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Driver Distraction Test Rig for HMI Studies

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***Abstract*— Driver Distraction Test Rig is an automotive fascia analog for Human Machine Interface studies, produced in conjunction with Swinburne University of Technology, GM Holden Innovation, and AutoCRC. The prototype will be used in the development and validation of test protocols for evaluating the level of driver distraction imposed by In-Vehicle Information Systems. By means of modular interfacing technologies, spatial reconfiguration of Radio/HVAC controls is achieved with robustness and flexibility. This will allow considerable testing to determine the consequences control positioning has with regard to the loss of attention concerning the primary task of driving. The design, manufacture, and implications of the project are discussed in this paper.**

***Index Terms*—HMI, IVIS, DDTR, HVAC, Backplane, I²C, FDM, SLA.**

I. Introduction

In-Vehicle Information Systems (IVIS) such as entertainment, navigation, and digital radio systems, are becoming standard due to their demand, appeal, and decreasing cost. Additional features may include: graphical color displays, touch screens, navigational buttons, and email access. A report into the automotive market for color displays predicts sales to triple in the next 5 years, forecasting "A $3 billion opportunity" [1].

However, studies have shown that cognitive processes undertaken when selecting a radio station divide attention between the road and the desired motor task, with its associated feedback elements. Furthermore, behavior research into glance analysis of driver eye movement reinforces that "Longer off-road fixation durations were observed in radio tuning" [2]. This loss in selecting the most important stimulus to attend causes the majority of automobile accidents[1] [3]. Correspondingly, close to 80% and 65% of crashes and near crashes, respectively, involve driver distraction from secondary multi-task demands[2] [4]. Thus, to overcome the potential increase in driver distraction being presented by IVIS, user-friendly designs (and follow-on adaptive real-time systems) are a challenge facing the automotive industry.

Analyzing the limitations of competing Human Machine Interface (HMI) solutions gives an insight into possible future trends. By complimenting vehicle HMI with the latest research and technologies, the potential exists to mitigate IVIS distraction and enhance safety.

For HMI studies, a Driver Distraction Test Rig (DDTR) is used to test protocols for evaluating the level of driver distraction imposed by IVIS. The DDTR described in this paper was designed as an automotive fascia replica with means to spatially reconfigure button and dial controls by way of modular interfacing technologies. This DDTR is a tool for generating flexible and robust test protocols due to its "plug-and-play" feature and ease of disassembly and reassembly[3] [5].

This paper is organised as follows. The next section covers the modular interface design of the electronic and mechanical subsystems. Section 3 concerns the system integration and prototype manufacture. Section 4 is devoted to the performance analysis relating to robustness and flexibility. Section 5 draws the conclusion.

II. Fascia Design for a Modular HMI

The project aim specified the design and construction of a modular radio interface based on the current VE commodore fascia. The purpose of the modular interface is to allow the user to relocate Heating, Ventilation, and Air Conditioning (HVAC) controls, and radio controls, to alternate locations. This allows tests to be conducted on the affects user interface control positioning has on the loss of attention regarding the primary driving task. The prototype must aim for maximum flexibility with regard to button location, whilst remaining robust, reliable, and portable.

To achieve design targets stated above, a PCB based "backplane" with reconfigurable button modules is proposed. Fig. 1 shows the PCB for mounting individual button or dial modules. This backplane is essentially a communications platform having a single master, multiple slave environment. A module event, button press or dial/encoder turn, triggers a response in one of the slave devices that monitors various module groupings. Data is transmitted to the master, processed, and results in a particular ASCII code being output via asynchronous serial communication to a GM test workstation. By implementing automatic module layout identification using serial IDs on each button/encoder module (via 1-wire bus protocol), the system's robustness has been greatly improved. Modularity necessi-

[1] Malaterre 1990, cited in [3]
[2] Klauer et al. 2005, cited in [4]
[3] Baldwin and Clark 1997, cited in [5]

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tates that each module slot be connected to at least 2 pins on the microcontroller, one for button activation and one for ID, requiring over 150 I/O with the encoders. With this realization the decision to incorporate port expanders into the design was made, introducing a third communications architecture, the Inter-Integrated Circuit (I^2C) bus. The system must have dedicated connections to each module slot in order to cross reference a change in state at a certain location with the module occupying a particular slot. Hence modularity further complicates any I/O interfaces.

Having determined the focus of modularization, methods for platform interfacing with this dynamically allocated system must be explored in depth. Firstly, a front modular panel must have a common sequential interface that contributes commonality and compatibility [5]. Electronic laboratory devices frequently achieve interface modularity with a grid like layout, seen most often in circuits testing with customizable units. The critical specification pertaining to the module's design (Fig.2) is its physical size, the fundamental unit dictating layout possibilities.

