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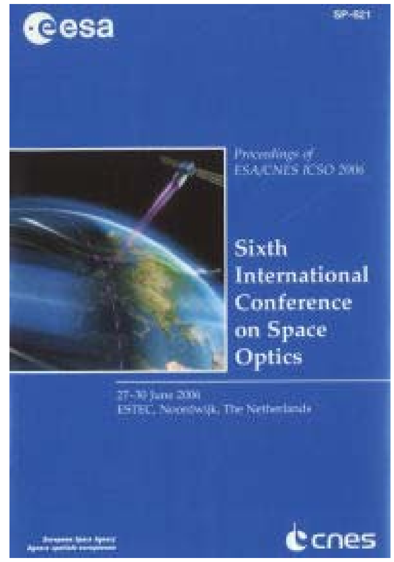

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STUDY OF A DIRECT VISUALIZATION DISPLAY TOOL FOR SPACE APPLICATIONS

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ABSTRACT

The study of a Direct Visualization Display Tool (DVDT) for space applications is reported. The review of novel technologies for a compact display tool is described. Several applications for this tool have been identified with the support of ESA astronauts and are presented. A baseline design is proposed. It consists mainly of OLEDs as image source; a specially designed optical prism as relay optics; a Personal Digital Assistant (PDA), with data acquisition card, as control unit; and voice control and simplified keyboard as interfaces. Optical analysis and the final estimated performance are reported. The system is able to display information (text, pictures or/and video) with SVGA resolution directly to the astronaut using a Field of View (FOV) of 20x14.5 degrees. The image delivery system is a monocular Head Mounted Display (HMD) that weights less than 100g. The HMD optical system has an eye pupil of 7mm and an eye relief distance of 30mm.

1. INTRODUCTION

1.1 Background and objectives

With the assembly of the International Space Station (ISS), astronauts shall perform more space walks in upcoming years than they have been conducted since spaceflight began. More than 160 space walks totalling 960 clock hours, or 1900 man-hours, will be performed to assemble and maintain the station. In addition to these planned EVAs (Extra Vehicular Activity) the ESA Exploration Programme intends to have several manned missions to the Moon and to Mars in the coming decades. To accomplish the increasing number of requirements and objectives for these EVAs new technologies need to be pursued to support and optimize the tasks of the astronauts. In particular a new information management and display system needs to be developed.

In the frame of the ESA GSP (General Study Programme) Lusospace LdA has performed a study aiming at proposing a baseline design for a future direct visualisation display tool to be used during EVAs. This activity included the review of novel technologies for different sub-systems, the identification of potential applications and the design of a preliminary configuration for a future direct visualization display tool for space applications.

1.2 Visualization of information during an EVA

In the current NASA space suit, also known as Extravehicular Mobility Unit (EMU), the astronaut has to rely exclusively on the information that he carries in his EVA cuff checklist [1]. The EVA cuff checklist, shown in Fig. 1, is a booklet of 25 procedural pages bound by a coil spring to an aluminium alloy bracket and attached to an armband.

Fig.1. EMU cuff- Checklist.

The checklist contains text and simple graphics of procedures used for EVA tasks and in case of EMU malfunctions. It is cumbersome to use, time-consuming to assemble, information and data formats are limited, and it is difficult to maintain proper management control. Additionally, mounted in front of the upper torso of the EMU, there is a DCM (Display and Control Module) that contains a small number of visual displays and electric and mechanical controls required only for the operation of the EMU.

The development of a tool to efficiently display information to the astronaut during an EVA has been a topic of concern for both ESA and NASA in the last decades [2],[3],[4]. However, the technology available at the time would lead to the development of a very complex system with large dimensions, high mass and power consumption. All these drawbacks dramatically reduced the advantages of such tool against the current existing cuff checklist. Nowadays novel technologies

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can be used in the design of a very compact, reliable and efficient information management and display tool. The system can be designed as a HMD (Head Mounted Display), if the display area follows the user head movement, or as a HUD (Head Up Display), if the display area is fixed in front of the user head. In both cases the goal is to have the information being displayed as close as possible of the astronaut FOV. Therefore the astronaut does not have to divert his attention from the tasks he is performing. In addition the display can be either “non see-through” or “see-through” depending if the display area blocks or not the background. Fig.2 illustrates the information data and format that could be displayed to the astronaut using a HMD/HUD during an EVA.

