Emulating Hard and Soft real-time ECUs in a vehicle

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Project 2: Advanced Embedded Software Development

PROJECT 2 REPORT

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EXECUTIVE SUMMARY

The objective of this project is to emulate ECU's in a vehicle. For simplicity, we have emulated two ECU's namely Hard real time ECU and Soft real time ECU. The hard real time ECU is responsible for responding to events which are asynchronous and critical from perspective of driver driving the vehicle. On the other hand, the soft real time ECU is responsible for processing the data sent by Hard real time ECU. The Hard real time ECU is connected to various sensors whose values are collected and relayed to Soft real time ECU for processing. The Soft real time ECU processes the data and tells the Hard real time ECU to actuate a particular actuator depending on the state. The Soft real time ECU is implemented using Beaglebone Green development board while the Hard real time ECU is implemented using TIVA TM4C1294XL. The software is written in Embedded C with coding conventions being taken into considerations.

Sensors on Remote Node:

1. Motion Sensor
2. Gyroscope
3. Temperature
4. Ultrasonic Sensor
5. Alcohol Sensor

Actuators on Remote Node:

1. 20*4 LCD
2. Servo Motor
3. DC Motor
4. Buzzer
5. LED

User Input:

1. Mechanical switch

Miscellaneous:

1. Motor H bridge driver
2. Potentiometer
3. Breadboard

4. Wires
5. External power supply

SYSTEM FUNCTIONALITY

1. User authentication based on motion sensor and mechanical switch values through a feedback from the Control Node
2. State detection on Control Node using fusion of sensor data
3. Feedback to remote node for actuation based on events (Soft Real Time)
4. Real-time response on remote node for critical events (Hard Real Time)
5. System response and operational status logging in normal, degraded and failed system execution
6. Error recovery and fault tolerance between 2 nodes

User Authentication based on sensor fusion of motion sensor and mechanical switch

1. The system is designed in such a way that the driver/user first needs to authenticate his/her identity before that individual is being granted access to the car. To achieve that purpose, we have used a **mechanical switch which is basically emulating a keypad**, and a **PIR motion sensor** which can detect motion in the car.
2. So, when the password entered on the keypad is incorrect(switch in OFF position) and motion is detected in the car, then a buzzer is triggered which rings at a resonant frequency of 2048 Hz.
3. The buzzer continues to sound in order to alert nearby people and it can only be stopped if the user enters correct password on keypad(switch in ON position).
4. In short, when user enters correct password, he/she is allowed to access the car. On the other hand, incorrect password and motion triggers a buzzer to alert nearby people.
5. This algorithm of authentication is part of authentication state implemented on both remote node and control node of the system.
6. After the user authentication is done, it implies that driver can drive the vehicle and motor starts running.

State detection on Control Node using fusion of sensor data

1. The control node is responsible for implementing a state machine that processes the data sent by remote node(usually sensor data).
2. Depending upon the values of sensor, appropriate state is being determined and output is determined.
3. The output of particular state is basically the actuator that the remote node must actuate.
4. For eg, if the temperature sensor on remote node is removed, that data is sent by remote node to control node. Now, by checking the value of temperature sensor(if it is

out of bounds), the control node determines that the sensor is removed, so it logs that data into a log file.
5. However, if the temperature value is within bounds, then control node determines to control the servo motor at remote node depending.

Feedback to remote node for actuation based on events (Soft Real Time)

Different actuation would be carried on the Remote Node after states are determined on the Control Node. For eg:

1. If System Authentication Success -> Motor starts running indicating vehicle is running
2. If Collision Probability Increases -> User is warned through blinking of Yellow LED
3. If Drowsiness Detected using alcohol level -> “Drunk” printed on LCD
4. If User comfort level decreases(temperature inside car increases) -> Servo Motor rotates emulating car window that lets air inside.
5. If Ultrasonic sensor removed -> Glow RED Led and LOG data on control node
6. If Temperature sensor removed -> LOG data on control node
7. If Gyroscope sensor removed (Critical) -> Halt DC motor and LOG data on control node
8. If Alcohol sensor removed (Non Critical) -> LCD prints “Degraded” and LOG data on control node
9. If TIVA Rx link down -> LOG data on control node and wait for communication link to restore communication
10. If TIVA Tx link down -> LOG data on control node and wait for communication link to restore communication

Real-time response on remote node for critical events (Hard Real Time)

1. Real time detection of critical event is crucial and there is a need of hard real-time response to it. Therefore, if an accident is detected through sudden change in gyroscope sensor value, first, our remote node would automatically decrease the speed of car (notified by reduction of motor speed).
2. If the Gyroscope sensor stops working when the vehicle is in motion(emulated by rotating motor), that will cause the motor being immediately stopped and values being reported to log files through control node.
3. After this actuation is performed, the information is relayed to the control node (soft real-time) for logging and post analysis.

System response and operational status logging in normal, degraded and failed system execution

1. In real world vehicle application, any fault generated inside the vehicle, either in Power Train, Body, Chassis, or the network is reported using a Diagnostic Trouble Code (DTC) which is indicated to the user through a Check Engine / Malfunction Indicator Light. To

emulate this behavior in our system, we would log the information on the control node for post-fault analysis Once the sensor is re-connected, the logs are updated.