Secondary to this design choice is both mounting arrangements that facilitate simple reconfiguration, and power and communications strategies. On these two topics the choice is entirely up to the designer with many options viable.

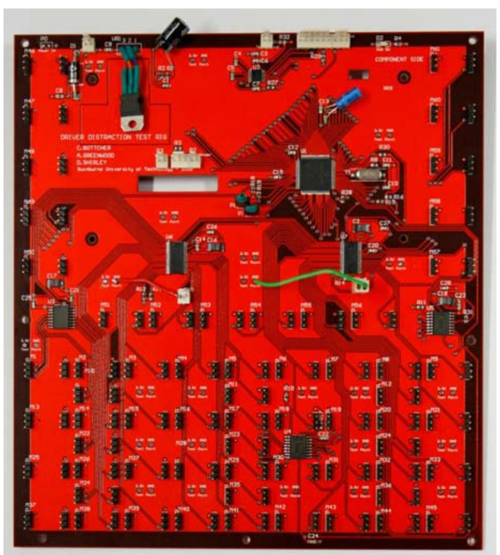

Fig.1 PCB layout with multiple header pin slots for module mounting

PCB stacking is commonly applied in industrial situations where parallel boards communicate with each other. The modular fascia design is no different. Each button or dial module slots into the appropriate grid position and acquires infrastructure for mounting, communication, and power. Because of the limited dashboard space and multiple buttons, the connector of choice should aim to serve as both an electrical connection and mounting device. As the application is automotive development and not general purpose, contact styles need to be selected to allow for substantial connections before failure. The significance of mating force is also crucial to ensure reliability.

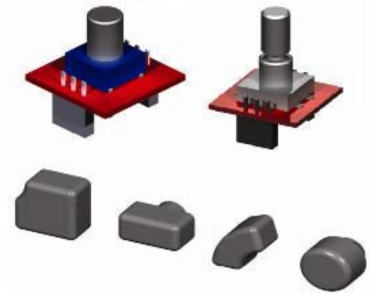

Fig.2 Button and encoder modules with custom made caps

The final design of the system has allowed for 61 possible locations for individual modules, each of which has a unique serial ID. Each pin for a given module slot needs to be wired to the correct component or plane e.g. microcontroller, ground/power planes etc., so that each module slot can facilitate a pushbutton. However, a decision was made to limit the encoder compatible locations to twelve slots strategically placed around the backplane. The number of components on the backplane PCB was also significantly reduced by locating additional circuitry, such as low-pass filters and pull-up resistors, onto the modules themselves. This has eliminated the placement of approximately 200 resistors and capacitors onto the main board. By having these components on the individual modules, unused locations will not draw a current as they are not pulled up to 3.3V. Subsequently, the electrical load of the system has been kept to a minimum and the use of the 1.5A voltage regulator is sufficient for the system.

An additional feature that was requested by GM Holden was the implementation of a navigational style button layout. This was implemented by utilizing the existing backplane PCB layout and designing a larger module which uses 6 module connections to plug into the backplane PCB.

The modular fascia concept of having a single generic module compatible with any location on the fascia is congruent with object orientated programming principles, even though the system uses C, rather than C++ code. The idea is simply that the physical re-allocation of modules is analogous to variable memory reallocation in software. Hence, structure data types (being the C language predecessor to objects) represent modules, which are then stored in an array whose index equates to a particular module location. Should an event occur at a given location the same segment of code is executed no matter which module happens to be loaded in that position. This hard-coded arrangement is necessary to maintain a fixed reference number for each slot, which will be utilized every time a module at that particular slot is activated. This is achieved by XORing the current and previous state values to isolate the event, and determine exactly what has changed and where. The module type is only acquired once, at the beginning of the program, to sort a compile-time array of module structures or ‘objects’. Each module maintains a 16-bit ID, and depending on whether the module is a button or a dial, 2 or 3 ASCII codes respectively. The three codes pertain to a module press, release, and rotation.

III. DDTR Manufacture and Communications

A. Design for Manufacture

Rapid Prototyping processes were selected as being a key feature in the design and implementation of the DDTR. Rapid prototyping was pivotal to produce one-off components at low cost and in a short period of time. By using rapid processes, CAD design files could quickly and easily go from being pictures on a monitor to real life products.