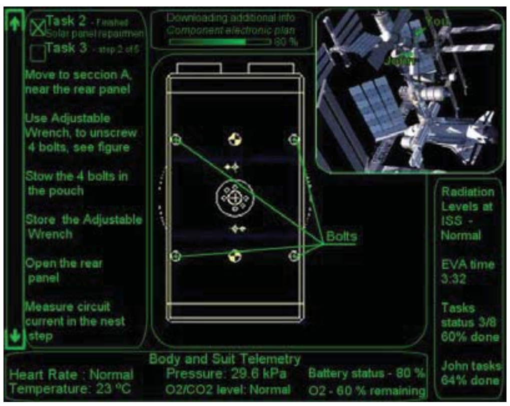


Fig.2. Illustration of the information that can be delivered to Astronaut during an EVA.

2. REVIEW OF TECHNOLOGY

2.1 Commercial HMD

At present, a wide offer of HMD products is commercially available. Some examples are the “Nomad HMD” from Microvision and the “EG-8 HMD” from MicroOptical, which are lightweight and compact in size. These two models are presented in Fig. 3.

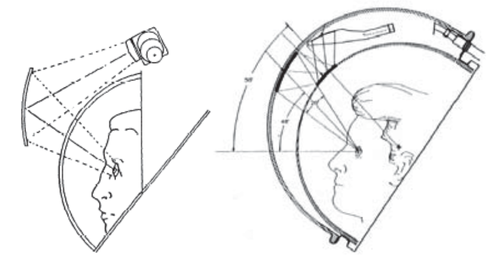
(a) (b)

Fig.3. Example of commercial HMD. (a) Nomad from Microvision. (b) EG-8 from MicroOptical.

The specifications of the available commercial HMD were reviewed. These systems are not sufficiently robust and have limited performance for space applications. Their poor image quality and low image source luminance prevents the use of the HMD against a bright background scenario. The exception is the Nomad system. However it occludes an important part of the user visual field and is monochromatic.

2.1 NASA research activities

NASA has conducted several researches for the implementation of HMDs in its EMU. This effort resulted in the production of four HMD prototypes [2], [5]. The Wright-Patterson AFB HMD (1987), the Hamilton Standard HMD (1988), the APA Optics HMD (1991) and the Technology Innovative Group HMD (1991). Fig. 4 illustrates two of these HMDs.



(a) (b)

Fig.4. Two NASA HMD prototypes. (a) Wright-Patterson AFB HMD layout [2](b). Technology Innovative Group HMD layout [5].

All the NASA HMDs are mounted on the bubble helmet. This prevents the use of the ExtraVehicular Visor Assembly. Moreover these systems have high power consumptions 5 to 20 W and use high voltages to control the image source (mini CRT). The Hamilton Standard HMD model is the only one that uses a LCD backlighted by a halogen lamp as image source.

2.3 Structure of DVDT

A DVDT for space use should have the following sub-systems:

- Display: non see-through or see-through (combiner)
- Relay/imaging optics
- Image source
- Central processing unit
- Interface with the space suit communication system (CCA)
- Data communication system
- DVDT/astronaut interfaces
- Power supply

The Central processing unit is the computer that manages the DVDT. It manages the information displayed to the astronaut and the DVDT interfaces. The image source is a microdisplay that receives the video signal from the central processing unit. The microdisplay image is transmitted through the relay/image optics and then is reflected to the eye by a combiner for see-through HMD, or transmitted (directly or reflected by a mirror or prism) to the eye in the case of a non see-through HMD.

