Realistic Train Simulator

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Abstract

The goal of the project is to design and build a low cost diesel locomotive train simulator for training and recreational purpose. Use of simulators has been found to be very effective by Railways across the world from safety point of view. By using simulators, the quality of training can be enhanced while at the same time it reduces training time and guarantees a constant high level of proficiency over the long term. The simulator can also be used for a realistic experience by the gaming community while playing train driving simulation games on a personal computer. The aim was to build a low cost driver console simulator using off the shelf components which could be installed at various crew resting points across the network of the Indian Railways for giving an easily accessible and realistic locomotive driving experience to the loco pilots, other crew members of the train as well as for recreational purposes.

I. INTRODUCTION

Rail simulation has become one of the most effective methods for the training and qualifying drivers of trains, light rail vehicles and trams.

The use of rail simulator systems in training and assessment programs improves the quality of the learning process by confronting the trainee driver with a great variety of situations and out of course events. In order to ensure safety and secure daily operation of railway vehicles, especially in high-speed and rapid public transport operational environment and in railway freight transportation, an extensive and qualified, individualized training is required. Simulator-based training is especially suited for training situations which are impractical, difficult, and dangerous/risky or too expensive to be conducted and reproduced in a live environment.

In recognition of their benefits as a key component of the driver training and assessment process, large numbers of railway systems today make extensive use of simulators, thereby improving the quality of training, reducing training time and guaranteeing a constant high level of proficiency over the long term.

In India, train simulators for loco-pilot training are available at select locations only. The training of a loco-pilot is mostly theoretical without much hands-on training inside a locomotive. Train Simulators help this cause by taking locomotives to the driver-trainees. Locomotive train simulators are made by only a few firms worldwide and cost upwards of Rs. 10 Crores, using proprietary modelling and graphics technologies.

This Train Simulator design aims to leverage the rapid advances in graphical modelling technology and control systems to provide low cost locomotive simulation at crew resting points.

Generally, the cost of simulators is very high. This simulator has been designed to address the economics behind real-time locomotive training by focusing on system integration using commonly available solutions, while striving to retain as much realism as possible. An old locomotive control stand has been used as the main interaction hardware for the user. Softwares like Microsoft Train Simulator, Auran Trainz and Railworks have today become highly realistic with high resolution CGI graphics / sound, mathematical asset modelling, custom locomotive and rolling stock packs and scripts for customization. They can be used to provide the simulation interface to the driver-trainees, who handle the loco-controls manually while being connected to the real-time environment generated by the software. This project provides the means to interface such simulation software to an actual locomotive driver's panel, providing a seamless 2-way exchange of information between them.

Design objectives of this project for industrial application are:

- Low cost of project and easy to perform simulation.
- Emulating controls for a more realistic locomotive experience.
- Audio, Visual and Tactile feel of a locomotive.
- Adaptable to different locomotives. Both ALCO and GM family locomotives used by the Indian Railways can be modelled.
- Customizable for Indian Railways.

II. Technical Background

The idea for the project is an original one, though there are various users of Microsoft Train Simulator, Railworks and Auran Trains gaming programs constantly striving to add realism to the train driving experience. Through the internet forums, one can find many enthusiasts making mock train cabs etc. [1]. There are several dedicated sites and forums where such users exchange their ideas. The project was motivated during a training session on the Railway's extremely expensive locomotive simulator situated in the institute's premises at Jamalpur. The project shows that it is possible to reduce the cost and complexity substantially in the locomotive simulator using off the shelf components.

A number of extremely realistic train simulators (such as Microsoft Train Simulator) developed for Gaming applications were examined as the main asset-modelling engine having a hi-resolution Computer Generated Imagery (CGI) display. Targeted at games, they take user inputs from keyboard /mouse/joystick etc. and display the outputs on the computer monitor. However, application for training purposes requires inputs and realistic feedback of system parameters and locomotive vibrations from a modelled locomotive control stand.

The project interface design consists of a primary control unit that takes input from the reverser & throttle levers (through existing cam operated contacts) and also from push-button switches on the control stand to control the horn, sander, lights etc. At the PC-end, the controller appears as a generic USB HID keyboard, which the simulation software can interface to. The primary controller design uses galvanic isolation through opto-couplers for protecting the Micro-Controller Unit (MCU) from damage from these high voltage controls. Brake handles inputs are taken by using potentiometers with analog amplification circuits to sense the lever positions and send the signals to the MCU Analog-to-Digital Conversion (ADC) pins. The CGI image rendered on the monitor is used as the primary display interface.

