Report quality	/2
Interface and sensor data	/2.5
State estimation	/2.5
Intelligence and Action	/3
Total Mark:	/10

MECHENG 312
Sensors and Actuators

Sensors Assignment Coversheet

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I am aware of the course outline regarding the format, structure and submission of this assignment (see note 2 below)
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Contribution %*:		

* You do not need to enter a % contribution if it is within a 60-40 split.

Intelligent Driverless Car Project

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Executive Summary

The “Intelligent Driverless Car” assignment is a student project aimed at teaching students the nature and characteristics of sensors in a simulated real world project. Students are to work with real world, non-ideal sensors, incorporating previous knowledge in real time software design, to design the logic for an autonomous vehicle (Figure 1). This process offers the students a better understanding of the benefits and disadvantages of different sensors in the application of automation.

Automation is one of the main areas Mechatronics knowledge and practice can be applied to, it aims to have processes or procedures operate without the input of humans. Automation, and the broader field of artificial intelligence, is an incredibly important industry to the world. It minimises the need for humans to perform mundane tasks, freeing more people up for intellectual work, while increasing global production volume. The first step to achieve this is the utilisation of sensors to detect the current state of the process.

Students are issued National Instruments’ “ELVIS II” virtual instrument suite, and an accompanying sensor board. The initial task is to explore the multitude of sensors available and select four appropriate for the requirements of the assignment. These sensors are then to be calibrated with an appropriate model using the provided software. Students are to then program state estimations for both the physical and simulated sensors to determine the condition of each aspect of the vehicle. Finally, a user friendly program is developed which uses these states to intelligently decide the appropriate actions to take, such as ignition, speed, acceleration, deployment of airbags etc.

Figure 1 Google's Self Driving Car

Table of Contents

1.0 Introduction

The objective of this project has been broken down into three main sections:

1. Read and calibrate raw inputs from four sensors on the NI board to determine the following.
    a. If the driver is in the seat
    b. The distance to the car in front
    c. If the door is open
    d. Seatbelt velocity

   Additional simulated sensors can be added as necessary to improve the accuracy of the model. All relevant simulated outputs should also be visible to the driver.
2. Use both physical and simulated sensors in a state estimation algorithm, which detects and displays the condition of various aspects of the car, to determine if it is safe to drive in.
3. Add intelligence to the system such that it can make decisions based on the various states from part 2.

This report will detail the physical sensors used, the reason for their choice, and the way they operate in the program. It will then describe the simulated sensors and control algorithm used, and why they were necessary for this project. Finally, a discussion will be made of the design decisions made throughout the completion of the project, along with potential room for improvement.

2.0 Physical and Simulated Sensing Implementation

2.1 Physical Sensing

Students are issued a National Instruments' sensor board to interface with the ELVIS II platform (Figure 2). The sensor board is host to 16 different sensors the user can choose from. Those sensors are split into 4 channels with 4 sensors each. To use a sensor, the user simply shorts the appropriate header with a jumper. The limited channel number means the user can only use up to 4 sensors at one time, which has provided some design challenges as later detailed in this report.

The four sensors used to achieve the first section of the requirements were Strain Gauge, Infrared, Push Button and Optical Encoder respectively. All sensors were calibrated using appropriate mathematical model and compared to ground truth to ensure high accuracy and precision.

Figure 2 NI Instrument Board with ELVIS II Platform

2.1.1 Strain Gauge

A Strain Gauge was chosen for the detection of a passenger in the driver's seat. The sensor measures deflection and is converted to weight. The sensor was calibrated using a linear relationship between the gauge's output voltage and the deformation of the medium it is attached to.

In practice, this sensor would be embedded into the driver's seat to measure the amount of deflection based on the weight applied. If it is not above a critical value, the car will not be able to start for safety and legislative reasons. If the car is moving and the user attempts to get off the seat, a red warning LED on the ELVIS board will light up. The critical value is set at 30kg, to distinguish between a person and other loads; such as bags or luggage.

