HEAD-MOUNTED DISPLAY IN DRIVING SIMULATION APPLICATIONS IN CARDS

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Abstract

CARDS is a driving simulator project using a head-mounted display, including motion platform and vibration seat. The project aims at providing a research and development tool addressing different automobile studies from vehicle design to human factors.

Under the management of Renault, CARDS is carried out in collaboration by eight European partners: the French carmaker RENAULT, the Norwegian AUTOSIM simulator provider, the Turkish infoTRON specialised in simulation and virtual prototyping, the British display maker SEOS Displays, the French motion seat supplier (and actuator manufacturer) PONS, a subsidiary of Thomson Marconi Sonar, the French Laboratoire de Physiologie de la Perception et de l'Action from Collège de France / CNRS, the Dutch TNO Physics and Electronics Laboratory and the Dutch motion system supplier Hydraudyne Systems & Engineering.

The CARDS concept and simulator were designed to be a tool for vehicle architecture, ergonomics and human factors studies related to driver's aid systems, among the most important fields. In that context, all subsystems used in the simulator, and especially the visual system have to be as little intrusive as possible, and as configurable as possible in order to reach the full-potential of prototyping.

The Head Mounted Display has the double advantage of being a light-weight display system to embark on a motion platform and a well fitted solution for modularity. The architecture and design choices that have allowed to build in CARDS a prototype HMD with low weight, high resolution and wide field-of-view will be described. In the targeted applications, this display is allowing to provide the driver with simultaneous vision of the road and entire cockpit with instruments as well as speed cues thanks to the lateral vision.

Résumé

CARDS est un projet de simulateur de conduite automobile s'appuyant sur une restitution visuelle par casque, incluant un mouvement de siège et une plate-forme mobile. L'objectif du projet est de concevoir un outil R&D couvrant les besoins liés à la conception des véhicules jusqu'à l'étude des facteurs humains.

Sous l'égide de Renault, chef de file du projet, CARDS est mené en collaboration par sept partenaires européens : le constructeur automobile français RENAULT, le fabriquant norvégien de simulateur AUTOSIM, la société turque spécialiste en maquettage virtuel et simulation infoTRON, le constructeur anglais de systèmes de visualisation SEOS, le fournisseur français de sièges vibrants (et le fabricant d'actuateurs) PONS, filiale de Thomson Marconi Sonar, et le laboratoire de recherche français LPPA (Laboratoire de Physiologie de la Perception et de l'Action), le Laboratoire de Physique et d'Electronique hollandais TNO et le fournisseur hollandais de plates-formes mobiles Hydraudyne Systems & Engineering.

Le simulateur et le concept CARDS ont été conçus comme un outil pour l'étude de l'architecture véhicule, l'ergonomie et l'influence des facteurs humains dans la conception des systèmes d'aide à la conduite, parmi les sujets les plus importants. Dans ce contexte, les systèmes utilisés dans le simulateur, et en particulier le système visuel, doivent être aussi peu intrusifs et aussi configurables que possible, afin de bénéficier de tout le potentiel du prototypage.

Les HMD ont le double avantage d'être un système de visualisation léger à embarquer dans un simulateur dynamique et une solution adaptée au concept de modularité. Les choix d'architecture et de conception qui ont permis de construire dans le cadre de CARDS un HMD prototype de faible masse, haute résolution et large de champ de vision seront décrits. Dans les applications cibles, ce système de visualisation permet de montrer au conducteur simultanément la route et le tableau de bord équipé de ses instruments, ainsi que de lui fournir des informations de vitesse grâce au champ de vision latéral.

Introduction

CARDS Overview

CARDS is a driving simulator project using a head-mounted display, including motion platform and vibration seat. The project aims at providing a research and development tool addressing different automobile studies from vehicle design to human factors.
Under the management of Renault, CARDS is carried out in collaboration by eight European partners: the French carmaker RENAULT, the Norwegian AUTOSIM simulator provider, the Turkish infoTRON specialised in simulation and virtual prototyping, the British display maker SEOS Displays, the French motion seat supplier (and actuator manufacturer) PONS, a subsidiary of Thomson Marconi Sonar, the French Laboratoire de Physiologie de la Perception et de l'Action from Collège de France / CNRS, the Dutch TNO Physics and Electronics Laboratory and the Dutch motion system supplier Hydraudyne Systems & Engineering.
CARDS has been designed to answer the needs of vehicle engineering and more specifically in the framework of new virtual prototyping methods. In that context, the use of a new, low weight, high performance Head Mounted Display (HMD) was decided.