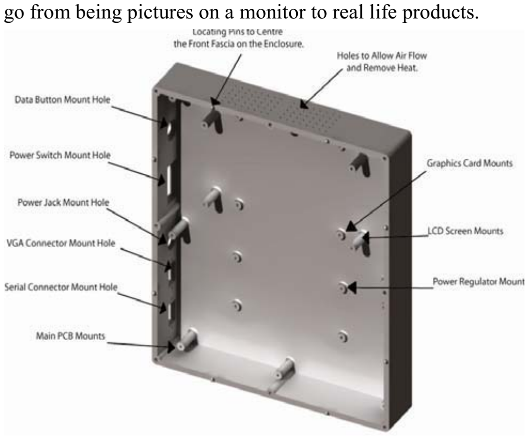

Fig.3 DDTR enclosure manufactured using FDM

This eliminated the need for large tooling and manufacturing costs and the extended time periods involved in traditional processes. Three processes which allowed direct manufacturing from CAD data were used in the implementation phase.

Fused Deposition Modelling (FDM) was the main process used in the manufacture of the DDTR. It was used to produce the enclosure shown in Fig.3. The strength comes from the use of ABS plastic which gives the part the same strength as an injection molded part. The downside to FDM is the surface finish of the part is quite rough requiring additional work.

Stereolithography (SLA), another process utilized, builds parts up in layers. The output has very good surface finish and extremely high accuracy, but the material is quite soft. Even though, SLA produced button caps were invaluable for validating the fit and finish during the design phase. Laser cutting was used to manufacture the front fascia inserts. By using a laser cutter it was possible to make the tolerance between the holes in the inserts and the button caps very small. This in turn helps greatly to reduce the amount of play in the buttons and give the fascia a professional looking finish.

Fig.4 depicts the fascia which covers the front of the enclosure. The modularity of the buttons means they can be shifted around to create a myriad of different layouts. But how do we make a fascia that is as flexible as the button locations? The answer is with custom made inserts for the different layouts which are required. Although this may limit the ease of changing layouts, with the current prevalence of laser cutting and CAD technology, a new insert is a simple task with a quick turnaround. The result is aesthetically professional, ensuring that the fascia itself does not become a source of driver distraction.

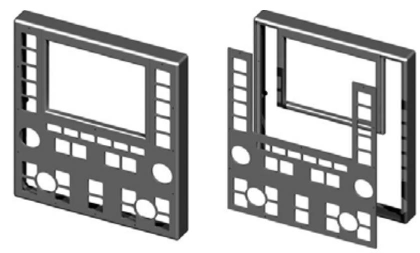

Fig.4 Custom made laser cut fascia inserts

Board-to-board mounting arrangements are also vast, as such the selection should focus on the components offering the best tradeoffs, if the optimal choice does not exist. The backplane PCB (or electrical communication subsystem) has vertical surface-mount pins for module board connection (Fig.1). Header pins have small pitch and are easy to connect, making them ideal for the small 20 x 20 mm button/encoder modules. Upwards of 700 connections are permitted with reliable connection, which is important as these modules will be swapped regularly. Rework can be administered easily without removing hardware by ensuring that the female connector is incorporated with the button/encoder modules, which are likely to fail first through loss of material.

B. Communications Architecture

Fig.5 depicts the backplane buses and their use. The 1-wire bus is used to read the serial ID ICs (DS2401) via a single line that serially pulses 64-bits of information preceding a specific timing arrangement. The pins used on the micro for ID have their appropriate registers timed to control data flow. Essentially the microcontroller (master) pulls the bus low then high causing a reset condition, consequently the ID chip (slave) pulls the line low to notify of its presence. A sequence of ones and zeros are written to the ID chip, which initializes data out. Fig.6 demonstrates a flow chart for reading any pin of a particular PORT using the 1-wire bus.

In order to handle the large number of I/O all pushbutton signals are sent to 40-bit I²C port expanders (PCA9506), whilst all encoder signals are passed through 8-bit I²C port expanders (PCF8574). These ICs register a high-to-low signal transition and cause an interrupt to occur in software.

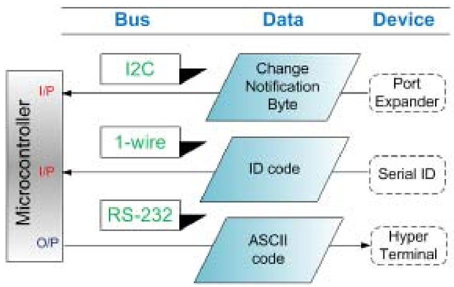

Fig.5 Bus platform breakdown

Each of the five I²C ICs has a dedicated interrupt line to the microcontroller. This interrupt is handled by cross-referencing the location of a button press then outputing the appropriate ASCII value via serial communications.

Whenever a module event occurs the I²C bus communicates a change byte to the microcontroller. Low pass filtering is required on the bus clock and data lines to ensure that high frequency signals, such as noise, do not trigger interrupts. All five port expander ICs are connected on this same bus and can be addressed individually to determine the status of buttons and encoders. For ease of manufacture signals are wired to convenient I²C chip locations rather than in numerical order.