2.1.2 Infrared (IR) Emitter and Receiver

An IR sensor was used to measure the presence of obstacles in the path of the car's desired motion and the distance to it. The output data was calibrated by fitting a second order polynomial to the sensor's response characteristics and subsequently scaled appropriately to generate a linear relationship between distance of obstacle in front of the sensor and the digital output. This distance is then used in the vehicle's speed control. If vehicle ahead is significantly close, the car will slow down accordingly so as to maintain a steady following distance. Detailed description of the position control can be found under 'Position Control' in this section.

The alternative for this application would be an ultrasound sensor, which can also detect distance. The Ultrasound sensor's signal is subjective to more noise and fluctuation in our experience, especially when the medium (air) is disturbed. IR has its own shortfalls, namely a limited range of colours it can be used on. Realistically, neither sensors would be used in an autonomous vehicle, either cameras or lidars will be employed instead, so for the purpose of the assignment we chose IR for its cleaner signal.

2.1.3 Push Button

A simple binary switch was used to determine whether the door was open or closed, where a depressed button corresponded to a closed door, and vice versa.

Should the car door be open while the car is stationary, the car will not move. If the car is moving, the same red LED described to in the Strain Gauge section will light up to notify the user that the car is not in a safe state to be driven.

2.1.4 Optical Encoder

The rotational motion of the spool a seatbelt coils around within its housing was simulated with an optical encoder. Because the encoder's response is a digital signal with either rising or falling edges per unit time representing angular velocity, the sensor did not require calibration.

Speed of rotation was calculated by counting the number of rising and falling edges in a set timeframe of 0.5 seconds. If the rotational velocity of the encoder exceeds a particular value while the car rapidly decelerates, a simulated air bag inflation will occur in the UI.

2.2 Simulated Sensing

Due to the aforementioned issue of being limited to operating a maximum of 4 sensors simultaneously, many other states which would need to be measured and controlled were instead simulated. These states vary in response to data measured by the physical sensors of the system.

The simulated states employed for testing include vehicle dynamics such as speed and acceleration, weather conditions, and navigating simulated corners.

2.2.1 Position Control

Position between the car and an upcoming obstacle is controlled using closed loop negative feedback. The system takes in a desired speed or the speed limit of the street and applies the difference between that and its current speed to the accelerator with an appropriate gain. This system effectively controls the relative position between the car ahead and itself A possible simplified control system to be used in an autonomous electric car prototype is shown in Figure 3.

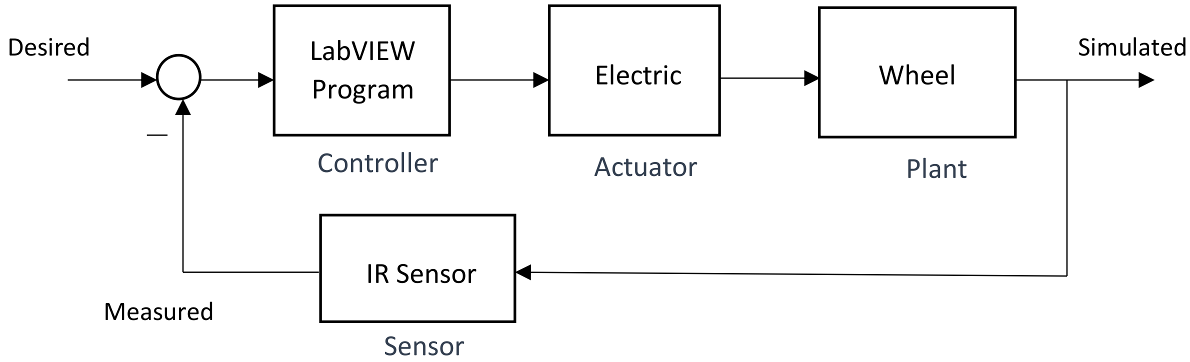


Figure 3 Control Logic for Position

2.2.2 Navigating Corners

Corners can be simulated using the UI, whereby a dial indicates the rotation of the vehicle's steering wheel. The program allows for left and right turning with a specified angle, and reduces the car's velocity enough to safely turn a corner. This algorithm can be used by a smart car's navigation system, where it directly interfaces with the GPS to navigate the vehicle to the destination.