The advantages of the HMD as a method of entering a virtual reality have been acknowledged for some time. The limitations of the devices previously available and the computer technology to drive them have, by and large, prevented their adoption in simulation. These limitations are: too small field of view that does not provide peripheral vision, excessive mass and poor balance leading to discomfort, low image update rate, poor head mounting rendering the image unstable and small exit pupil leading to loss of image as the eyes swivel to regard the scene.
An HMD that may be worn for long periods in comfort, whilst providing the field of view, image quality and dynamic characteristics necessary for driving simulation did not exist. In order to address these issues critical to a successful device, multiple innovations had to be arrived at in the course of the project.

CARDS driving simulator

Vehicle design process requirements

Virtual prototyping is an answer to the decreasing physical prototype numbers as well as to the reduction of testing periods driven by shorter vehicle development cycles. The design and production process of vehicles is including an increasing number of computer assisted assembly testing, and complete subsystems are validated before any mechanical part is being built.

Simulator are allowing for interactive testing of subsystems in areas going from MMI Ergonomics to driving aid systems and to vehicle handling, so that test drivers and experts can express their recommendations much earlier in the design process. Renault has been performing such virtual tests on headlights since 1999 [AD2000]: project managers, test drivers, engineers and providers are gathered around a common set of virtual objects and are comparing side by side current design proposals to measured reference headlights and project requirements. The result of such practices is a real reduction on development time and prototyping costs.

Most areas of vehicle development can benefit from similar approaches. Driving station man-machine interfaces, or even passenger-oriented interfaces, can be objectively evaluated through a tool such as CARDS.

Application

In the field of MMI design, for example, the early stages of design, when no functioning prototype is available, the engineering department is using a dimensionally correct mock-up to evaluate parameters such as, but not limited to, readability, accessibility of information and perceived quality. However, dynamic man-machine interface and realistic mental workload testing can only be performed on a simulator, or when the first prototypes are available.

To answer those issue, at an acceptable cost compared to using physical prototypes, CARDS provides the following features:

- The driving station is easily configured;
- The test conditions are easy to set up and highly repeatable;
- The mental workload is realistic, with a high fidelity reproduction of driving tasks;
- The stimulation of the driver is dynamic, through the driving tasks and the rendering of the different visuo-haptic, kinaesthetic and sound perceptual cues corresponding to the vehicle dynamics.

Those features are similarly used in the other application fields of the simulator.

Use of an HMD

Using an HMD in a driving simulator is not a new concept, whether in static [PB1999], or dynamic configuration [VS1997]. However, the implementations were limited in industrial usability by the cost of satisfactory IG hardware and the cost and weight of a good quality HMD, as well as by the unavailability of easily implemented and low transport delay motion tracking hardware.

Driving station visualization

Digital mock-up software is allowing building realistic visualisation of vehicle interior and exterior based on CAD digitisation files, directly provided by engineering design departments. The results can be rendered interactively through generic software like Dassault's DMU© or Renault's P2V© which has been developed in co-operation with the users in vehicle engineering. Configurable animation scenarios allowing to demonstrate a larger range of options for colour and materials harmonies, or packaging and architecture solutions are increasingly used. CARDS allows engineers to test the options they propose in realistic driving conditions by linking the resulting driving station elements, resulting from CAD data through processing by P2V©, to an interactive and real-time driving simulator, equipped with Renault's SCANeR© II. Therefore, decisions are made based not only on static observations, but also on dynamic use of the resulting cockpit and information systems.

Adaptations to SCANeR© II architecture to fit virtual driving

In the framework of CARDS, several modules in SCANeR© II have been developed further in order to take advantage of the possibility for multiple configuration testing.

