



# Vehicle Intersection Control

McMASTER UNIVERSITY

Verification and Validation

SE 4G06

GROUP 6

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## 1 Revisions

Table 1: VIC Table of Revisions

Date	Revision Number	Authors	Comments
February 27, 2017	Revision 0	Alex Jackson Jean Lucas Ferreira Justin Kapinski Mathew Hober Radhika Sharma Zachary Bazen	N/A

## 2 Purpose

The purpose of this document is to examine the previous project goals and requirements, and to see how the end system complies with these requirements. Through validation, it will be determined if the project goals were met. Verification will allow for the detection of errors, and build a level of confidence in the system.

This document will include a traceability matrix to map the test cases to the functional requirements.

The intended audience for this document consists of Dr. Alan Wassyng and the course's teaching assistants.

## 3 Validation

### 3.1 Project Goals and Functional Validation

The system consists of two main components: Vehicle Controller and Intersection Controller. Each component of the system has its own specific goals. By integrating these component-specific goals with our functional requirements, the entire project goals are realized. Therefore, if we can validate that our system components meet our functional requirements, we can assert that they fulfill our project goals.

Table 2: Vehicle Controller Component Goals

Component Name	Goals	Functional Requirement
Image Processing	- Detect lanes, obstacles, and the intersection	V2, V3, V5, V6
Vehicle Navigation	- Guide the vehicle movements on the track - Stop the vehicle when necessary	V2, V4, V5, V6
Communication	- Send request messages to the Intersection Controller - Receive response messages from the Intersection Controller	V1
Servo Motor	- Set the desired angle of the wheels	V2, V5, V6
Speed Controller	- Set the desired speed of the vehicle	V2, V4, V5, V6

Table 3: Intersection Controller Component Goals

Component Name	Goals	Functional Requirement
Vehicle Detection	- Detect location of cars and obstacles present at the intersection	IC1, IC3
Communication	- Receive request messages from the Vehicle Controller - Send response messages to the Vehicle Controller	IC5
Intersection Management	- Control the traffic flow of the intersection	IC4

## 4 Traceability Matrix

Identifier	Reqs Tested	V1	V2	V3	V4	V5	V6	IC1	IC3	IC4	IC5
Test Cases	13	8	26	5	11	12	21	7	6	4	20
HC1.1	3		X			X	X				
HC1.2	3		X			X	X				
HC1.3	3		X			X	X				
HC1.4	3		X			X	X				
HC2.1	4		X		X	X	X				
HC2.2	4		X		X	X	X				
HC2.3	4		X		X	X	X				
HC2.4	4		X		X	X	X				
VC1.1	1	X									
VC1.2	1	X									
VC1.3	1	X									
VC1.4	1	X									
VC2.1	1		X								
VC2.2	1		X								
VC2.3	1		X								
VC2.4	1		X								
VC2.5	1		X								
VC2.6	1		X								
VC2.7	1		X								
VC2.8	1		X								
VC2.9	1				X						
VC2.10	1				X						
VC2.11	1				X						
VC2.12	1				X						
VC2.13	1						X				
VC2.14	1						X				
VC2.15	1						X				
VC2.16	1						X				
VC2.17	1						X				
VC2.18	1						X				
VC2.19	1						X				
VC2.10	1						X				
VC3.1	1		X								
VC3.2	1		X								
VC3.3	1		X								
VC3.4	2		X	X							

Identifier	Reqs Tested	V1	V2	V3	V4	V5	V6	IC1	IC3	IC4	IC5
VSC3.5	2		X			X					
VC3.6	1						X				
VC3.7	1						X				
VC3.8	2					X	X				
VC3.9	2					X	X				
VC3.10	1		X								
VC3.11	1		X								
VC3.12	1		X								
VC3.13	1		X								
VC3.14	2		X	X	X						
VC3.15	2		X				X				
IC1.1	2							X			X
IC1.2	2							X			X
IC1.3	2							X			X
IC1.4	2							X			X
IC1.5	1							X			
IC2.1	1										X
IC2.2	3	X								X	X
IC2.3	1										X
IC2.4	1										X
IC2.5	1										X
IC3.1	1										X
IC3.2	1										X
IC3.3	1										X
IC4.1	1										X
IC4.2	2								X		X
IC4.3	2								X		X
IC4.4	1										X
IC4.5	1								X		
IC4.6	1								X		
IC4.7	1								X		
IC4.8	1								X		
VIC.1	2						X				X
VIC.2	3						X			X	X
VIC.3	1	X									
VIC.4	3			X						X	X
VIC.5	5			X	X	X				X	X