2.2.3 Weather Conditions

Road conditions such as rain and snow can be simulated on the UI, which alters the minimum allowable following distance for cars in front according to the nature of the conditions.

2.2.4 Time of Day

A simple binary day/night state was added to the UI, which will automatically toggle the car's headlights off/on respectively. However, given certain weather or road conditions, a manual headlight setting was added to override this should the driver see fit. Normally, autonomous vehicles should not require headlights to operate. This feature was implemented for the benefit of the passengers and pedestrians, as it is important for autonomous vehicles to seamlessly integrate into the existing transportation infrastructure.

3.0 Discussion

3.1 Findings

From a software design perspective (see Appendices for screenshots of front panel and block diagram), implementing intelligent decision making into a model of a simulated autonomous vehicle shows some initial feasibility. That being said, the simulation designed for the project was a simplification of the underlying principles which govern locomotion, and much work can be done to improve its applicability.

From the perspective of sensor design, producing a car which can perform simple tasks such as controlling uni-directional motion, maintaining a set distance between surrounding cars, and changing behaviour based on weather conditions is a viable task. However, there are more complexities which have not been considered and must be implemented to fully simulate an autonomous vehicle.

3.2 Suggested Improvements

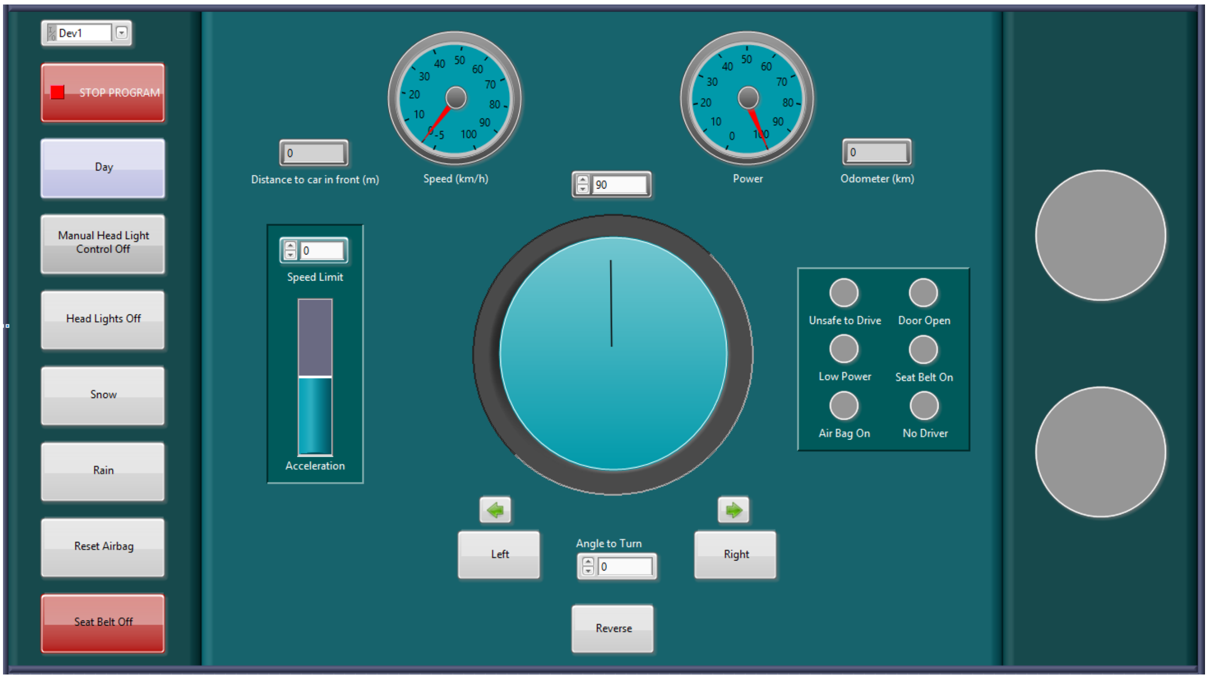
The simulation designed for this project only used four sensors for different state detection due to the circuit design on the ELVIS Board. However, to successfully simulate an autonomous vehicle would require far more sensors. For example, obstacle detection would need more than one range sensor to determine the size and nature of obstacles in the car's vicinity.