Network layer

SCANeR© II is based on a proprietary network layer. This layer has been improved with the addition of a new set of messages aiming at making available to all the modules the position of the observer's head and hands. This has been unified with the messages previously used for tilt co-ordination when using a dynamic simulator and fixed screens [GR2000]: the feed-back from a motion platform's position is actually similar to the one of a position device; the driver is supposed to remain in a given position for lack of devices measuring his actual position, whereas he/she is actually moving with reference to the cockpit. Therefore, SCANeR© II uses the same protocol to transfer data from a motion tracker or a motion platform, and can combine both.

Visual module

The visual module is adapted to HMD viewing. It is constructed on an abstract layer that calls Performer™ or OpenGVS™, today, and can be configured to run on various operating systems and can account for aspect ratios, resolutions and varying overlapping ratios between the eyes. Each eye is run on an independent machine, the synchronisation being ensured by the position data fed by the network in multicast mode. At 60 Hz update rate for the visual subsystem, the first trials have shown that on low dynamic driving scenarios no additional synchronisation process needs to be implemented to ensure coherence between the eyes. This result will be complemented by perception studies in the next stage to assess the absence of adverse effects.

figure 1 : SCANeR© II visual module with animated dashboard

Animation of driver station

In order to enhance the feeling of driving when using an HMD, and to allow testing of dashboard elements and layouts, a general animation procedure has been implemented. It is built onto the software architecture pre-existing to CARDS that manages animation of roadside elements, such as traffic lights and barriers, or vehicle elements such as vehicle lights and wheels. Driver's input is linked to the animations of the cockpit through network channels configured at initialisation-time depending on input and visual objects available for animation. Those channels are collected by SCANeR© II's visual sub-system and combined following an interpreted language. The result of the processing is used to animate elements pertaining to the scene-graph.
A hierarchy of "most-usually-found" elements has been built to allow for automatic generation of the scene-graph by P2V©. However, additional objects are easily managed, through addition to configuration files, without need for additional coding (see figure 2 : Data flow and configuration of new input).

The mechanism of animation of dashboard elements also relies on the possibility to easily add physical interfaces that the driver will be able to activate. In CARDS, this is made possible through the use of a CAN bus. This terrain bus is found in an increasing number of vehicles to minimise cabling complexity and increase data sharing. In the case of CARDS, it also allows easy adding of elements through small size, remote acquisition modules, linked to the bus, and located closest to the input generation point.