Identifier	Reqs Tested	V1	V2	V3	V4	V5	V6	IC1	IC3	IC4	IC5
VIC.6	3	X		X	X						
VIC.7	1	X									

## 5 Verification

## 5.1 Hardware Verification

### 5.1.1 Individual Vehicle Hardware Component Verification

#### 4.1.1.1 Servo Verification

Test ID	Requirement ID	Description	Input	Expected Behaviour	Actual Behaviour	Pass/Fail
HC1.1	V2, V5, V6	To test the servo, commands telling the servo to go to a specified angle will be sent to the servo. The actual angle of the servo will be measured using a protractor and the actual angle needs to be within 2 degrees of the desired angle to be considered a pass.	Set servo to -45 degrees	Servo is between -47 and -43 degrees	N/A	N/A
HC1.2			Set servo to -30 degrees	Servo is between -32 and -28 degrees	N/A	N/A
HC1.3			Set servo to 0 degrees	Servo is between -2 and 2 degrees	N/A	N/A
HC1.4			Set servo to 30 degrees	Servo is between 28 and 32 degrees	N/A	N/A

#### 4.1.1.2 Speed Controller Verification

Test ID	Requirement ID	Description	Input	Expected Behaviour	Actual Behaviour	Pass/Fail
HC2.1	V2, V4, V5, V6	The speed controller will be tested by having the car start at rest and then giving the speed controller a specified speed. The speed will be measured by timing how long it takes the car to drive 10 meters.	Set speed to 0.5 m/s	Travel time is 20 s	N/A	N/A
HC2.2			Set speed to 0.8 m/s	Travel time is 12.5 s	N/A	N/A
HC2.3			Set speed to 1 m/s	Travel time is 10 s	N/A	N/A
HC2.4			Set speed to 1.25 m/s	Travel time is 8 s	N/A	N/A



## 5.2 Software Verification

Some of the modules are not fully implemented, and thus the actual behaviour/output given from the module can not be determined as of yet. To symbolize this issue, any tests with a value of N/A in the *Expected Behaviour* and *Pass/Fail* columns represent a module that cannot be tested at the moment.

Any necessary variables for describing the inputs/outputs will be defined prior to the respective verification test table.

### 5.2.1 Vehicle Software Verification

#### 5.2.1.1 Vehicle Communication Verification

Note: This module is currently not complete.

Variables used:

- string: request\_msg = "carId\_comingFrom\_goingTo\_listeningPort\_timestamp" (example: '1\_N\_S\_3000\_1488233082083')
- integer: response\_msg  $\in [0, 1, 2]$

Test ID	Requirement	Description	Input	Expected Behaviour	Actual Behaviour	Pass/Fail
VSC1.1	V1	An intersection has been detected, and a request has <b>not</b> been sent to the Intersection Controller	request_msg	Entire message successfully delivered (all 28 bytes sent)	28 bytes delivered	Pass
VSC1.2	V1	An intersection has been detected, a request has already been sent to the Intersection Controller, and another car approaching the intersection	response_msg	response_msg = 0 car stops at intersection	N/A	N/A
VSC1.3	V1	An intersection has been detected, a request has already been sent to Intersection Controller, and there is <b>no</b> other car approaching the intersection	response_msg	response_msg = 1 car proceeds through intersection without stopping	N/A	N/A

VSC1.4	V1	An emergency stop signal broadcasted from the Intersection Controller has been received	response_msg	response_msg = 2	N/A	N/A
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### 5.2.1.2 Vehicle Navigation

Note: This module is currently not complete.