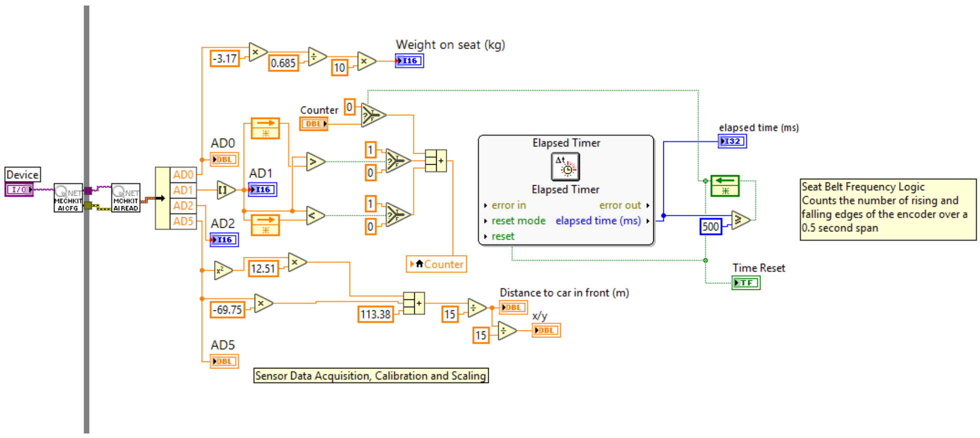
Another way to improve our designed model is to use more reliable sensors in the context of proximity sensors. Both the provided IR and Ultrasound have individual limitations for use in a physical model as discussed earlier. An alternative to these sensors is Lidar, which has far greater range than IR, and less signal contamination than Ultrasound.

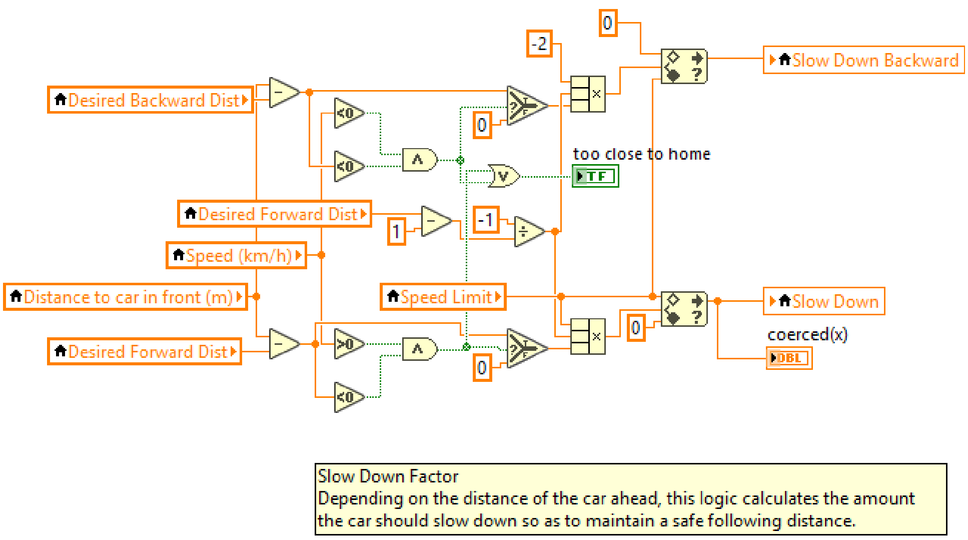
A further point of focus for improving the car model would be transition to more complex state representation. Many of the simulated external car states possess a binary structure, which would not be the case for a physical car. For example, weather is effectively represented as wet or dry and the following distance is changed accordingly. While this is a suitable starting point, it would be more advantageous to change the distance as a function of the road's surface friction.