2. If any sensor except Gyroscope sensor is removed from the system, the system would generate logs and indicate with the respective actuator but would continue working. For example, removing alcohol sensor would print “Degraded” on LCD but would keep working
3. Also, if the gyroscope sensor is removed, it indicates failed system and the car is immediately stopped(motors stops rotating).
4. Any such change in state or events are duly logged in the control node for post failure analysis

Error recovery and fault tolerance between 2 nodes

In our ECU modules, accident detection is a key requirement for operating a vehicle in safe condition. Therefore, if gyroscope sensor malfunctions at any point of time, our system is bound to stop the vehicle gracefully (if vehicle was in motion) or not let vehicle to start (if vehicle is already in halt). Before the motion actually happens and the system is authenticated, BIST software routines are executed which would give user a clear indication of issues through glowing of Blue LED or indicating normal operation through Green LED.

TEST PLAN:

Sr #	Category	Device/ System	Test Title	Test Preconditions	Test Method	Expected Output
1	Automatic Startup	Control Node	System should startup automatically and wait for user authentication	Rx/Tx Pin connected, Powered one, valid OS image and automatic script invoker	Connect the Tx/Rx Pin of BBG with respective Tx/Rx pins of Tiva board and plug the BeagleBone through USB power supply	BBG automatically running
2	Automatic Startup	Remote Node	System should startup automatically and wait for user authentication	Rx/Tx Pin connected, Powered one, valid program built	Connect the Tx/Rx Pin of Tiva with respective Rx/Tx pins of BBG board and plug the TIVA through USB power supply	BBG automatically running
3	BIST	System	Built in self test	All sensor connected on TIVA board and all boards are powered up	If all sensors connected on TIVA - Green LED glows, if any sensor removed before startup - Blue LED glows	Green/Blue LED Glows based on BIST success/fail conditions
4	Authentication - Original User	System	Authenticates the system using Motion sensor and button to further start the complete functionality	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Start the boards, do some motion and press the switch button to be On. Motor should start working	Motor should start working

5	Authentication - Intruder	System	Authenticates the system using Motion sensor and button to further start the complete functionality	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Start the boards, do some motion and do not press the switch button to be On. Buzzer should continue working to indicated theft condition	Buzzer should continue working to indicated theft condition
6	Performance - Normal	System	Test for operational status of system	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Start the system and authenticate it	System Running, Normal Actuator operations
7	Performance - Degraded	System	Test for operational status of system	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Remove alcohol sensor (Non-Critical) while system is running	LCD displays "Degraded"
8	Performance - Failed	System	Test for operational status of system	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Remove Ultrasonic sensor (Critical) while system is running	Red LED glows
9	Communication - TIVA	System	UART Communication test	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	LCD, LED, Buzzer, Servo Motor, DC Motor - All actuated by feedback from Control node via UART	All actuators working properly

10	Communication - TIVA	Remote Node	TIVA Rx link broken	Rx pin to Tiva / Tx pin to BBG broken	Break the Tiva Rx link	LOG data on BBG, TIVA Still keeps sending sensor data & comm link broken info to BBG
11	Communication - TIVA	Control Node	TIVA Tx Link broken	Tx pin to Tiva / Rx pin to BBG broken	Break the Tiva Tx link	LOG data on BBG, BBG waits for a timeout period to receive communication packet and LOGs the error condition if comm not restored within timeout condition
12	Sensor - Motion	Remote Node	Test motion sensor	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Power on system and do some motion to start buzzer if not authenticated with switch	buzzer starts working when motion detected but not authenticated
13	Sensor - Ultrasonic	Remote Node	Ultrasonic sensor test	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Power on system and bring object near to sensor or Unplug the VCC of sensor	If object near - Yellow LED, if removed - Red LED
14	Sensor - Gyroscope	Remote Node	Gyroscope sensor test	Rx/Tx Link Up, all sensors and	Power on system give sudden vibration to system	Motor should stop working

				user input button working and full system is powered on		
15	Sensor - Temperature	Remote Node	Temperature sensor test	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Increase temperature beyond 28 deg Celsius and reduce below 28	If Temp > 28, Servo motor rotates clockwise, below 28, anti-clockwise
16	Sensor - Alcohol	Remote Node	Alcohol sensor test	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Spray perfume/alcohol over the sensor or reduced its Sensor Output pin	If alcohol detected, "Drunk" printed on LCD, if sensor removed, "Degraded" printed on LCD and data LOGGED
17	Actuator - LCD	Remote Node	LCD Test	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Connect LCD properly and power the system	LCD displays "LCD INITIALIZED" if working properly, else nothing displays
18	Actuator - Buzzer	Remote Node	Buzzer Test	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Connect Buzzer to TIVA and generate proper PWM	Buzzer on if not authenticated
19	Actuator - Servo	Remote Node	Servo Motor	Rx/Tx Link Up, all	Connect Servo motor to TIVA and generate	Servo rotates

	Motor		Test	sensors and user input button working and full system is powered on	proper PWM	based on different temperatur e values
20	Actuator - DC Motor	Remote Node	DC Motor Test	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Connect DC motor to TIVA with its motor drive circuit powered from external power supply and generate proper PWM	DC Motor actuates based on authenticat ed state and stops if Gyro value suddenly changes
21	Actuator - LED	Remote Node	LED Test	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Connect LED to TIVA and generate proper voltage	LEDs glows for BIST success/fail ure and Ultrasonic sensor working/re moved
22	User Input - Switch	Remote Node	Switch Test	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Connect Switch to TIVA and make it as a GPIO Input	Button switch user input detected
23	Full System Testing	Remote Node	Integratio n Test	Rx/Tx Link Up, all sensors and user input button working and full system is powered on	Follow the state machine procedure	Full system works as expected with 3 layers of operation with fault/failure analysis and recovery