Test ID	Requirement	Description	Input	Expected Behaviour	Actual Behaviour	Pass/Fail
VSC2.1	V2	A straight lane has been detected and the vehicle is travelling at a very low speed	leftAngle $\approx$ rightAngle intersectionDetect = 0 obstacleDetect = 0 speed = 0.5 m/s	Vehicle travels along middle of lane and stays within lane lines	N/A	N/A
VSC2.2	V2	A straight lane has been detected and the vehicle is travelling at a low speed	leftAngle $\approx$ rightAngle intersectionDetect = 0 obstacleDetect = 0 speed = 0.8 m/s	Vehicle travels along middle of lane and stays within lane lines	N/A	N/A
VSC2.3	V2	A straight lane has been detected and the vehicle is travelling at a moderate speed	leftAngle $\approx$ rightAngle intersectionDetect = 0 obstacleDetect = 0 speed = 1 m/s	Vehicle travels along middle of lane and stays within lane lines	N/A	N/A
VSC2.4	V2	A straight lane has been detected and the vehicle is travelling at a high speed	leftAngle $\approx$ rightAngle intersectionDetect = 0 obstacleDetect = 0 speed = 1.25 m/s	Vehicle travels along middle of lane and stays within lane lines	N/A	N/A
VSC2.5	V2	A curved lane has been detected and the vehicle is travelling at a very low speed	$ \text{leftAngle} - \text{rightAngle}  \gg 0$ intersectionDetect = 0 obstacleDetect = 0 speed = 0.5 m/s	Vehicle follows curve of lane and stays within lane lines	N/A	N/A
VSC2.6	V2	A curved lane has been detected and the vehicle is travelling at a low speed	$ \text{leftAngle} - \text{rightAngle}  \gg 0$ intersectionDetect = 0 obstacleDetect = 0 speed = 0.8 m/s	Vehicle follows curve of lane and stays within lane lines	N/A	N/A

VSC2.7	V2	A curved lane has been detected and the vehicle is travelling at a moderate speed	$ \text{leftAngle} - \text{rightAngle}  \gg 0$ intersectionDetect = 0 obstacleDetect = 0 speed = 1 m/s	Vehicle follows curve of lane and stays within lane lines	N/A	N/A
VSC2.8	V2	A curved lane has been detected and the vehicle is travelling at a high speed	$ \text{leftAngle} - \text{rightAngle}  \gg 0$ intersectionDetect = 0 obstacleDetect = 0 speed = 1.25 m/s	Vehicle follows curve of lane and stays within lane lines	N/A	N/A
VSC2.9	V4	An intersection has been detected and the vehicle is travelling at a very low speed	$\text{leftAngle} \approx \text{rightAngle}$ intersectionDetect = 1 obstacleDetect = 0 speed = 0.5 m/s	Vehicle slows down and stops at intersection line while remaining within lane lines	N/A	N/A
VSC2.10	V4	An intersection has been detected and the vehicle is travelling at a low speed	$\text{leftAngle} \approx \text{rightAngle}$ intersectionDetect = 1 obstacleDetect = 0 speed = 0.8 m/s	Vehicle slows down and stops at intersection line while remaining within lane lines	N/A	N/A
VSC2.11	V4	An intersection has been detected and the vehicle is travelling at a moderate speed	$\text{leftAngle} \approx \text{rightAngle}$ intersectionDetect = 1 obstacleDetect = 0 speed = 1 m/s	Vehicle slows down and stops at intersection line while remaining within lane lines	N/A	N/A
VSC2.12	V4	An intersection has been detected and the vehicle is travelling at a high speed	$\text{leftAngle} \approx \text{rightAngle}$ intersectionDetect = 1 obstacleDetect = 0 speed = 1.25 m/s	Vehicle slows down and stops at intersection line while remaining within lane lines	N/A	N/A
VSC2.13	V6	An obstacle has been detected in a straight lane and the vehicle is travelling at a very low speed	$\text{leftAngle} \approx \text{rightAngle}$ intersectionDetect = 0 obstacleDetect = 1 speed = 0.5 m/s	Vehicle stops before making contact with obstacle	N/A	N/A
VSC2.14	V6	An obstacle has been detected in a straight lane and the vehicle is travelling at a low speed	$\text{leftAngle} \approx \text{rightAngle}$ intersectionDetect = 0 obstacleDetect = 1 speed = 0.8 m/s	Vehicle stops before making contact with obstacle	N/A	N/A