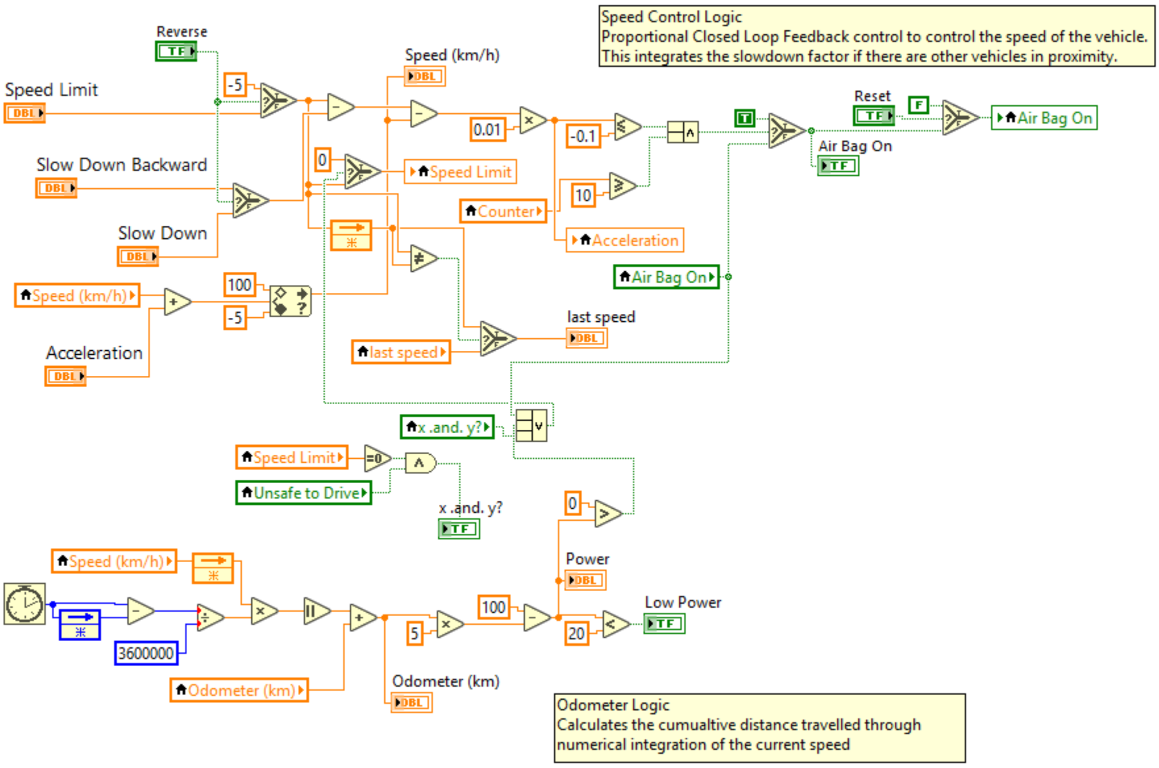
Finally, our control method could be improved further. Currently, closed loop control of the position is achieved through a proportional controller. This is functional but not ideal as it has a slower rise time. With a better model of the system, we could apply control methods such as a PID controller or Kalman Filters.

