, 500cm, 400cm, 500cm, 500cm] after 4 seconds, [500cm, 500cm, 450cm, 500cm, 500cm] after 5 seconds and [500cm, 500cm, 500cm, 500cm, 500cm] after 6 seconds	TBD	TBD

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 [500cm, 500cm, 275cm, 500cm, 500cm], [500cm, 275cm, 500cm, 500cm, 500cm] after 2 seconds, [275cm, 500cm, 500cm, 500cm, 500cm] after 4 seconds and [500cm, 500cm, 500cm, 500cm, 500cm] after 5 seconds	TBD	TBD

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, 500cm, 500cm, 500cm, 500cm], after 2 seconds is [500cm, 300cm, 500cm, 500cm, 500cm], after 4 seconds is [500cm, 500cm, 250cm, 500cm, 500cm], after 6 seconds is [5000cm, 500cm, 500cm, 200cm, 500cm] and after 8 seconds is [500cm, 500cm, 500cm, 500cm, 150cm]	TBD	TBD

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 [500cm, 500cm, 200cm, 500cm, 100cm], after 2 seconds is [500cm, 500cm, 200cm, 100cm, 500cm], after 4 seconds is [500cm, 500cm, 100cm, 500cm, 500cm], after 6 seconds is [500cm, 100cm, 200cm, 500cm, 500cm] and after 8 seconds is [100cm, 500cm, 200cm, 500cm, 500cm]	TBD	TBD

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, 500cm, 500cm, 500cm, 100cm], after 2 seconds is [200cm, 500cm, 500cm, 100cm, 500cm], after 4 seconds is [200cm, 500cm, 100cm, 500cm, 500cm], after 6 seconds is [200cm, 100cm, 500cm, 500cm, 500cm] and after 8 seconds is [100cm, 500cm, 500cm, 500cm, 500cm]	TBD	TBD

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 $50cm/sec$ straight towards the object	Object reading initially is [500cm, 500cm, 300cm, 500cm, 500cm], after 1 second is [500cm, 500cm, 250cm, 500cm, 500cm] and after 3 seconds is [500cm, 500cm, 150cm, 500cm, 500cm]	TBD	TBD
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 $50cm/sec$ straight towards the wall	Object reading initially at [200cm, 200cm, 200cm, 200cm, 200cm], after 1 second is [150cm, 150cm, 150cm, 150cm, 150cm], and after 3 seconds is [50cm, 50cm, 50cm, 50cm, 50cm]	TBD	TBD

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 [500cm, 500cm, 300cm, 30cm, 150cm], after 1 second are [500cm, 500cm, 250cm, 500cm, 100cm] and after 3 seconds are [500cm, 500cm, 150cm, 500cm, 500cm]	TBD	TBD
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 [500cm, 500cm, 500cm, 350cm, 350cm], after 1 second are [500cm, 500cm, 500cm, 250cm, 250cm] and after 2 seconds are [500cm, 500cm, 150cm, 150cm, 150cm]	TBD	TBD

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 [500cm, 500cm, 350cm, 500cm, 500cm] and changes to [500cm, 500cm, 300cm, 500cm, 500cm] after 1 second, [500cm, 500cm, 250cm, 500cm, 500cm] after 2 seconds, [500cm, 500cm, 2000cm, 500cm, 500cm] after 3 seconds, [500cm, 500cm, 150cm, 500cm, 500cm] after 4 seconds, and [500cm, 500cm, 100cm, 500cm, 500cm] after 5 seconds	TBD	TBD

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 [500cm, 500cm, 275cm, 500cm, 500cm], [500cm, 225cm, 500cm, 500cm, 500cm] after 2 seconds, [175cm, 500cm, 500cm, 500cm, 500cm] after 4 seconds and [500cm, 500cm, 500cm, 500cm, 500cm] after 5 seconds	TBD	TBD

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 $25 cm/sec$	Object reading initially is [450cm, 500cm, 500cm, 500cm, 500cm], after 2 seconds is [500cm, 350cm, 500cm, 500cm, 500cm], after 4 seconds is [500cm, 500cm, 250cm, 500cm, 500cm], after 6 seconds is [5000cm, 500cm, 500cm, 150cm, 500cm] and after 8 seconds is [500cm, 500cm, 500cm, 500cm, 50cm]	TBD	TBD

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, 500cm, 500cm, 500cm, 400cm], after 2 seconds is [100cm, 500cm, 500cm, 300cm, 500cm], after 4 seconds is [500cm, 500cm, 200cm, 500cm, 500cm], after 6 seconds is [500cm, 100cm, 500cm, 500cm, 500cm] and after 8 seconds is [500cm, 500cm, 500cm, 500cm, 500cm]	TBD	TBD

Table 11: Sensor Fusion Tests

5.7 System Diagnostics Module

Test Number	**Description**	**Requirement Reference**	**Inputs**	**Expected Outputs**	**Actual Outputs**	**Results**
1	Test that the system is able to detect a connection issue with the Lidar	FR14	Loosen the power connection of Lidar	Error code for Lidar connection error	TBD	TBD