VSC2.15	V6	An obstacle has been detected in a straight lane and the vehicle is travelling at a moderate speed	$\text{leftAngle} \approx \text{rightAngle}$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 1$ $\text{speed} = 1 \text{ m/s}$	Vehicle stops before making contact with obstacle	N/A	N/A
VSC2.16	V6	An obstacle has been detected in a straight lane and the vehicle is travelling at a high speed	$\text{leftAngle} \approx \text{rightAngle}$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 1$ $\text{speed} = 1.25 \text{ m/s}$	Vehicle stops before making contact with obstacle	N/A	N/A
VSC2.17	V6	An obstacle has been detected in a curved lane and the vehicle is travelling at a very low speed	$ \text{leftAngle} - \text{rightAngle}  \gg 0$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 1$ $\text{speed} = 0.5 \text{ m/s}$	Vehicle stops before making contact with obstacle	N/A	N/A
VSC2.18	V6	An obstacle has been detected in a straight lane and the vehicle is travelling at a low speed	$ \text{leftAngle} - \text{rightAngle}  \gg 0$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 1$ $\text{speed} = 0.8 \text{ m/s}$	Vehicle stops before making contact with obstacle	N/A	N/A
VSC2.19	V6	An obstacle has been detected in a straight lane and the vehicle is travelling at a moderate speed	$ \text{leftAngle} - \text{rightAngle}  \gg 0$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 1$ $\text{speed} = 1 \text{ m/s}$	Vehicle stops before making contact with obstacle	N/A	N/A
VSC2.20	V6	An obstacle has been detected in a straight lane and the vehicle is travelling at a high speed	$ \text{leftAngle} - \text{rightAngle}  \gg 0$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 1$ $\text{speed} = 1.25 \text{ m/s}$	Vehicle stops before making contact with obstacle	N/A	N/A

### 5.2.1.3 Image Processing Verification

Note: This module is currently not complete.

The following table are verifications tests for the lane detection and lane extraction from a real-world image scenario (VC3.1 to VC3.9). As well as the verification of the image processing logic and identification (VC3.10 to VC3.15).

Variable Definitions:

- imgData :
  - float leftAngle, rightAngle, leftLength, rightLength
  - boolean intersectionDetect, obstacleDetect

Figure 1: imgData Reference Example

The white lines are detected through a Canny edge detection.

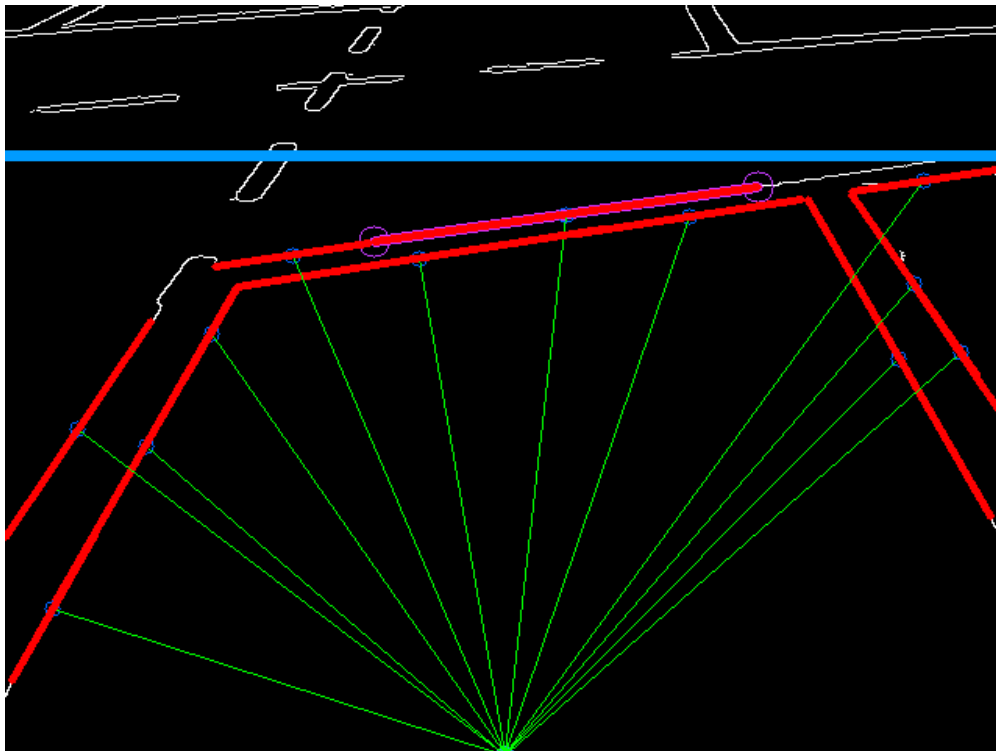
Red lines are created through a Probabilistic Hough Transform.

The blue horizontal line symbolizes the cutoff point for the image.

The green lines connects the detected red lines to the center of the image, and allows the creation of two sets of lines: the left side lines and the right side lines.

Lastly, the intersection is symbolized by the pink coloured line.

Using the two sets of green lines, we can calculate the average left angle, average right angle, average left line length, and average right line length.