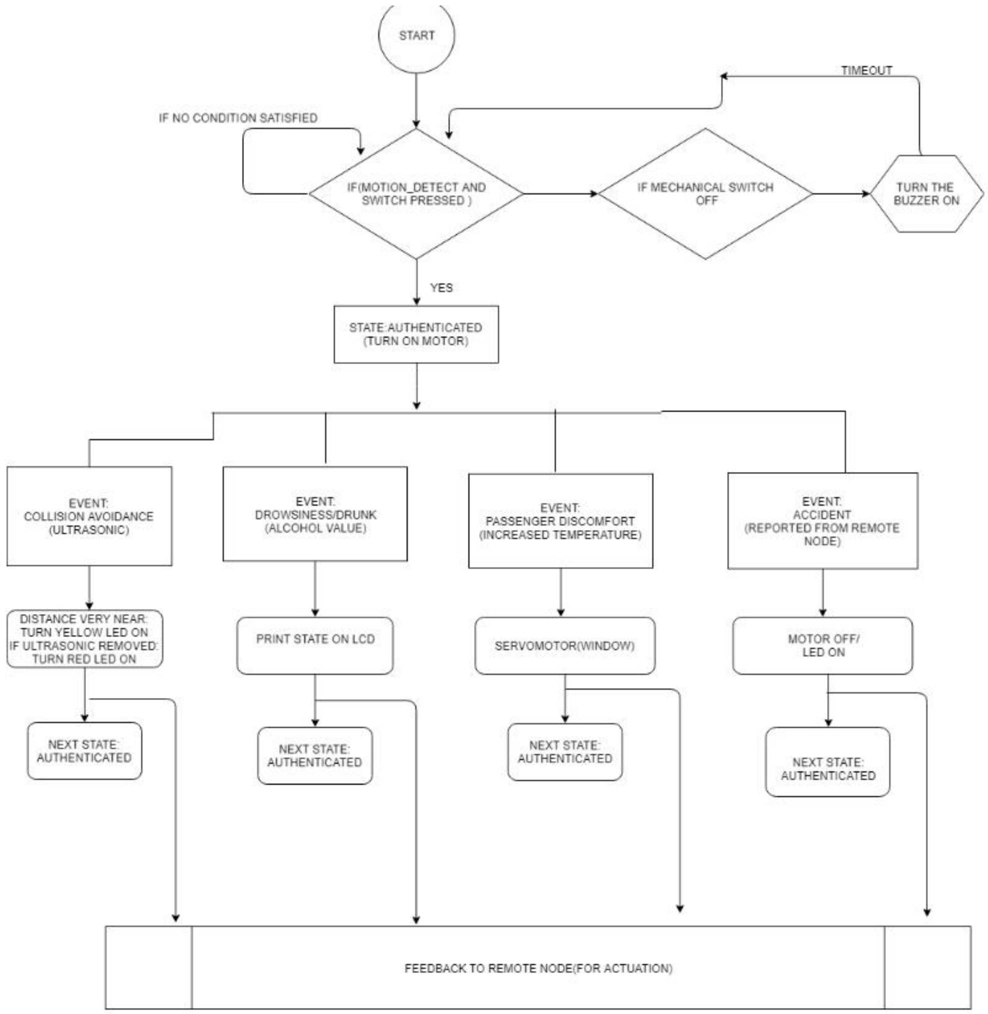
TEST RESULTS:

Test #	Category	Device/System	Test Title	Test Result
1	Automatic Startup	Control Node	System should startup automatically and wait for user authentication	Pass
2	Automatic Startup	Remote Node	System should startup automatically and wait for user authentication	Pass
3	BIST	System	Built in self test	Pass
4	Authentication - Original User	System	Authenticates the system using Motion sensor and button to further start the complete functionality	Pass
5	Authentication - Intruder	System	Authenticates the system using Motion sensor and button to further start the complete functionality	Pass
6	Performance - Normal	System	Test for operational status of system	Pass
7	Performance - Degraded	System	Test for operational status of system	Pass
8	Performance - Failed	System	Test for operational status of system	Pass
9	Communication - TIVA	System	UART Communication test	Pass
10	Communication - TIVA	Remote Node	TIVA Rx link broken	Pass
11	Communication - TIVA	Control Node	TIVA Tx Link broken	Pass
12	Sensor - Motion	Remote Node	Test motion sensor	Pass

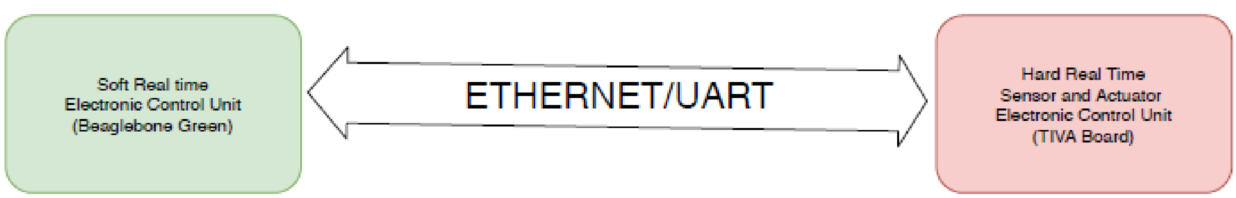
13	Sensor - Ultrasonic	Remote Node	Ultrasonic sensor test	Pass
14	Sensor - Gyroscope	Remote Node	Gyroscope sensor test	Pass
15	Sensor - Temperature	Remote Node	Temperature sensor test	Pass
16	Sensor - Alcohol	Remote Node	Alcohol sensor test	Pass
17	Actuator - LCD	Remote Node	LCD Test	Pass
18	Actuator - Buzzer	Remote Node	Buzzer Test	Pass
19	Actuator - Servo Motor	Remote Node	Servo Motor Test	Pass
20	Actuator - DC Motor	Remote Node	DC Motor Test	Pass
21	Actuator - LED	Remote Node	LED Test	Pass
22	User Input - Switch	Remote Node	Switch Test	Pass
23	Full System Testing	Remote Node	Integration Test	Pass