Thus, the trainee using the equipment operates controls on a mock up-model of a locomotive driver's panel as in a real locomotive. The visual output generated by the simulation engine responds accurately to the controls operated by him on the panel.

For handling the outputs, another ARM microcontroller is used to receive data about gauge readings from the simulation engine and drive the gauges on the panel.

Tactile feedback has also been added to enhance the user's experience. This is done by taking the audio output generated by the simulation program and then separating the low frequency component using suitable low pass filters [2] to isolate the engine sound and low frequency locomotive noises from track fittings etc. This filtered output is used to drive a speaker modified to work as a vibration generator, which transfers these vibrations to the driver's seat.

Thus the user gets a comprehensive audio, visual and a tactile simulation experience.

The simulator can also be used for a realistic experience by gaming community while playing simulation games on a personal computer. The electronics and other hardware developed during the course of the project can also be used to make a realistic steam locomotive cab, a perpetual rail-fanner's dream.

III. PROPOSED SOLUTION

Figure 1 shows the system level block diagram of the implementation.

Various support devices used for interfacing are as follows:

- Locomotive control panel
    - Wired for reading reverser, throttle lever and switch inputs
    - Servo motors for pressure gauges and electric meters driven using Pulse Width Modulation (PWM).
- Opto-isolators
    - To read digital signals from the locomotive panel
- Potentiometers and analog front end
    - To convert brake valve position to a filtered analog value for feeding to microcontroller.
- Low-pass filter, amplifier and tactile transducer
    - To provide locomotive vibrations feedback.

The project has been designed so that the existing locomotive panel can be interfaced to a personal computer with as few modifications as possible while retaining as much realism as possible.

IV. IMPLEMENTATION

A. Hardware Implementation

The block diagram of the system is given in Figure 1.

Figure 2 shows the overall input overview and Figure 3 gives the overall output overview.

Interfacing the digital signals is done through an opto-isolator board. Another 8 port lines are used to drive a Notch Indication display. This is fairly straightforward.

There are two vital Analog subsections. The first subsection is the brake lever interface. The schematic of the same is in Figure 5.

TI's quad op-amp TLV 2374 [3] has been used as the basic analog building block. There are 4 analog channels. These receive inputs from potentiometers connected to the train brake, locomotive brake, combined handle and dynamic brake levers each. The first section in each channel is a first order low pass RC filter. This helps in reducing the contact scratch noise. Since the active travel of the sense potentiometers of train brake & locomotive brake controls is less than half of the potentiometer range, the signal is passed through a gain stage of 2x gain to bring it within the measurement span of the microcontroller's ADC.

The fourth channel for the Dynamic Brake (DB) potentiometer features a variable gain of 1 to 21. This has been done because though the dynamic brake potentiometer is already available on the locomotive control stand for interfacing, it has a low value of 50 ohms resistance. Using this potentiometer as a voltage divider draws too large a current due to the low 50 ohm resistance. Therefore the power to the dynamic brake potentiometer has been supplied through a 1Kohm resistance ensuring that the sense current is within reasonable limits. The output signal from the dynamic brake potentiometer is then amplified by 20 times to generate a reasonable ADC input voltage span. This channel is also useful for interfacing 10-turn linear potentiometers in a panel, which was found to have the best linearity and reliability performance.

The processed digital and analog signals are then passed on to the LM3S9D92 (TI Stellaris ARM Cortex-M3 Series Microcontroller). Stellaris microcontroller was chosen due to its fast ADC performance, large number of port lines and good USB communication support. Sample applications of Stellarisware library proved to be a big help when working with USB and other peripherals.

Figure 8 shows the primary controller board. It handles all the signals – analog and digital coming from the panel levers, switches, and potentiometers etc. and appears to the PC simulation application as a Human Interface Device (HID) keyboard for transmitting the corresponding key sequences expected by the simulation program. The close-up of the TLV2374 analog circuitry is at Figure 9.

The second analog subsection is a low-pass filter for the tactile actuator [4], [5]. The schematic of the same is in Figure 4, while Figure 11 shows the constructed module. This subsection receives the composite audio signal from the train simulation program and filters out the low frequency signals to isolate the engine vibrations and noises felt by the driver. A second order Butterworth low-pass filter has been implemented using TI's UAF42 integrated circuit [2], [6]-[8]. It has following parameters, which are similar to the characteristics as in [2].

f(-3dB)=120Hz, Av=1, Q=0.707

Filter design requires precision resistors and capacitors, which are difficult to get. Using UAF42, all that is required are three resistors to set the cut-off frequency and the Q-factor of the filter. TI's FILTER42 program was used to determine the component values for a 120 Hz low-pass filter. The output of the filter is given to an amplifier and then to a Tactile Transducer.