Test ID	Requirement	Description	Input	Expected Behaviour	Actual Behaviour	Pass/Fail
VC3.1	V2	At any point of the track, the lanes must be detected and extracted from the image.	Car on straight track segment	A straight line detected on each side of the car	Figure ??	Pass
VC3.2	V2	“”	Car on left turn segment	A small left turning curve on the left side of the screen. A large left turning curve on the right of the screen	Figure ??	Pass
VC3.3	V2	“”	Car on right turn segment	A small right turning curve on the right side of the screen. A large right turning curve on the left of the screen	Figure ??	Pass
VC3.4	V2, V3	“”	Car approaching intersection	Two vertical lines, one on each side of the car, terminating at a horizontal line	Figure ??	Pass
VC3.5	V2, V5	“”	Car navigating through intersection	Small vertical line segments on each side of the car	Figure ??	N/A
VC3.6	V6	Any obstacles in the path of the vehicle must be detected	Obstacle ahead of car on a straight segment	Contours of obstacle detected	N/A	N/A
VC3.7	V6	“”	Obstacle ahead of car on a turning segment	Contours of obstacle detected	N/A	N/A
VC3.8	V5, V6	“”	Obstacle ahead of car at the intersection	Contours of obstacle detected	N/A	N/A
VC3.9	V5, V6	“”	Obstacle ahead of car at the intersection	Contours of obstacle detected	N/A	N/A

Test ID	Requirement	Description	Input	Expected Behaviour	Actual Behaviour	Pass/Fail
VC3.10	V2	The geometry of the captured image must be valid in order to correctly deduce logic and navigate the vehicle	Car on straight track segment and centered on its lane	$\text{leftAngle} \approx \text{rightAngle}$ $\text{leftLength} \approx \text{rightLength}$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 0$	$\text{leftAngle} = 42.81$ $\text{rightAngle} = 40.96$ $\text{leftLength} = 358.31$ $\text{rightLength} = 361.45$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 0$	Pass
VC3.11	V2	“”	Car on straight track segment and off-centered to the left	$\text{leftAngle} \approx \text{rightAngle}$ $\text{leftLength} \ll \text{rightLength}$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 0$	$\text{leftAngle} = 47.84$ $\text{rightAngle} = 43.62$ $\text{leftLength} = 464.34$ $\text{rightLength} = 279.36$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 0$	Pass
VC3.12	V2	“”	Car on a left turn and centered on its lane	$\text{leftAngle} \ll \text{rightAngle}$ $\text{leftLength} \ll \text{rightLength}$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 0$	$\text{leftAngle} = 24.50$ $\text{rightAngle} = 51.34$ $\text{leftLength} = 335.14$ $\text{rightLength} = 408.33$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 0$	Pass
VC3.13	V2	“”	Car on a right turn and centered on its lane	$\text{leftAngle} \gg \text{rightAngle}$ $\text{leftLength} \gg \text{rightLength}$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 0$	$\text{leftAngle} = 64.12$ $\text{rightAngle} = 10.43$ $\text{leftLength} = 377.55$ $\text{rightLength} = 291.06$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 0$	Pass
VC3.14	V2, V3, V4	“”	Car approaching intersection	$\text{leftAngle} \approx \text{rightAngle}$ $\text{leftLength} \approx \text{rightLength}$ $\text{intersectionDetect} = 1$ $\text{obstacleDetect} = 0$	$\text{leftAngle} = 67.44$ $\text{rightAngle} = 61.23$ $\text{leftLength} = 332.12$ $\text{rightLength} = 396.56$ $\text{intersectionDetect} = 1$ $\text{obstacleDetect} = 0$	Pass
VC3.15	V2, V6	“”	Car approaching an obstacle on a straight line segment	$\text{leftAngle} \approx \text{rightAngle}$ $\text{leftLength} \approx \text{rightLength}$ $\text{intersectionDetect} = 0$ $\text{obstacleDetect} = 1$	N/A	N/A

## 5.2.2 Intersection Controller Software Verification

### 5.2.2.1 Communication - Receive

Car:

- Abstract data type that contains all pertinent car request information
- This object is created for each new vehicle request
- Fields: car\_ID, destination\_Port, destination\_bluetooth\_address, direction\_from, direction\_to, proceed\_status and proceed\_message and time\_stamp

Arrival Queue:

- Queue that preserves the order of the intersection requests in the form of Car objects

Note: This module is currently not complete.