2.4 Image sources

One of the first image sources to be used was the micro CRT (1-inch diameter Catodic Ray Tube). The main advantages of the CRT were low cost, easy availability, bright images and good image quality. However, CRTs, even miniature ones, have inherent drawbacks which include weight, size (primarily depth), power requirements, high anode voltage, and heat generation. Due to these drawbacks the current preferred display technologies are based on Flat Panel Displays (FPD). FPD can be less than one inch in diagonal, creating a high-resolution image, typically smaller than a postage stamp. Typically FPDs have low power consumption (<1W) and voltage requirements, low heat output, and low weight. Therefore they are good candidates to be used as image source on space HMD/HUD.
A novel display technology that has recently emerged is the OLED (Organic Light-Emitting Diode) [5]. OLEDs are electroluminescent microdisplays. OLED light emitting materials can be small organic molecules or long polymeric molecules. OLEDs are brighter, consume less energy and are easier to manufacture than other displays based on liquid crystals. Being an emissive technology OLEDs do not require backlight. Also they have low power consumptions (ex: <200 mW "eMagin" OLED), operate at low voltage (3-10V) and have Lambertian emission.

3. REVIEW OF REQUIREMENTS AND APPLICATIONS

The DVDT is intended to be used by astronauts in three different scenarios:

- Moon exploration;
- Mars exploration;
- EVA activities in orbit, for instance at the ISS or during Intra Vehicular Activities (IVA) as well;

The contents and layout of the information displayed by the DVDT depend on each particular mission scenario. This data shall consist of alphanumeric characters (including text), drawings, video and schematics, related with the different aspects of the astronaut's activity. Some examples of data are:

- Bio-medical data, space suit telemetry data and warnings, such as: astronaut's BTU; heart rate; remaining electrical power; remaining O_2 levels; and remaining time left for tasks.
- Replacement of the current cuff checklist and digital display of the NASA EMU.
- Procedures for suit management and other tasks (astronaut's tasks status and status of the team).
- Navigation information (display of the current and other astronaut's position, initial landing point and guidance to the next waypoint).
- Data concerning the support on spacecraft piloting and manipulation of robotic systems.
- Real-time instructions from the crew inside the space-shuttle or space-station, as well as from the mission control centre, regarding procedures, tasks, remote assistance information and general conduct of the activity.
- Results of on-site sample analysis, during planetary surface exploration.
- Warnings relative to health conditions and external environmental hazards (space radiation, dust storm activity, wind speed and other).
- Images transmitted from another astronaut's camera (this can be useful when two astronauts need to coordinate tasks during an EVA activity).

The requirements for the DVDT depend as well on proposed applications and scenarios. The tool can be design to be used either inside or outside the EMU. Outside the EMU it must withstand the outside environment conditions, namely dust abrasion in the Moon or Mars or high temperature differences. Inside the EMU the electronics must be safe to operate in nearly 100% Oxygen. Ergonomic constrains need to be considered as well. The tool needs to be capable of displaying information with sufficient detail and brightness to be easily seen and understood by the astronaut. This determines the FOV, resolution and luminance.
The input and control interface shall be designed to be handled by astronauts using pressurized gloves, which limits the possibility of using a traditional keyboard.
As this tool is to be used by humans, the radiation requirements shouldn't be as demanding as for unmanned spacecraft. Nevertheless the tool needs to be qualified at least for human equivalent levels.

The major specifications were defined as follows:
Optical requirements:
-FOV: approx. 25º diagonal
-Luminance: 600 Cd.m^{-2}
-Resolution: 800 x 600 pixels
-Colour: Yes
-Eye relief: 2-3 cm
Mechanical requirements:
-Fit inside space helmet;
-The eye wear device should be less than 100g.
-Total mass less than 1kg (limited by battery)
-Input interfaces with the astronaut:
-Voice recognition and control;
-Three or four button control;
-Image superimposed on astronaut field of view (see-through), but on a marginal angle;

-Interface with the spacecraft computer should be wireless (802.11b).

General and Ergonomic:

-Power dissipation should be limited to a few Watt
-All parts should be thin enough to be sewed to the space suit and not making it uncomfortable.
-Radiation hard device (no failure < 900 rad);
-Operational endurance (maintenance free): Moon scenario > 800 hours, 8000h for Mars.