Figure 12 shows the tactile transducer for seat mounting to transfer the vibrations to the driver's seat.

A TIVA-C series launchpad board (Figure 10) has been used to display the speed, load and air-brake system parameters on the control panel through familiar meters and gauges. The implementation converts the received parameters into PWM and servo pulse signals for driving either moving coil type meters or servo-motor driven gauges (Figure 13).

A compact power supply is built using DCR021205P DC-DC converter for powering the servo driven gauges. This is preferable to driving servo motors directly from the USB port as there is no risk of damage due to current spikes and surges.

Finally, Figure 14 shows a snapshot of the project showing how the whole integration looks and feels like. The overall arrangement of various peripherals and devices is diagrammatically illustrated in Figure 15.

B. Software Implementation

The system firmware for the Input Stellaris Controller Board reads the digital and analog inputs on every system-tick, and converts them to keystrokes for sending to the simulator application running on the PC. The firmware supports both Railworks and Auranz Trains, two of the most realistic simulator programs [1]. While writing the firmware, Stellarisware example *usb device keyboard* template was used. Because the firmware emulates a standard USB HID keyboard, no operating-system drivers are required for this plug-and-play device.

For the Output TIVA Controller board, a simple sketch was written using Energia IDE to read the data values received on the virtual USB COM port and generate PWM and servo-pulse width signals.

To generate the data values itself, a lua script was used to extract data from the simulator program (Railworks) and continuously write the same to a text file. This file was continuously read using a small C# program and the values output on the virtual USB COM port.

V. RESULTS

The Interface via the Stellaris and TIVA Controller boards allowed the user to control the locomotive simulation program from the Locomotive panel and view the speed, load and air-brake parameters as in a actual locomotive. The CGI Display of the simulation program gave a very realistic display once the correct locomotive packs were installed and tweaked.

The Analog filter sub circuit performance extracted by the FILTER42 program for the components selected is shown in Figure 7.

The actual results grabbed from an Agilent 100 MHz DSO for 120 Hz and 200 Hz sine wave signals supplied through the filter are shown in Figure 6. At frequencies above 1 kHz, virtually no output signal can be seen on the DSO. The performance of the filter in Bass reproduction far exceeded the expectations [2], [6]-[7]. The tactile vibration feedback mechanism through this filter adds a lot more realism to the project.

VI. CONCLUSIONS

The implementation demonstrates that it is possible to build a low-cost realistic train simulator using off the shelf components / software at a fraction of the cost of professional units. Several railway drivers and trainees have been invited to test and evaluate the developed system and their feedback has been extremely encouraging. This has been a constant motivating factor in continuing development of the project.

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c) Shri Utkarsh, Professor at IRIMEE for his new ideas and guidance for improving the project.
d) Shri Swapnil Garg, Sr. Professor at IRIMEE for guiding us with the documentation of the project.

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[7] Johnnie Molina and R. Mark Stitt, Filter Design Program For The UAF42 Universal Active Filter, Burr-Brown Application Bulletin, 2000

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APPENDIX A – BILL OF MATERIALS

	Component	Manufacturer	Cost per component	Qty	Total cost of component
1	Micro Controller Stellaris LM3S9D92	TI	Rs. 6000	1	Rs. 6000
2	UAF42	TI	Free sample	1	Free sample
3	TLV2374	TI	Free sample	1	Free sample
4	Opto-Isolators	Sharp	Rs. 15.00	12	Rs. 180
5	Power Supply (12V/24V Supply)		Rs. 1500	2	Rs. 3000
6	Push Buttons		Rs. 50	3	Rs. 150
7	Stepper Motors		Rs. 900	3	Rs. 2700
8	7-segment display		Rs. 400	1	Rs. 400
9	Software platform–Railworks TS2013	Railworks	Rs. 2400	1	Rs. 2400
10	Software platform–MSTS 2004	MS	Rs. 700	1	Rs. 700
11	Wire wound potentiometers	Bourns	Rs. 180	3	Rs. 540
12	Locomotive control stand and Master Control	Indian Railways			NA
13	Speaker for Tactile Actuation with		Rs. 3500	1	Rs. 3500