Test ID	Requirement	Description	Input	Expected Behaviour	Actual Behaviour	Pass/Fail
IC1.1	IC1, IC5	Intersection request has been sent to the intersection controller from a single vehicle	Single vehicle intersection request	Car object containing the request information pushed into the arrival queue	N/A	N/A
IC1.2	IC1, IC5	Two vehicles arrive at the intersection at the same time and request to proceed through the intersection.	More than one vehicle intersection request	Car objects containing the request information pushed to the arrival queue in the order that they were received	N/A	N/A
IC1.3	IC1, IC5	Vehicle intersection requests that are transmitted incompletely should be dropped by it intersection controller	Vehicle intersection request that is terminated prior to receive completion	Timeout/ disconnected receive error is caught and system becomes available for subsequent requests	N/A	N/A
IC1.4	IC1, IC5	The system should be able to handle large request volumes without losing requests.	Many vehicle requests	Car objects containing the request information pushed to the arrival queue in the order that they were received	N/A	N/A



IC1.5	IC1	Messages that have invalid or corrupt message contents should be dropped	Invalid message request	Invalid/corrupt message detected and dropped	N/A	N/A
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### 5.2.2.2 Communication - Send

Proceed Queue:

- Queue of car objects that preserves the order determined by the intersection controller that vehicles should proceed through the intersection.
- Proceed commands are sent to the vehicles based on the FIFO sequence of the proceed queue

Note: This module is currently not complete.

Test ID	Requirement	Description	Input	Expected Behaviour	Actual Behaviour	Pass/Fail
IC2.1	IC5	Vehicle proceed request has been determined safe and must be communicated to the vehicle	Car object in the proceed queue	Remove vehicle from proceed queue and send proceed message to vehicle	N/A	N/A
IC2.2	V1, IC4, IC5	Multiple vehicle proceed requests have been determined safe and must be communicated to the vehicle	More than one car object in the proceed queue	Remove vehicles from departure queue and send proceed message to vehicles in FIFO order.	N/A	N/A
IC2.3	IC5	The system should be able to handle large send volumes without dropping proceed commands	Many vehicles in the proceed queue	"?"	N/A	N/A
IC2.4	IC5	System should make further attempts to transmit messages to an unresponsive connection up to a max limit	Car object in the proceed queue	Inactive connection error should be caught. The system should then attempt to send the message again (up to the maximum attempt limit)	N/A	N/A

IC2.5	IC5	“”	“”	Timeout/ disconnected send error should be caught. The system should then attempt to send the message again (up to the maximum attempt limit)	N/A	N/A
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### 5.2.2.3 Communication - Message Extraction

Note: This module is currently not complete.

Test ID	Requirement	Description	Input	Expected Values	Actual Values	Pass/Fail
IC3.1	IC5	Vehicle message contents are separated by an agreed upon separator	2_N_S_1_timestamp	Car(2, bluetooth Address, 1, 'N', 'S', ',', ', 'timestamp')	N/A	N/A
IC3.2	IC5	The intersection communication module should drop incomplete or corrupt message contents	2_N_N_1_timestamp	Incorrect Message contents error caught	N/A	N/A
IC3.3	IC5	“”	2_N_N_1_	Incorrect Message contents error caught	N/A	N/A

### 5.2.2.4 ImageProcessing

Note: This module is not yet completed.

Test ID	Requirement	Description	Input	Expected Behaviour	Actual Behaviour	Pass/Fail
IC4.1	IC5	The IC must be able to detect when there are the intersection is occupied	Video frame of the intersection with no cars on the track	The module determines that there are no cars in the intersection	N/A	N/A
IC4.2	IC3, IC5	" "	Video frame of intersection with a car in the intersection	Module determines the intersection is occupied	N/A	N/A

IC4.3	IC3, IC5	" "	Video frame of car leaving the intersection	The module changes the intersection from occupied to unoccupied	N/A	N/A
IC4.4	IC5	" "	Video frame of a stationary obstacle in the intersection	The module determines that the intersection is occupied indefinitely	N/A	N/A
IC4.5	IC3	The intersection must determine which car has navigated through the intersection using directions	Video clip showing vehicle proceeding from North to South of the intersection	The module records the movement	N/A	N/A
IC4.6	IC3	" "	Video clip showing vehicle proceeding from South to North of the intersection	The module records the movement	N/A	N/A
IC4.7	IC3	" "	Video clip showing vehicle proceeding from East to West of the intersection	The module records the movement	N/A	N/A
IC4.8	IC3	" "	Video clip showing vehicle proceeding from West to East of the intersection	The module records the movement	N/A	N/A

### 5.2.3 Integrated Vehicle Intersection Software Verification

#### 5.2.3.1

Note: The VIC system is only partially implemented, integrated system testing will take place in the future.