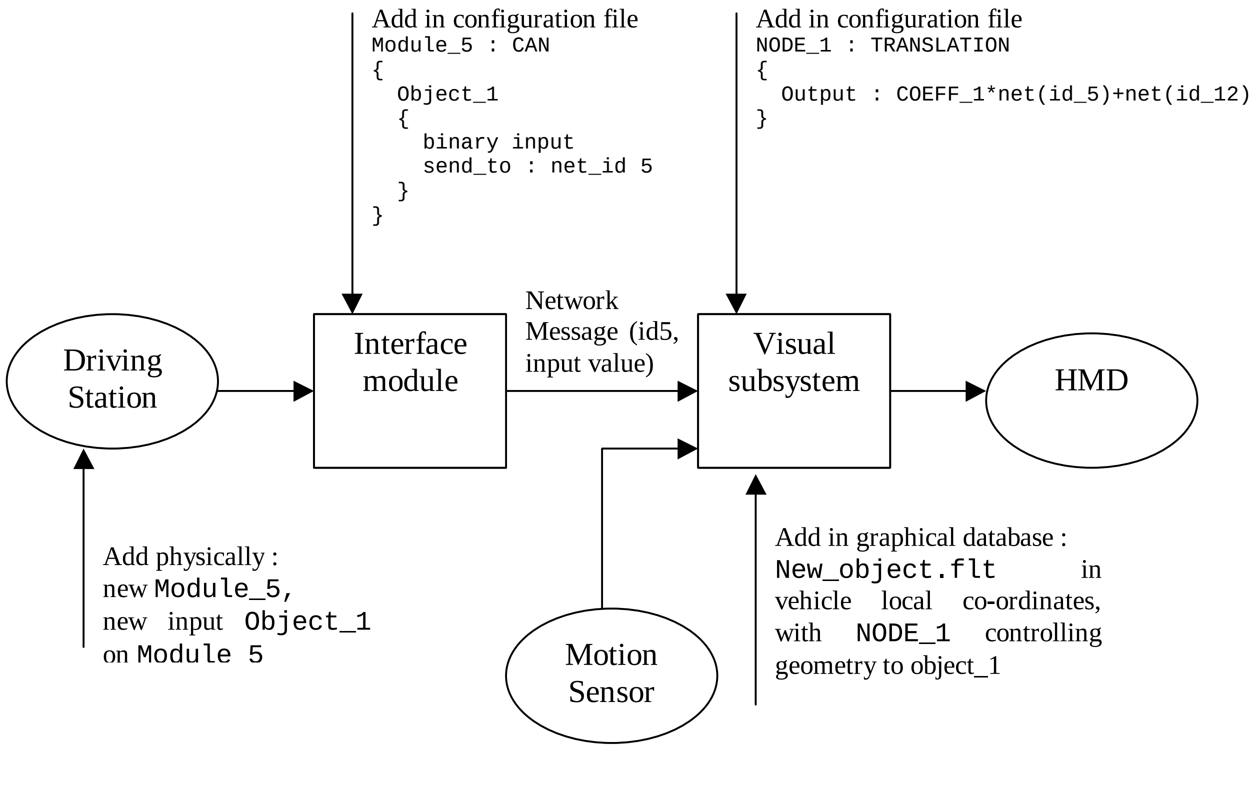

Figure 2 : Data flow and Configuration of new input

Use of a motion platform

Increased realism of the driving simulation relies also on stimulation of kinaesthetic sensors as was discussed previously [GR2000, IS2001]. The use of a motion platform is therefore an important requirement of the simulation tool. Renault has experience with motion rendering, notably since the installation of RVI's fixed screens dynamic truck simulator in 1997, and Renault Technocentre's fixed screens dynamic driving simulator, installed in 1999. Fixed screens are an efficient solution for designing a dynamic simulator while limiting the payload onboard the motion platform. However, they limit the range of motion of the motion platform and the dynamic field of view for the driver: the intrusion of fixed boundaries in a moving environment is proving disturbing [BK1999], sometimes breaking the immersion of the driver. Therefore, a good HMD is a satisfactory solution provided that it is not intrusive and has large field of view.

Summary of requirements for the HMD to be used in driving task

Field of view is both important in horizontal and vertical directions. The horizontal extent of the field of view is allowing for the perception of speed, which is needed for realistic driving. When the dashboard is displayed in the HMD, vertical field of view is necessary in order to be able to have a perception of the dashboard while concentrating on the driving tasks, and accordingly, to be able to still perceive the visual information while looking at dashboard or during manipulation of commands.

Innovative design features of the SEOS HMD 120/40

Eyepiece

The SEOS HMD 120/40 uses an eyepiece based on the pancake window. This is a device where a spherical mirror does most of the optical work. In its usual implementation the mirror does all of the work and is placed with the mirror concentric about the eye. The image source is also usually a spherical surface. It therefore has no chromatic aberration. However, it was decided that the SEOS eyepiece should be closer to the eye than the concentric case in order to achieve the large field of view and eye-pupil in a compact device. This causes some spherical aberration, which is corrected by refractive elements. These elements also permit the input image to be flat.

The field of view achieved is 80° x 67° per eye. The eyepieces are toed out by 20° to give a total FOV of 120° x 67° with 40° of stereo overlap.

Image source

A key enabling technology is the availability of microdisplay image panels made by MicroVue in Scotland. The recent availability of a single panel colour device with SXGA (1280 x 1024) resolution has been vital to the success of the project. The image is relayed from this panel to the eyepiece by an optical system comprising no fewer that four aspheric surfaces formed on polymer lenses. Another benefit of this system is that it permits the image panels to be folded back around the sides of the head to provide the correct centre of gravity.
Colour is rendered by a field sequential colour system. Drive system options are available for the panel and the LED illumination system, which suppress the colour break-up usually

associated with this system. Alternative display device technologies were considered, such as single-panel colour LCDs. However, two problems precluding this approach were that there was no near-term prospect of approaching SXGA resolution and that the high magnification of the eyepiece would render the colour triads visible. Three panel systems were also considered but again availability of a system with SXGA resolution and the weight of the combining optics were seen as disadvantages.