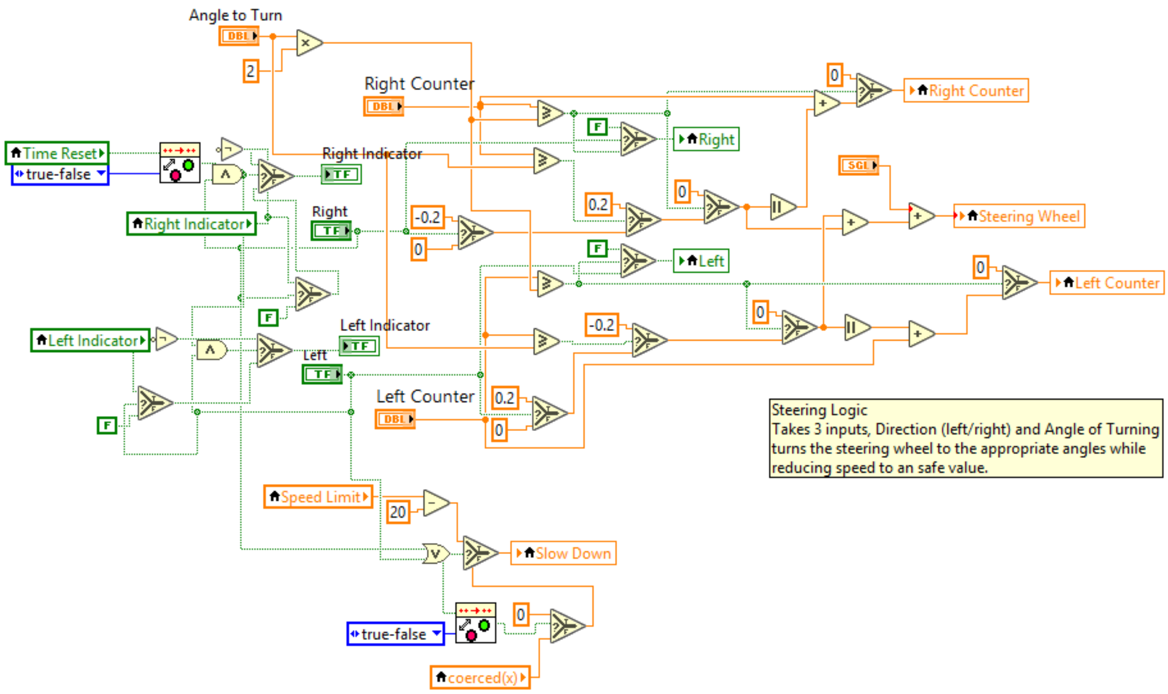
Appendices

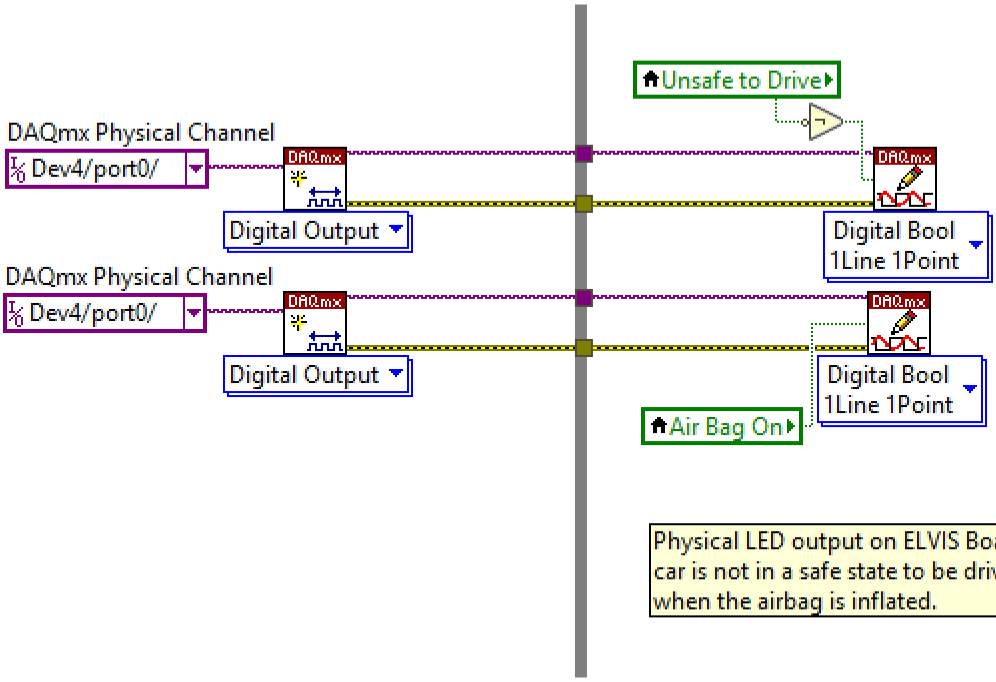

Dev1
STOP PROGRAM
Day
Manual Head Light Control Off
Head Lights Off
Snow
Rain
Reset Airbag
Seat Belt Off
Distance to car in front (m)
Speed (km/h)
Power
Odometer (km)
Speed Limit
Acceleration
Unsafe to Drive
Door Open
Low Power
Seat Belt On
Air Bag On
No Driver
Left
Angle to Turn
Right
Reverse