Test ID	Requirement	Description	Input	Expected Behaviour	Actual Behaviour	Pass/Fail
VIC.1	IC1, IC5	Vehicles are allowed to proceed directly through the intersection, without stopping if the intersection is deemed safe and clear	Single vehicle, clear intersection	Vehicle proceeds directly through the intersection	N/A	N/A

VIC.2	IC1, IC4, IC5	Vehicles are designed to stop at the intersection until they receive a proceed command from the intersection	Single vehicle, obstacle in intersection	Vehicle should stop at the intersection	N/A	N/A
VIC.3	V1	“”	Single vehicle, intersection controller system not working	Vehicle should stop at the intersection and wait	N/A	N/A
VIC.4	V3, IC4, IC5	Vehicles are allowed to proceed directly through the intersection, without stopping if the intersection is deemed safe and clear and the intended paths are parallel	Multiple vehicles, parallel directions, clear intersection	Vehicles proceed directly through the intersection	N/A	N/A
VIC.5	V3, V4, V5, IC4, IC5	Vehicles with crossing directions must stop at the intersection, the vehicle that arrived first proceeds through the intersection first	Vehicle A and Vehicle B, crossing directions, clear intersection, Vehicle A is first	Vehicles A proceeds directly through the intersection, Vehicle B stops at the intersection	N/A	N/A
VIC.6	V1, V3, V4	Vehicles are designed to stop at the intersection until they receive a proceed command from the intersection	Multiple vehicles, obstacle in intersection	Vehicles should stop at the intersection	N/A	N/A
VIC.7	V1	“”	Multiple vehicles, intersection controller not working	Vehicles should stop at the intersection and wait	N/A	N/A