The image is projected onto a screen at the back of the eyepiece. The screen component was an unexpected challenge. It serves to spread the light from the relay system to provide the wide eye-pupil of the eyepiece. This permits the use of a much narrower-angle illumination (high F#) and therefore lighter relay system. It also means there is no hard-edged pupil boundary to the eyepiece. If the eye moves out of the eye-pupil, rather than encountering sudden darkness there is instead a gradual loss of brightness and resolution. All the conventional screen materials that were tried had a visible structure when viewed through the eyepiece. SEOS therefore had to develop its own screen material to fulfil this requirement. This component is sealed into the eyepiece shell to prevent dust contamination that would produce visible artefacts.

Mass Reduction

Minimising mass and inertia has been a key consideration in every aspect of the design. A number of radical solutions have been employed to meet the weight target of under a kilogram.

Minimum Eye Relief

It is conventionally believed that the minimum eye-relief permissible in a head-mounted display is 25mm in order to accommodate the wearing of spectacles. SEOS has abandoned this constraint by reducing the eye-relief to just 10mm. Long and near near-sight can be accommodated by adjusting the focus of the eyepiece through four diopters in either direction. Many spectacle wearers also have contact lenses, which can of course be used. There is a cube-law relationship between eye-relief and eyepiece volume (and hence mass). The advantage of this approach can be seen to lead to a weight reduction in these components by a factor of fifteen.

Polymer Optics

Where possible, diamond-turned polymer lenses have been used. Recent advances in this technique have allowed the production of components that are equal to glass in accuracy and finish. Advantage has also been taken of the possibility of using aspheric surfaces, thereby reducing the number of elements required to a minimum.

Light-Weight Electronics

MicroVue has identified 'near-to-eye' as a key target sector for their panels. For this reason they have carried out a great deal of development aimed at reducing the weight of electronics and, equally important, the weight of the cable required to transfer the signal to the head.

Polymer Foam Structure.

As with many optical systems the casing serves to hold all the components in precision alignment with each other. Polymer foam has been chosen for this purpose, shaped by CNC machining. The density of this material is one thirtieth that of solid polymer. Its use for lightweight yet rigid structures is well known to builders of model aircraft and human powered aircraft. This method of construction also provides an easy path to customised products. The material has excellent energy absorption giving the internal components protection against shocks. One potential drawback is that the foam can sustain cosmetic damage quite easily. But however, most of our early customers have indicated that this is an acceptable trade off in view of the weight saving.

Conformal Head Mounting

A method was sought of creating a lightweight headband that could form a rigid element around the head. By this means the transfer of angular motion to the HMD against its inertia would be driven by the shape of the head, instead of relying on friction on the skin. The friction method is unsatisfactory because it requires a tight fit to create the friction, and the skin is not located immovably on the skull. Again using polymer foams for lightweight, a system was devised where an inner and outer band were separated by a foam block structure. The foam blocks were fixed to the inner band in such a way that when it bends around the head, gaps open up between the foam blocks. The surfaces of the blocks and the inner face of the outer band are coated in a material that has the property of naturally adhesion when coming into contact. Thus, when the outer band is secured a double-walled beam is formed which has a considerable stiffness.

The head-mount clips onto the HMD and permits adjustment fore and aft to ensure the optimum eye-relief. Individual users can be supplied with their own head-mounts where this is required for reasons of hygiene or convenience.

Conclusion

CARDS aims at vehicle engineering applications where virtual prototyping is a key issue. Efficient use of virtual prototyping is achieve-able when using a Head Mounted Display to display a virtual cockpit in realistic and interactive driving situations. However, the HMD should not bias the behaviour of the driver.

The CARDS simulator utilises the immersive field of view Head Mounted Display based visual system to achieve an unlimited field of regard and a dramatic weight saving compared with conventional simulation displays. This in turn permits a much lighter, low cost motion system to be used. In addition the use of PC based image generation means that a very high level of simulation fidelity is achieved in relation to the cost.

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