ARCHITECTURE DESCRIPTION

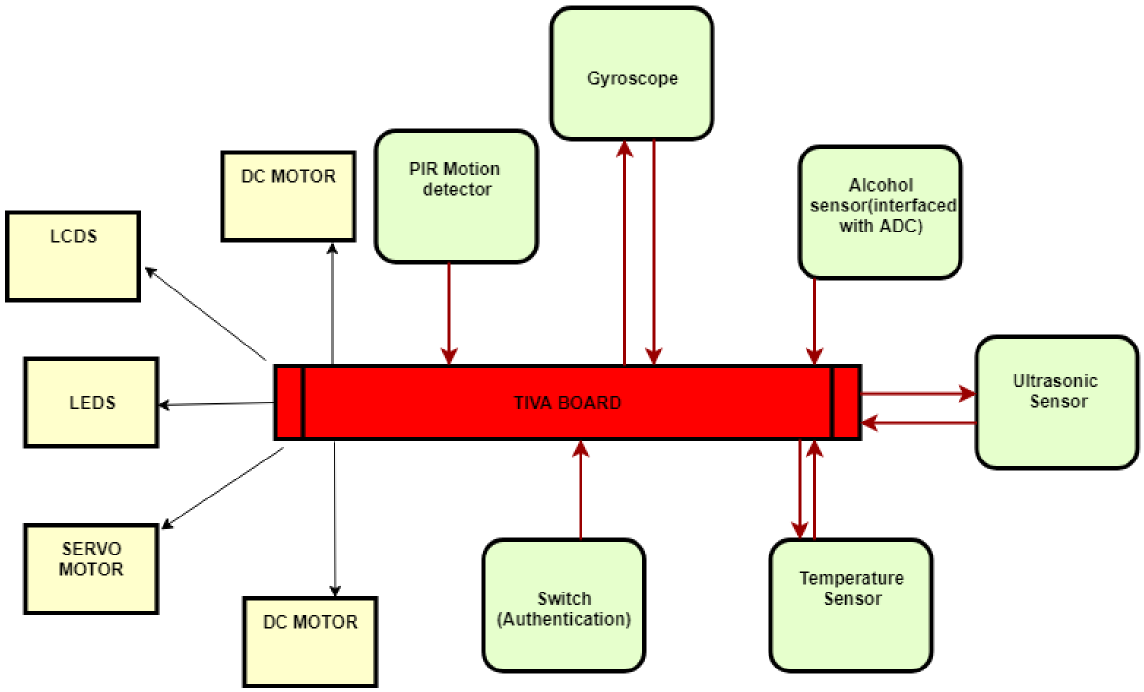
State machine



A broad overview of our system is presented below:



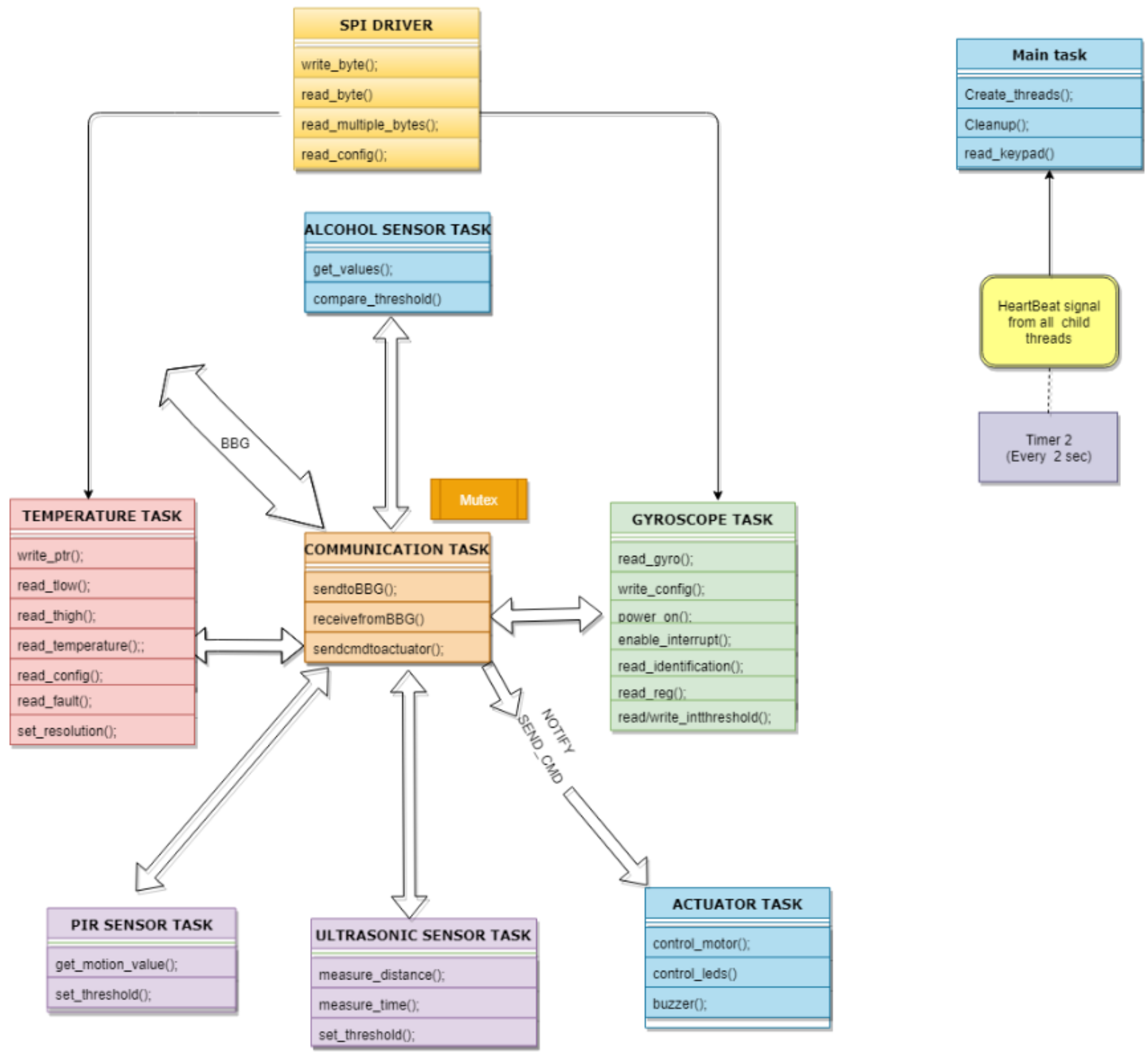
In our remote node, following sensors and actuators are interfaced:



SENSORS

ACTUATORS

We would be using SPI, I2C and ADC GPIO-based communication interface to acquire sensor data.
Also, xTaskCreate() would be used to create multiple tasks.
Functionality of remote node is explained below through the flow chart:



For authentication, we are first communicating a pre-determined pattern through user input via mechanical switch on the remote node to the control node. Once the authentication is successful, then only our system would start.

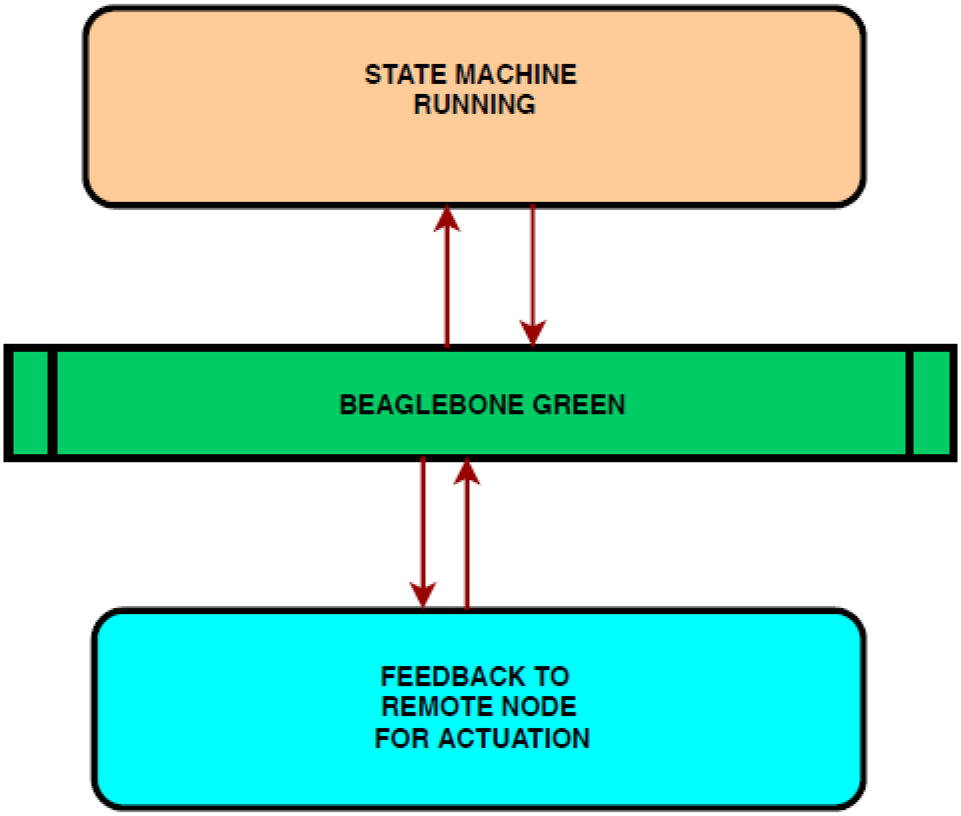
Once the system is started on the remote node, multiple sensor tasks would span that would acquire sensor data based on their respective APIs. All this information would be transmitted through sendtoBBG() API through a wired connection between the control node and remote node. We are proposing following data packet structure for individual sensor node:

| Data Payload | Data Payload | Data Payload | Data Payload |

Each sensor node would generate its own packet and the communication task running on the TIVA board would group all packets into a continuous serial bitstream. The communication task would receive actuation information from the Control Node through receivefromBBG() and use xTaskNotify() API to notify the actuator task for any actuation requirement.