2	Test that the system is able to detect the Lidar producing false data	FR14	Overwrite the output of Lidar to Data Collection module with false data	Error code for Lidar data error	TBD	TBD
3	Test that the system is able to detect a connection issue with one of the ultrasonic sensors	FR14	Loosen the power connection of one of the ultrasonic sensors	Error code for ultrasonic sensor connection error	TBD	TBD
4	Test that the system is able to detect one of the ultrasonic sensors producing false data	FR14	Overwrite the output one of the ultrasonic sensors to Data Collection module with false data	Error code for ultrasonic sensor data error	TBD	TBD
5	Test that the system is able to detect a connection issue with the input button	FR14	Loosen the data connection between input button and Arduino	Error code for input button connection error	TBD	TBD
6	Test that the system is able to detect the input button producing false data	FR14	Overwrite the output of input button to User Input module with false data	Error code for input button data error	TBD	TBD

7	Test that the system is able to detect a connection issue with one of the Haptic motor	FR14	Loosen the power connection of one of the Haptic motor	Error code for Haptic motor connection error	TBD	TBD
8	Test that the system is able to detect a connection issue with the speaker	FR14	Loosen the data connection between speaker and Arduino	All five Haptic motor buzzes	TBD	TBD

Table 13: System Diagnostics Module 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**
1	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 physically buzzing	TBD	TBD

2	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 physically buzzing, after 2 seconds, user turns to the right and the center haptic motor physically buzzes, after 3 seconds no buzzing.	TBD	TBD
3	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 physically buzzing, after 1.5 seconds, center-right haptic motor physically buzzes and user turns to the right, then the center buzzer buzzes, after 2 seconds no buzzing.	TBD	TBD

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

Note that 500cm is the value returned when no object is detected by an ultrasonic sensor (ie. max distance).

Some of the modules included in the hazard analysis and the system design documents have been modified. An updated component diagram and behaviour overview section have been included below to highlight these changes.

The main changes that took place are; the Sensor Calibration Module has being removed, a new Sensor Fusion Module has being added, the user now inputs information into the system using a button instead of a speaker, and finally a Lidar is now being used to collect data instead of a camera. Additionally, it was mentioned in the requirements document that NextStep would provide a Google maps like service incorporated into the product and this is no longer the case. This results in FR6, FR8, FR10 and FR11 being removed from the requirements document. Slight modifications have also been made to the mechanism by which NextStep communicates with the user. In previous design documents it was stated that a speaker would be user to communicate directions to the user. While the speaker is still used to communicate certain messages to the user, any information pertaining to which direction the user should travel in is now done by a series of five haptic motors. Since we are using haptic motors instead of a speaker to communicate user guidance, FR24 has been modified such that NextStep must provide information about an obstacle 2 seconds before potential contact with a user. Please refer to previous design documents for any additional context that is required.

7.1 Behaviour Overview

1. **Data Collection Module:** This component collects and filters data from an indoor setting using ultrasonic sensors and a Lidar. This component will communicate this information to the Sensor Fusion module.

2. **Object Avoidance System** This component receives fused data from the Sensor Fusion component and then uses the Bubble Rebound algorithm to calculate a path through the obstacles for the user to follow.

3. **User Guidance Mechanism** This component receives the necessary information from the Object Avoidance System and relays to the user via haptic feedback guidance on how to avoid running into obstacles.

4. **User Inputs** Responsible for collecting user height and width to pass on to the Object Avoidance System.

5. **Sensor Fusion** This component receives unfiltered data from the Data Collection Module and then proceeds to run a Kalman filter on it. The Kalman filter serves two purposes, to filter and then fuse the two data streams coming from the ultrasonic sensors and the Lidar. When this data is fused we can then send it to the Object Avoidance System to be used in the navigational algorithm.

6. **System Diagnostics Module** This module will relay non-guidance information back to the user. This will include things such as battery level and any sensors that are malfunctioning.