	Amplifier				
	Total Cost of the Project				Approx Rs. 20000

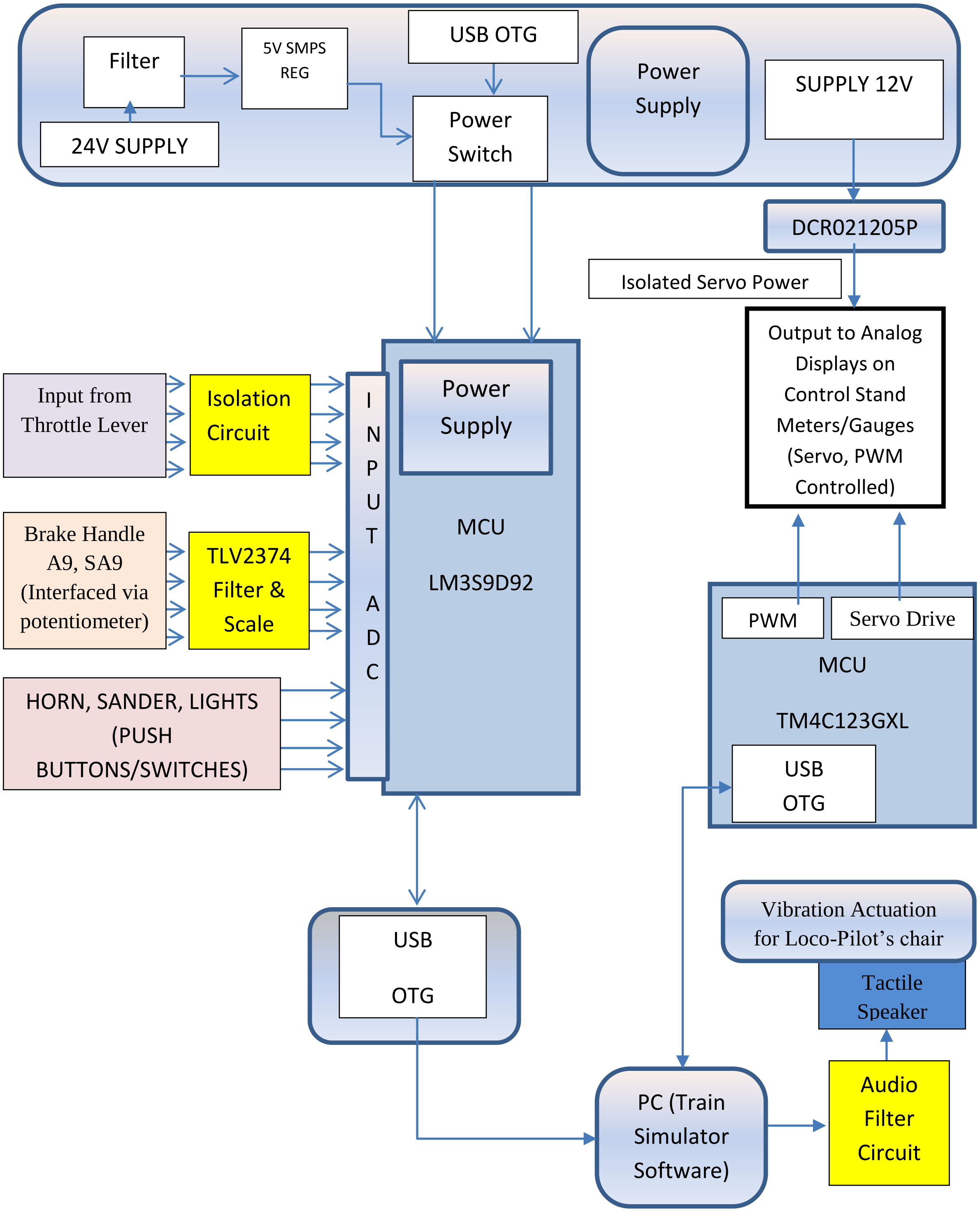


Figure 1 – System Level Block diagram

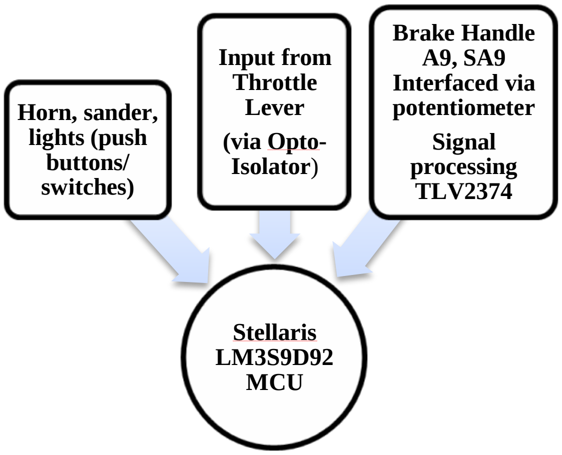


Figure 2 – Block diagram (Input Overview)