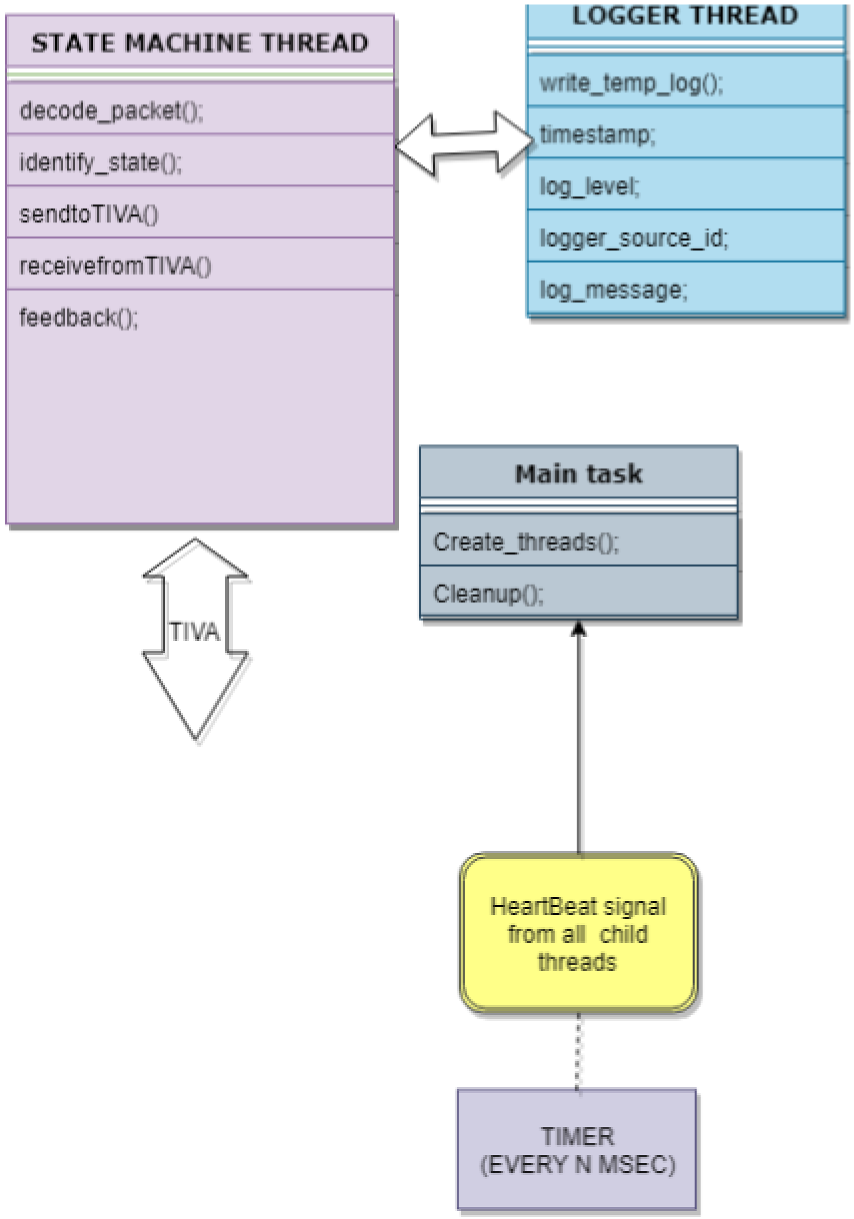
The actuator task would wait for any notification using xTaskNotifyWait() FreeRTOS API and would signal respective actuators as per the determined state.

An overview of our control node is presented below:



Functionality of control node is explained below through the flow chart:

A stream of packets would be received by the control node and parsed to segregate



different sensor values, using decode_packet() api call. Once the data is segregated, identify_state() API would identify different states and events in the state machine thread based on different sensor values. After the states are identified, actuation information would be relayed back to the control node through the same full-duplex communication protocol (either TCP/IP or UART). Moreover, the logger thread would log all the states, events, alerts, critical/non critical condition information for post failure system analysis.

The IPC mechanism we would be using for inter-task communication in TIVA board and inter-thread communication in BBG is queues. We would be using pthreads on beaglebonegreen.

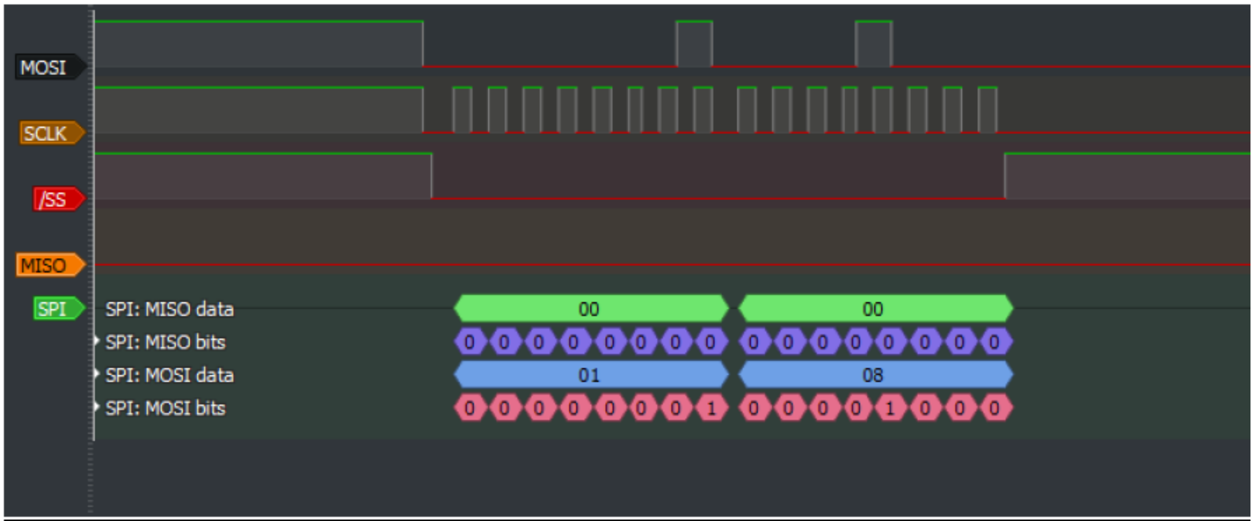
As per requirement, we would be employing synchronization and critical section protection using semaphores and mutexes to maintain reliable data communication inside and outside the boards. We are planning to deploy our software for the control node on its user space.