7.2 Component Diagram

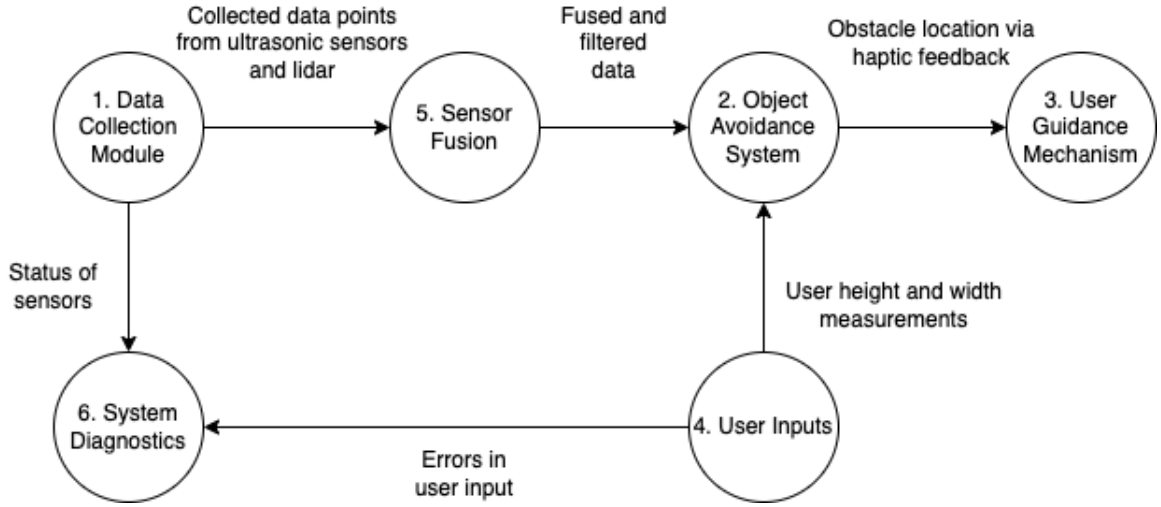

Figure 1: Component Diagram

7.3 Sensor Layout

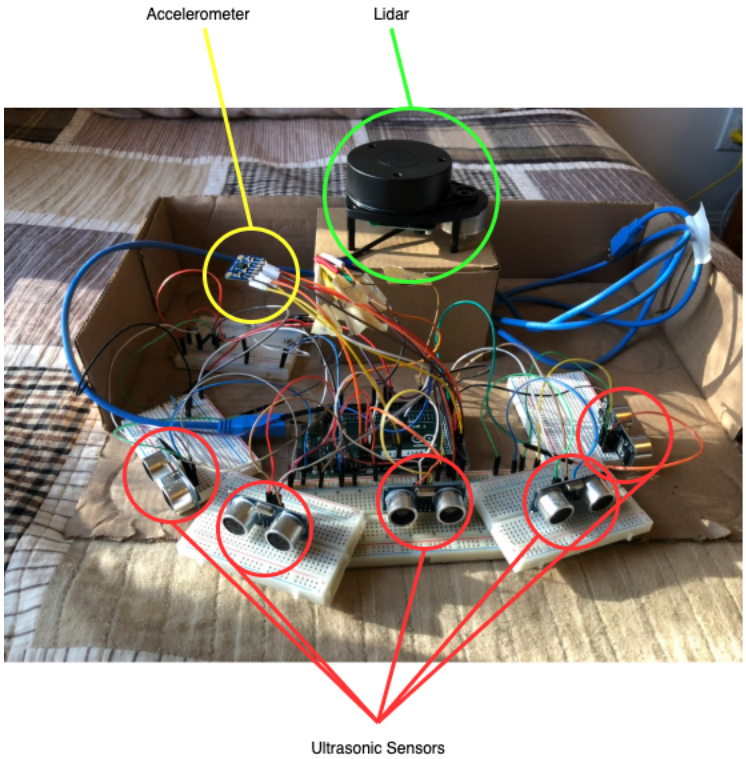

Figure 2: Layout of the ultrasonic sensors and the Lidar

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**
01	FR1, FR7, PR5
02	FR1, FR7, PR5
03	FR1, FR7, PR5
04	FR1, PR5
05	FR1, PR5
06	FR1, PR5
07	FR1, PR5
08	FR1, PR5
09	FR1
10	FR7

Table 16: Data Collection Module Traceability

Test Cases	**Functional and Non-Functional Requirements**
01	FR19
02	FR19
03	FR9, FR19
04	FR19
05	FR19

Table 17: Object Avoidance System Traceability

Test Cases	**Functional and Non-Functional Requirements**
01	FR3, FR9, FR19
02	FR3, FR9, FR19
03	FR3, FR9, FR19
04	FR3, FR9, FR19
05	FR3, FR9, FR19
06	FR24, PR1
07	FR24, PR1

Table 18: User Guidance Mechanism Traceability

Test Cases	**Functional and Non-Functional Requirements**
01	FR12, UH2, UH5, UH6
02	FR12
03	FR13
04	FR13

Table 19: User Inputs Traceability

Test Cases	Functional and Non-Functional Requirements
01	FR1
02	FR1
03	FR9
04	FR1, FR7
05	FR1
06	FR1
07	FR1
08	FR1
09	FR1
10	FR1
11	FR1
12	FR1
13	FR1
14	FR1
15	FR1
16	FR1
17	FR1
18	FR1
19	FR17
20	FR1
21	FR1
22	FR1
23	FR1
24	FR1
25	FR1
26	FR9
27	FR1, FR7
28	FR1
29	FR1
30	FR1
31	FR1
32	FR1

Table 20: Sensor Fusion Traceability

Test Cases	Functional and Non-Functional Requirements
01	FR14
02	FR14
03	FR14
04	FR14
05	FR14
06	FR14
07	FR14

Table 21: System Diagnostics Module Traceability

Test Cases	Functional and Non-Functional Requirements
01	FR1, FR7, PR1, PR5
02	FR1, FR7, PR1, PR5
03	FR1, FR7, PR1, PR5

Table 22: Integration Testing Traceability