In order to produce a proper DVDT design, to be used by astronauts, the identification and addressing of astronaut's needs and concerns was fundamental. A questionnaire has been prepared and delivered to ESA astronauts. The DVDT concept and its applications were also presented to ESA astronauts and their assessment and suggestions were implemented. In particular suggestions were made regarding the type of the information to be displayed. Technical and functional aspects of the DVDT design, its interfaces with the astronaut and with the space suit environment were also discussed. The conclusions are also considered in the definition of the system specifications and applications.

4. BASELINE DESIGN FOR DVDT

4.1 Optical design and image source

The optical system was designed for a diagonal FOV of 25º (HFOV 20,6º and VFOV 14,5º), an exit pupil of 7mm and eye relief of 30mm to permit the use of eyeglasses. The optical system main part is the 10mm thick polycarbonate (ZEONEX) prism. The optical prism has two off axis aspheric surfaces without rotational symmetry. These surfaces, Free Form Surfaces (FFS), can correct the first order aberrations and also the off-axis aberration [6]. Light emitted by the OLED display is collected by an achromatic lens and enters the prism at one of the FFS. Inside the prism, the light undergoes two total internal reflections, reaches the other FFS that is half-mirrored, and reflects in the direction of the user's eye. Anti-reflection coatings are considered on the prim surfaces, except on the half mirrored FFS**.** The image is focused at infinity. Fig. 5 shows a schematic layout of the polycarbonate prism.

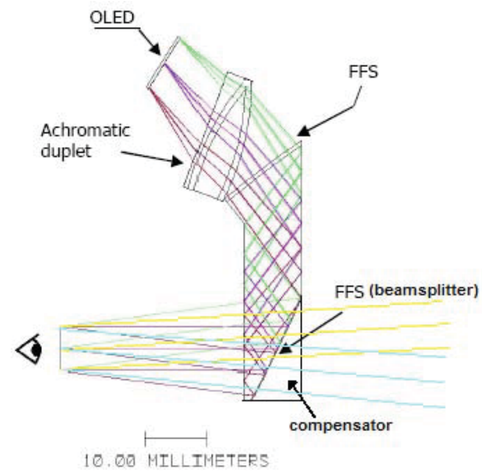


Fig.5. Schematic layout of the optical system

In order to enable the vision of the outside background, a compensator prism is added to the back of the half mirror FFS (beamsplitter). Light coming from the outside background will cross the medium with minimal disturbances. The complete optical system was designed and optimized using ZEMAX software.
The selected image source is the colour SVGA OLED from eMagin. Some of its specifications are: assembly envelope of 20x16x4mm; 852(x3)x600 pixels; a power consumption of 200 to 400mW; maximum luminance of 400 $Cd.m^{-2}$; and a weight of 1,8g.
Fig. 6 shows a photograph of the OLED displaying the image presented on Fig.2.

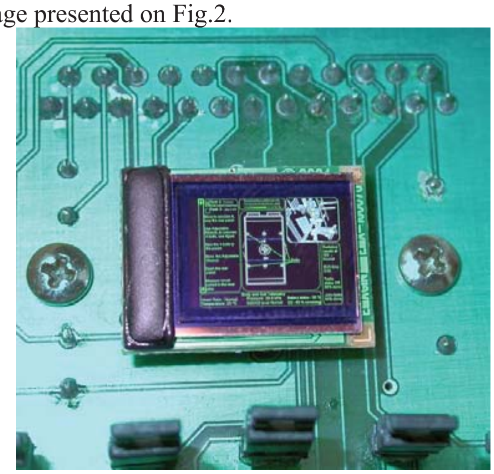


Fig.6. Photography of the SVGA+ OLED microdisplay.

4.2 Processing and control unit

The use of a PDA as control unit of an EVA HMD has been considered [7]. The selected processing unit is the DELL Axim X50v PDA. This selection was based on the following reasons: fast processor, manually selectable clock rate, adequate pixel resolution, connection to an external display and include accessories such as sound card and wireless card.