HARDWARE TESTING

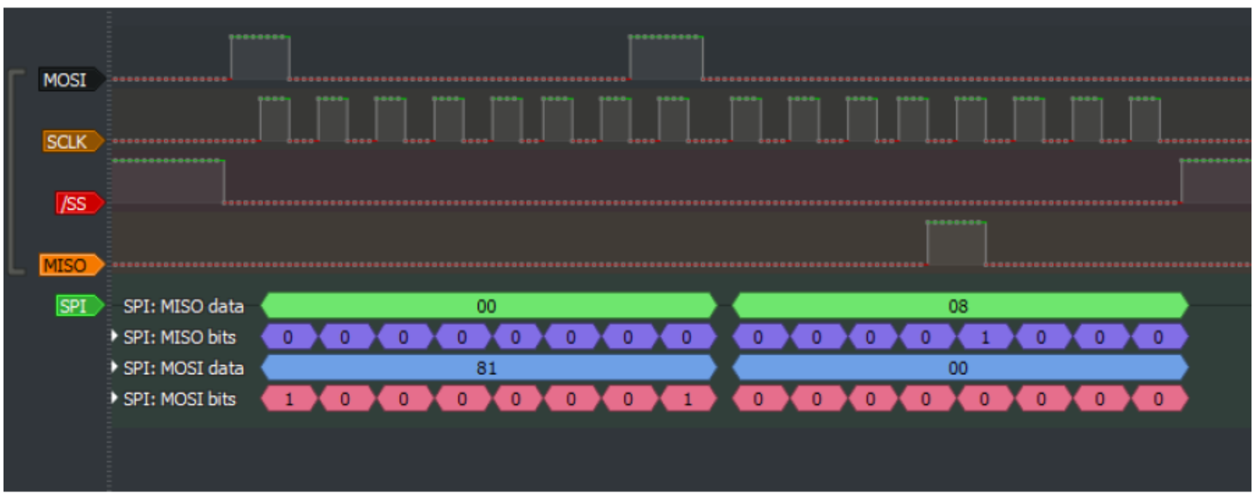
Note that the testing is being done using logic analyser and Digital signal oscilloscope

Testing SPI interface:

SPI write byte: A byte having value 0x08 is written into one of the register at location 0x01



SPI read byte: a byte having value 0x08 is read from pedometer register.
Note: The 0x81 address is because the MSb specifies read/write bit

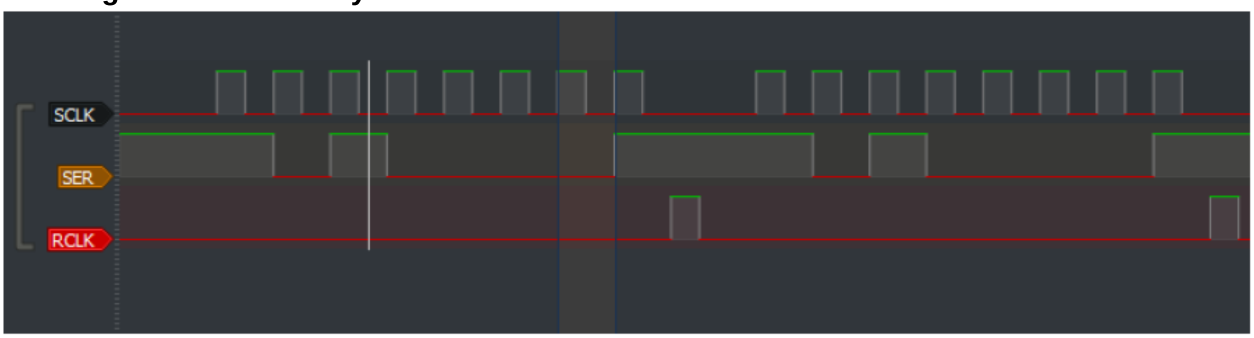


Testing I2C interface:

I2C read byte:

Shift register testing:

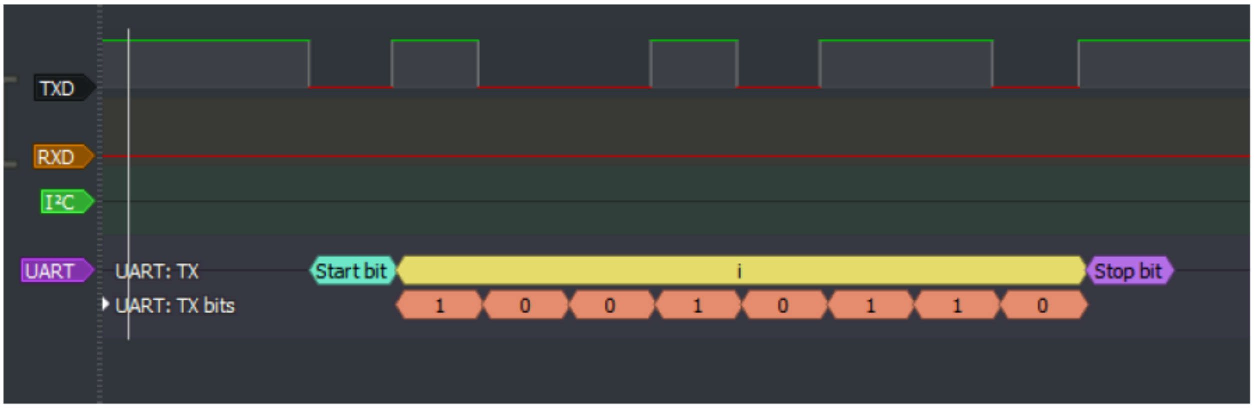
Sending 0x0A followed by 0xA1.LSb is transmitted first.