Weight on seat (kg)
Device
Counter
AD0
AD1
AD2
AD5
Elapsed Timer
error in
error out
reset mode
elapsed time (ms)
reset
elapsed time (ms)
Time Reset
Distance to car in front (m)
x/y
Seat Belt Frequency Logic
Counts the number of rising and falling edges of the encoder over a 0.5 second span
Sensor Data Acquisition, Calibration and Scaling

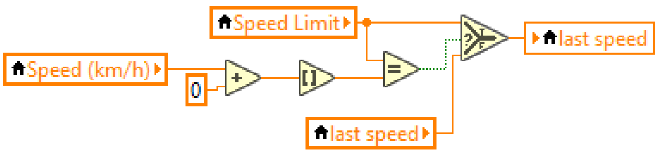

Desired Backward Dist
Slow Down Backward
too close to home
Desired Forward Dist
Speed (km/h)
Distance to car in front (m)
Speed Limit
Slow Down
coerced(x)
Desired Forward Dist
Slow Down Factor
Depending on the distance of the car ahead, this logic calculates the amount the car should slow down so as to maintain a safe following distance.

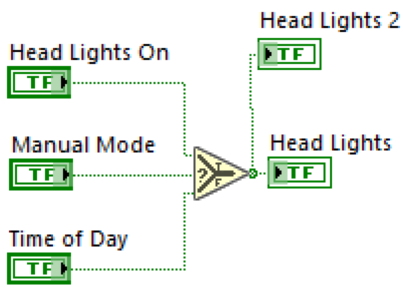

Speed Control Logic
Proportional Closed Loop Feedback control to control the speed of the vehicle.
This integrates the slowdown factor if there are other vehicles in proximity.
Reverse
Speed Limit
Slow Down Backward
Slow Down
Speed (km/h)
Acceleration
Speed Limit
Counter
Acceleration
Air Bag On
last speed
Reset
Air Bag On
x .and. y?
Unsafe to Drive
Power
Low Power
Odometer (km)
3600000
Odometer Logic
Calculates the cumualtive distance travelled through
numerical integration of the current speed


Angle to Turn
Right Counter
Time Reset
true-false
Right Indicator
Right
Left Indicator
Left
Left Counter
Right Counter
Right
Steering Wheel
Left
Left Counter
Steering Logic
Takes 3 inputs, Direction (left/right) and Angle of Turning
turns the steering wheel to the appropriate angles while
reducing speed to an safe value.
Speed Limit
Slow Down
true-false
coerced(x)



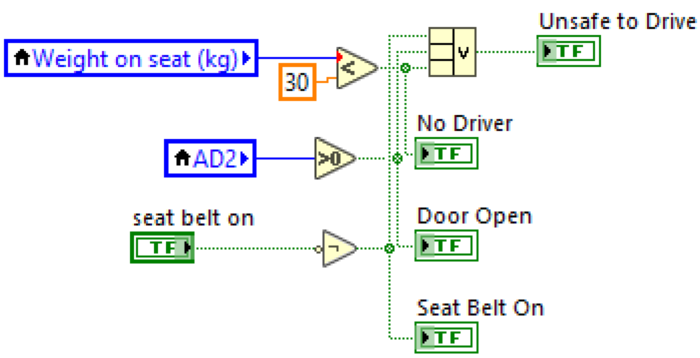
Physical LED output on ELVIS Board. Red LED lit when car is not in a safe state to be driven. Yellow LED Lit when the airbag is inflated.





Sets the last speed the car was set to. Used for controlling speed and acceleration

Controls the state of the car's headlights



Determines if the car is in a safe state to be driven. Conditions: Person is sitting in driver's seat, the driver's door is shut, and driver's seat belt is on.