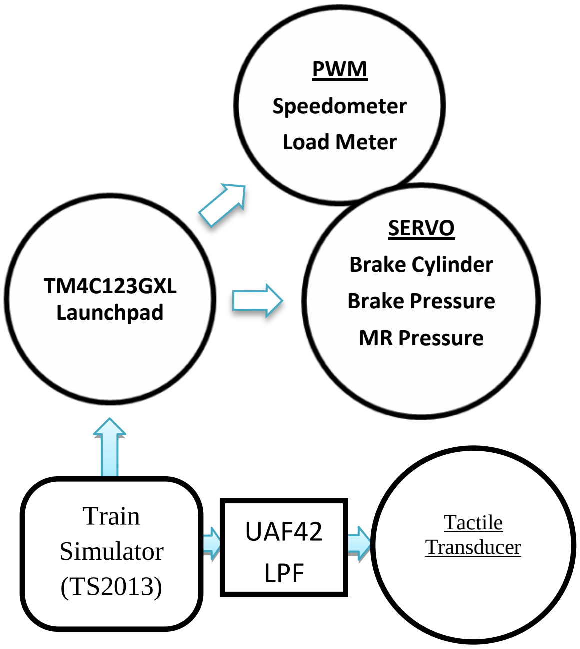


Figure 3 – Block diagram (Output Overview)

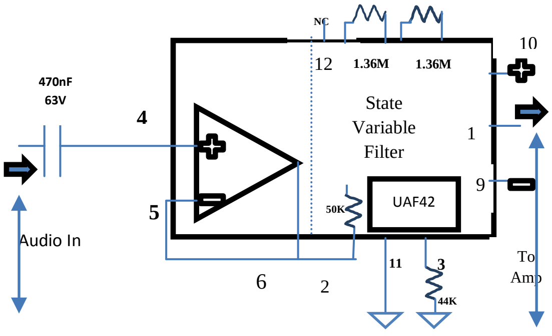


Figure 4 – Pin diagram of UAF42 LPF

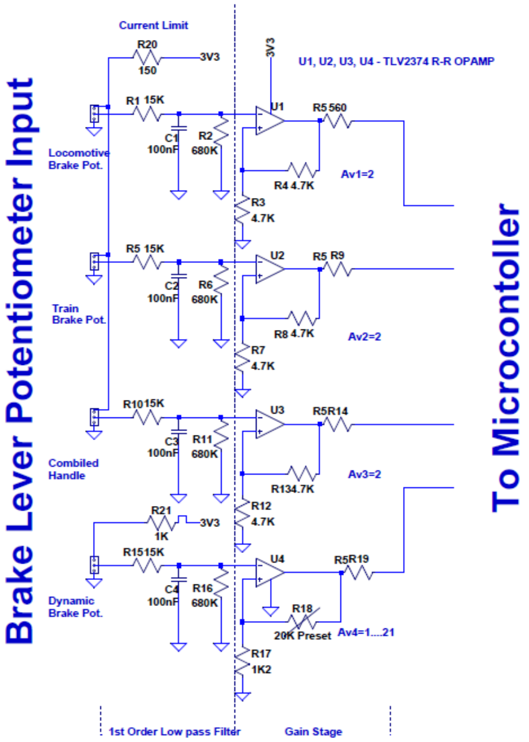


Figure 5 – Filtering and scaling analog inputs using TLV2374 quad op-amp.