The VGA cable accessory will be used to connect the OLED display. In addition this PDA can accept a compact flash acquisition card. This card has the capability to acquire inputs from external sensors. This can be used to display for example the Bio-sensors data (such as: astronaut heart rate). The PDA microphone audio input will be connected to the EMU voice communications system. The voice signal will then be processed by voice recognition software (such as ScanSoft VoCom3200) in the PDA. This will enable the astronaut to control the DVDT. In addition a simplified keyboard control shall be also considered. The connections for the PDA 5-way navigation button will be re-routed to four buttons on the EMU left wrist, implementing functions such as: scroll up, scroll down, enter/select, and escape/cancel. A power off switch will exist as well.

Two high capacity lithium-ion batteries (3,7V; 2200mA.h) will be used to get not less than 8 hours autonomy.

Fig. 7 shows the DVDT block diagram.

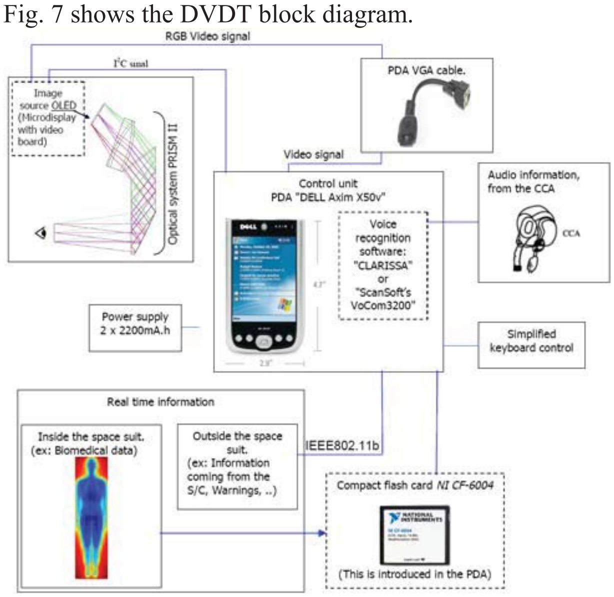


Fig.7. DVDT block diagram

5. ESTIMATED PERFORMANCE

5.1 Optical performance

For the proposed optical system the off-axis aberrations, astigmatism and coma were corrected. The image spot size is less than 66µm. In case of daylight operation were the astronaut eye pupil diameter is approximately 3mm the spot size is less than 55µm. In the 0° field of view the transverse ray aberration is very small, less than 30µm; the maximum value obtained in the marginal field of view is 215µm. Vignetting (<1%) and distortion (<4%) are negligible.

Fig. 8 shows the bitmap simulation of an image transmitted through the optical system. This image completely fills the DVDT FOV and it was simulated using 10^8 rays.

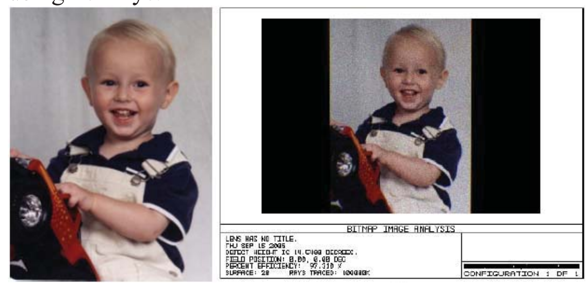


Fig.8. Simulation of an image: left- at the OLED; right- as seen through the optical system.

Fig. 9 shows the Modulation Transfer Function (MTF) of the optical system.