## 6 Appendix

### 6.1 Image Processing Verification Results

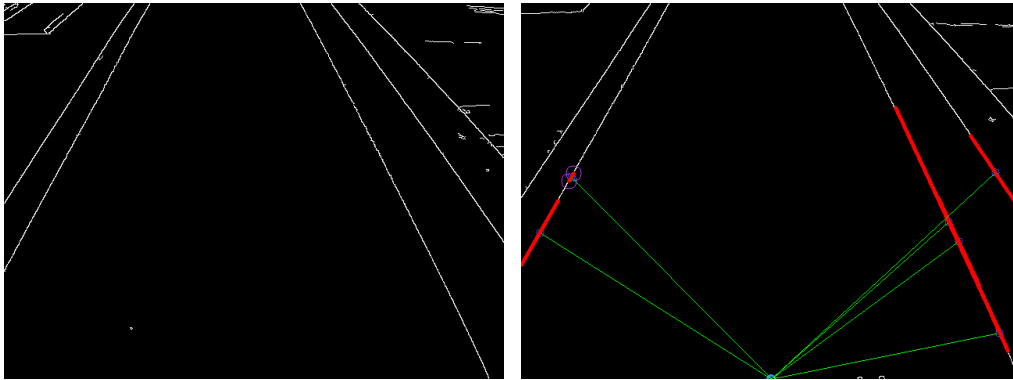


Figure 2: Straight line segment

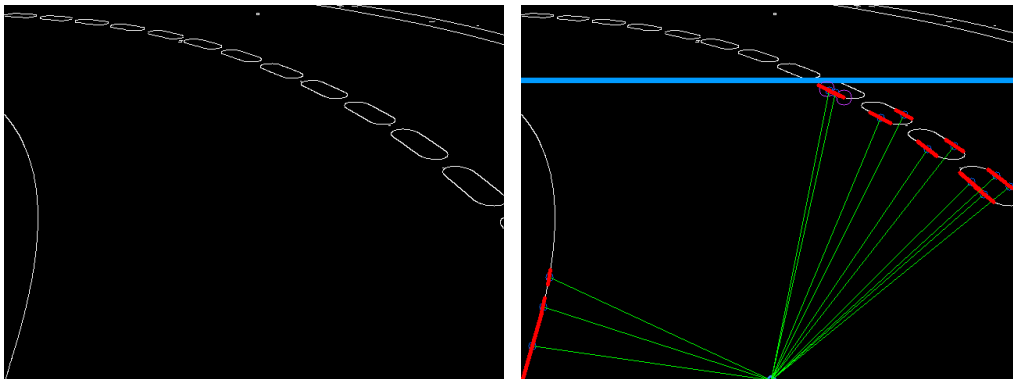


Figure 3: Left turn segment

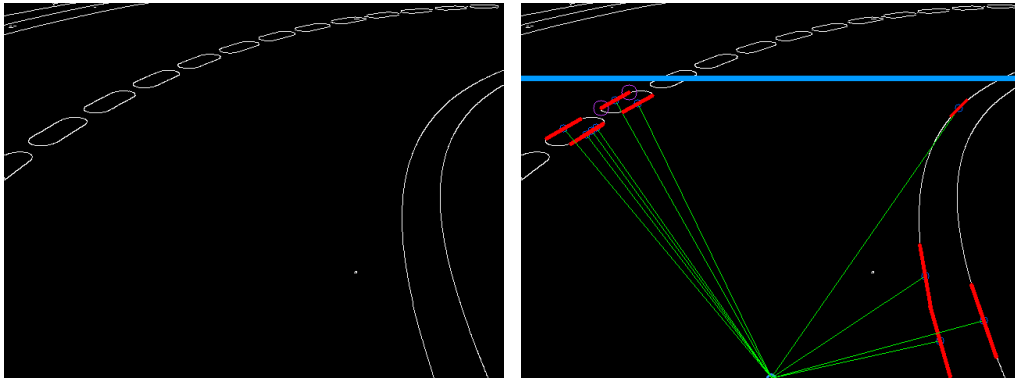


Figure 4: Right turn segment

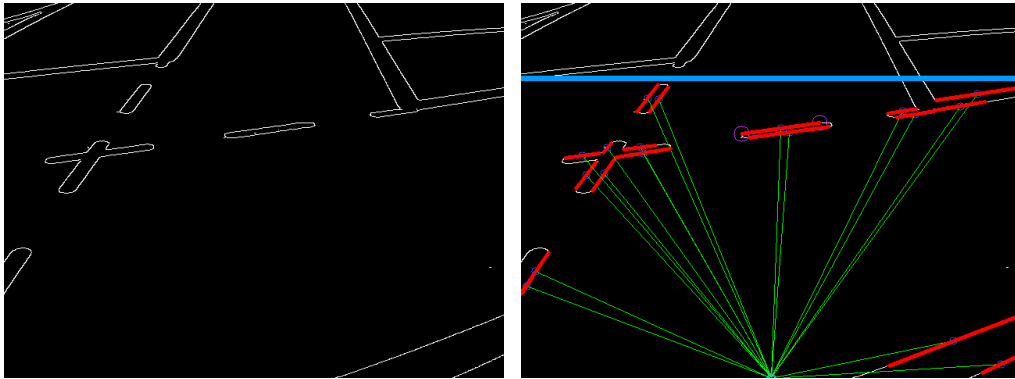


Figure 5: Approaching an intersection

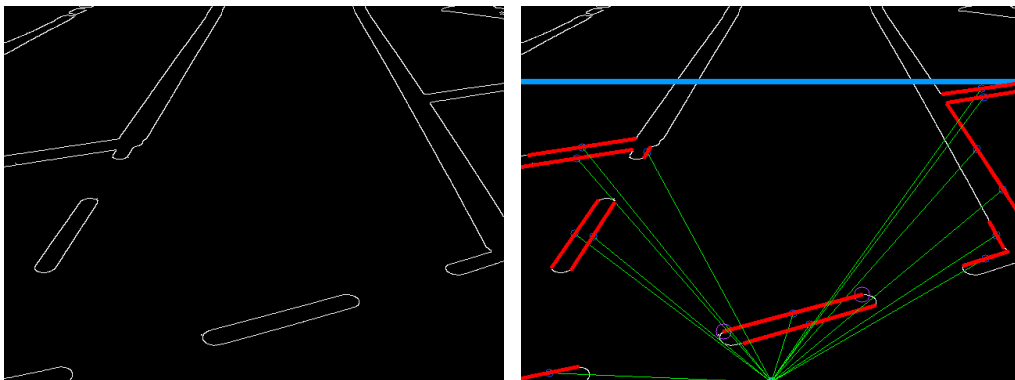


Figure 6: Navigating through an intersection