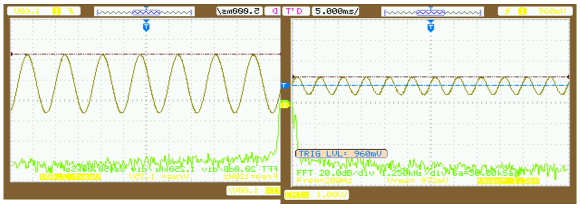
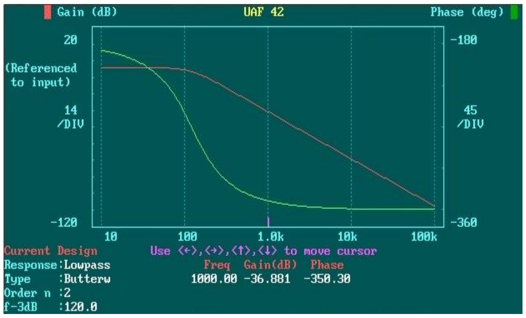


Figure 6 – Audio filter performance analysis on DSO for 120 Hz and 200 Hz sine wave signals



```
Current Design
Response:Lowpass
Type    :Butterw
Order n :2
f-3dB   :120.0
```

```
Freq     Gain(dB)   Phase
1000.00  -36.881   -350.30
```

Figure 7 – Analog filter sub circuit simulation.

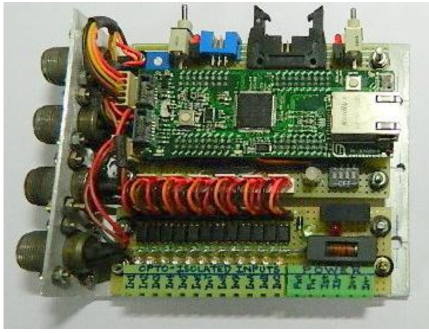


Figure 8 – Stellaris LM3S9D92 based control board

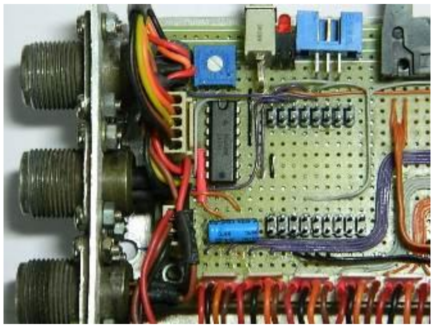


Figure 9 - TLV2374 analog circuitry

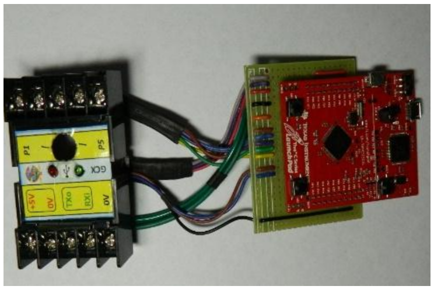


Figure -10- TM4C123GXL TIVA board for driving gauges and speedometer.

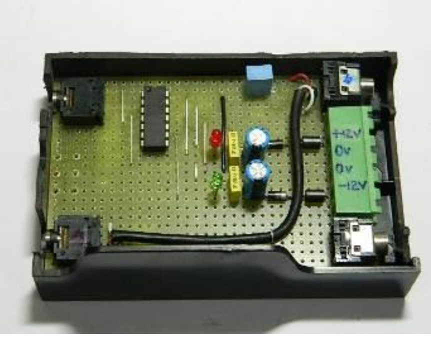


Figure 11 - Audio Filter Circuit board

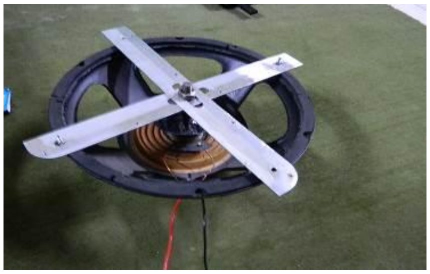


Figure 12 –Tactile transducer for seat mounting.

Figure 13 – Servo motors to drive gauges.

Figure 14 – Final setup of the simulator.

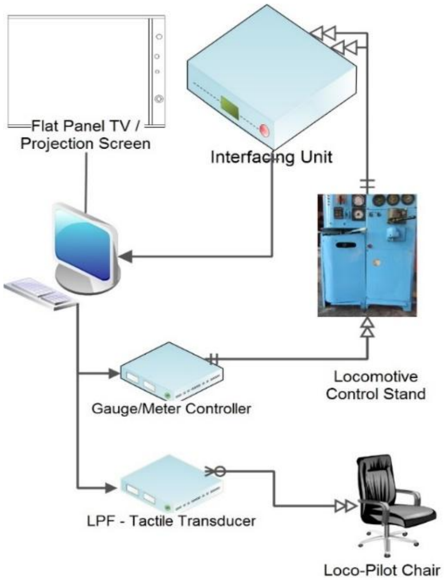


Figure 15 – Overall arrangement of component elements (Diagrammatic illustration)