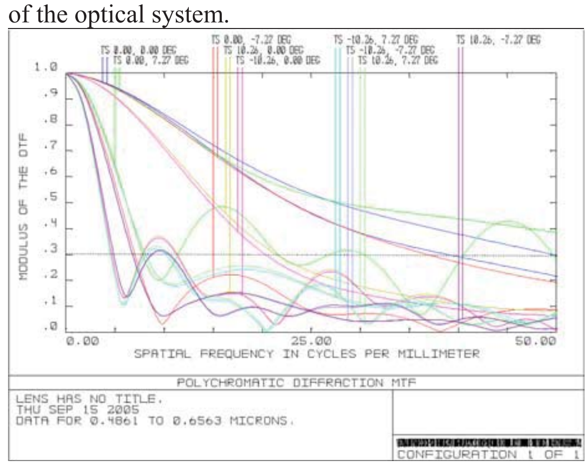


Fig.9. Modulation Transfer Function

The maximum spatial frequency where the MTF is greater than 0.3, is 40cycles/mm (equivalent to 80pixels/mm). An MTF greater than 0.3 is a typical value for the discrimination of images with high spatial frequencies (such as 50cycles/mm). The SVGA eMagin OLED has a resolution of 67pixels/mm. Therefore the resolution achieved by the optical system (80pixels/mm) is superior to the SVGA+ OLED resolution (67pixels/mm). Preliminary thermo-mechanical analysis shows that the prism suffers negligible deformations when exposed to thermal gradients of 20°. Table 1 summarizes the major DVDT specifications.

Table 1. DVDT specifications

System data	
Optics and mechanical support mass:	< 100g
Total mass :	< 900g (500g for batteries)
Power consumption:	< 2W
FOV:	approx. 25 º diagonal
Autonomy:	> 8 hours

6. FUTURE APPLICATIONS

The purpose of the DVDT is to assist astronauts in the execution of mission's tasks, either in IVA or EVA activities, by displaying all useful and relevant data. The level of importance of the DVDT usage, concerning its contribution to the accomplishment of mission's objectives and to the maintenance of safety conditions, will depend on each particular mission scenario.

The future mission scenarios which involve astronaut's activities and, therefore, could greatly benefit with the use of the DVDT, include Low-Earth-Orbit (LEO), Moon and Mars EVAs and IVAs.

Table 2. Possible IVA and EVA activities of astronauts, in LEO, Moon and Mars mission scenarios.

Scenario	*Possible activities of astronauts*
LEO, Moon and Mars IVAs	- Scientific experimentation - Management of EVA activities - Piloting and docking spacecrafts to the ISS - Transference of equipment from spacecrafts to space stations, namely the ISS - Repairing equipment at the ISS - Training activities
LEO EVAs	- Service, inspection, maintenance, repair or replacement of space equipment - Assembly and repairing of space stations - Extravehicular experimentation - Construction of large structures - Satellite deployment and retrieval - Manoeuvring robotic systems
Moon and Mars EVAs	- Planetary surface exploration and analysis - Piloting, navigating and communicating with fly-open cockpit landers and drive rovers - Service, inspection, maintenance, repair or replacement of space equipment - Extravehicular experimentation - Construction of large structures in the planetary surface

7. CONCLUSION

The baseline design of a compact information management and display tool, with low mass and power consumption, has been presented. The proposed DVDT is able to display information (such as text, pictures, diagrams or/and video) directly into the astronaut field of view without obscuring it. The system is inside the space helmet and operates as a monocular HMD attached to the astronaut head. This allows the display FOV to follow the astronaut head movements. The DVDT weights less than 900g from which only approximately 100g correspond to the mechanical structure, display and optics attached to the astronaut head. Several space applications have been identified where the use of such tool could help the astronaut in the execution of his tasks. Novel technologies (like OLEDs, PDAs, high precision optical components) can be used nowadays to develop a feasible information display system for space applications. Fig. 10 shows and artistic representation of the DVDT being used by an astronaut during EVA. This image includes the proposed mechanical enclosure for the DVDT.

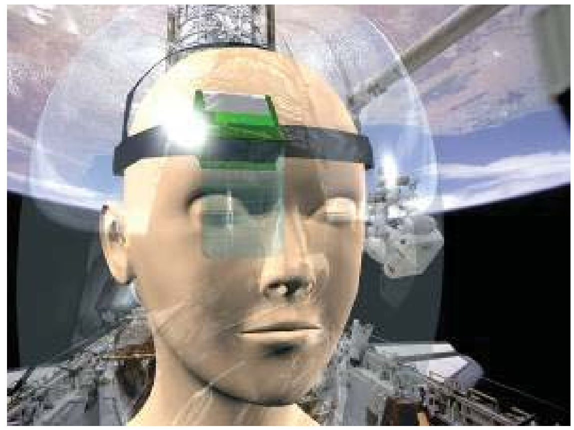


Fig.10. - 3D artistic representation of an astronaut using the proposed DVDT during an EVA.

8. ACKNOWLEDGMENTS

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