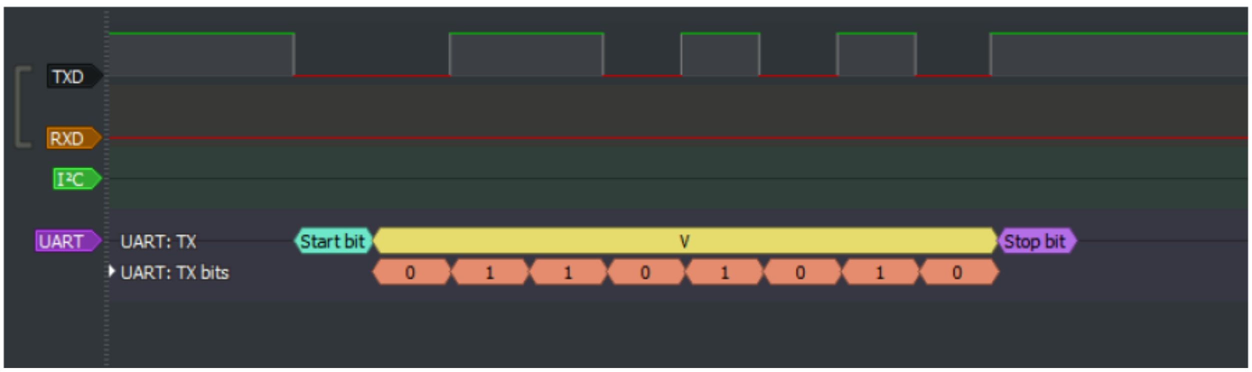
Uart testing:

Uart write:

Uart write:



Uart write:



LOGS WHILE TESTING:

```
[1014283.774828] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014294.183870] [CHECK FOR ULTRASONIC SENSOR]:                LOGLEVEL:4 SENSOR VALUE: 129
[1014315.980662] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014335.853287] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014368.141287] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014387.938745] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014420.220912] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014440.037828] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014472.239078] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014492.122203] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014524.385245] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014544.191828] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014576.475120] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014596.283537] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014628.497787] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014648.366953] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014680.622703] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014700.451495] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014732.719578] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014752.547953] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014762.955120] [Ultrasonic]:          LOGLEVEL:4 SENSOR VALUE: 130
[1014784.752203] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014804.621037] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014836.903620] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014856.703745] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014888.983328] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014908.799620] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014919.212662] [CHECK FOR ULTRASONIC SENSOR]:                LOGLEVEL:4 SENSOR VALUE: 130
[1014941.010037] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1014947.236328] [Gyro]:                LOGLEVEL:1 SENSOR VALUE: 103
[1014960.872078] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1014993.185287] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015012.967703] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015023.386370] [CHECK FOR ULTRASONIC SENSOR]:                LOGLEVEL:4 SENSOR VALUE: 130
[1015045.347245] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015051.510495] [Gyro]:                LOGLEVEL:1 SENSOR VALUE: 103
[1015065.056162] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015097.259787] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015117.132328] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015127.564120] [CHECK FOR ULTRASONIC SENSOR]:                LOGLEVEL:4 SENSOR VALUE: 130
[1015149.402120] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015169.221120] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015201.589703] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015221.311037] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015253.519745] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015273.389453] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015305.679703] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015325.470578] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015338.031412] [Ultrasonic]:          LOGLEVEL:4 SENSOR VALUE: 0
[1015357.773453] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015364.031037] [Gyro]:                LOGLEVEL:1 SENSOR VALUE: 103
[1015377.568912] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015409.774578] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015429.644412] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015461.922162] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015468.144245] [Gyro]:                LOGLEVEL:1 SENSOR VALUE: 103
[1015481.725037] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015514.003828] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015533.827703] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1015566.025370] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENSOR VALUE: 0
[1015585.900578] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28 ^C
```

If communication link broken

```
[1118818.789091] [Temperature]:                LOGLEVEL:3 SENSOR VALUE: 28
[1118850.973424] [ALCOHOL SENSOR REMOVED.EXPECT DEGRADED PERFORMANCE]:        LOGLEVEL:2 SENS
[1119994.355883] [TIVA TX LINK WORKING]:                LOGLEVEL:6 SENSOR VALUE: 0
[1125994.390800] [TIVA TX LINK DOWN]:          LOGLEVEL:6 SENSOR VALUE: 0
[1131994.421967] [TIVA TX LINK DOWN]:          LOGLEVEL:6 SENSOR VALUE: 0
[1137994.413260] [TIVA TX LINK DOWN]:          LOGLEVEL:6 SENSOR VALUE: 0
[1143994.531094] [TIVA TX LINK DOWN]:          LOGLEVEL:6 SENSOR VALUE: 0
```

AUTOMATIC STARTUP FILES
Location of file is /usr/local/bin

```
#!/bin/bash
echo Program runnning
cd /home/debian
./main >> tanmay.txt
~
~
~
~
```

Another modification in /etc/rc.local

```
#!/bin/sh -e
#
# rc.local
#
# This script is executed at the end of each multiuser runlevel.
# Make sure that the script will "exit 0" on success or any other
# value on error.
#
# In order to enable or disable this script just change the execution
# bits.
#
# By default this script does nothing.
#/usr/local/bin/startupfile
exit 0
~
```

KEY LEARNINGS

1. We learned inter-board communication between a remote and control node using UART
2. We learned the development of LCD Driver, I2C driver, SPI driver, Timer driver, ADC driver, and PWM driver
3. We learned complex system integration
4. We learned time management and incremental system development
5. We learned inter-process communication and inter-thread communication