Following a button press the appropriate port expander triggers an interrupt which runs a routine to acquire the current change byte and compare it with a previous state. This process is initialized by first reading each serial input ID pin in an arbitrary order creating a dynamically allocated array of ID's, representing the current module layout of buttons and encoders on the fascia.

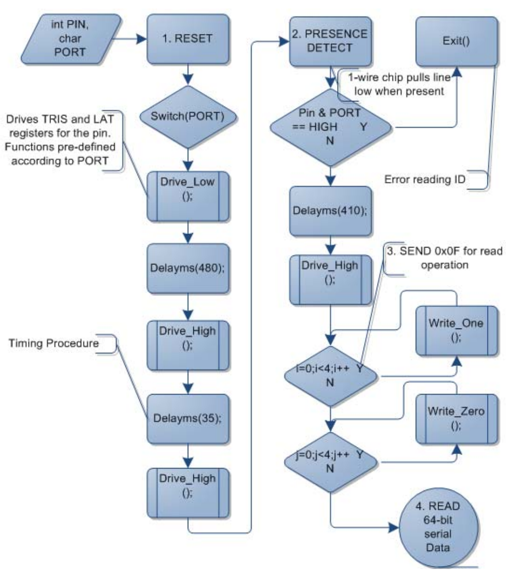

Fig.6 1-wire ID chip software implementation flow chart

With the variable data obtained, namely each modules position and type, a bubble sort rearranges the compile time array of modules to match the runtime array, by serial ID. Fig.7 illustrates the module configuration process. After some additional port expander setup in software, the DDTR is calibrated without the need for user input relating to the physical arrangement of buttons and encoders.

IV. Design Performance Analysis

Automatic module calibration via readily available bus systems found on microcontrollers, coupled with low cost Commercially-Off-The-Shelf technology, has provided the resources for a robust HMI. With module size kept minimal, multiple layout combinations realized, and timely LCD feedback ensuring user response expectancy is maintained, the result is an effective tool that promises increased driver safety in the near future.

Furthermore, longevity of the device is increased by designing a practical and professional prototype with the added benefits of time stamping each button/encoder interaction, which is output to a hyperterminal connection upon test completion.

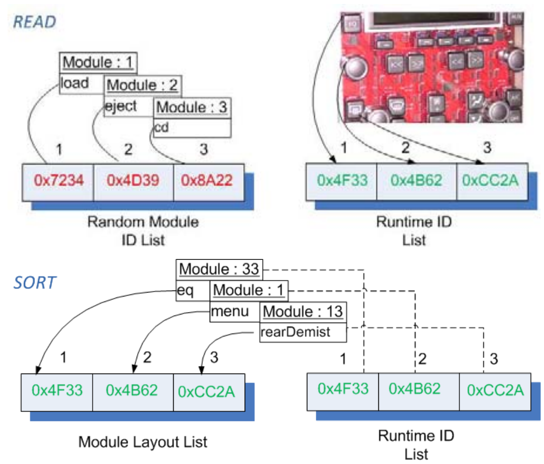

Fig.7 Module configuration process over I²C bus

Perhaps the greatest insight into the success of the DDTR from a design perspective is posited by the navigational module. Its inclusion was after the design of the backplane and even though it is six times the size of a module slot, with simply a change in the CAD drawings for a newly cut insert and minimal change in software, the module was incorporated. The implication is that different module designs can easily be tailored to mount with the backplane, allowing interesting and varied control arrangements to be tested later down the track.

Lastly, the project as a whole highlights the intuitiveness inherent in any design that automates calibration where modular rearrangement techniques are employed.

V. Conclusion

There is no doubt that future IVIS will innovate and redefine HMIs, and in the process alter the users' in-car interactions. Conversely, a task redesign (change in the system) can better support human decision making and reduce driver distraction [3]. Thus by changing the system before changing the person we can better understand HMI performance with current IVIS, regardless of whether or not later models utilize buttons and dials.

In this paper the overall research question being asked here is: can a truly modular radio/HVAC HMI be achieved (for research purposes) by selecting the most appropriate mechanical and electronic hardware to enable robust testing protocols, in this case to determine the affect button layout configuration has on driver distraction? By approaching the project from an abstract level, modular concepts can best be integrated across each subsystem. Concessions to a generic module offer a more practical implementation to the designer, and should not be discounted. Thus there is no definitive approach, merely preconditions and biases such as financial limitations, previous experience, simplicity, and resource availability. The rigorousness of this review is such that iterations to any design choice governing modularity in mechatronic systems are necessary in order to achieve a workable result. However, the additional ideas presented here are invaluable in selecting appropriate devices and methodologies that interface well and have been utilized in similar applications.

Fig.8 DDTR shown with replica fascia insert

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