A Multi-purpose Tactile Vest for Astronauts in the International Space Station

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Abstract. During a 10 day taxiflight to the International Space Station (ISS) in 2004, Dutch astronaut André Kuipers is scheduled to test a multi-purpose vibrotactile vest. The main application of the vest is supporting the astronaut's orientation awareness. To this end, we employ an artificial gravity vector analogy. The location of vibration on the torso indicates the direction of a vector representing the standard ISS orientation. This application is hypothesised to increase the astronaut's performance and safety. A second application is designed to be used during rest. Additional vibrating elements are attached to the ankles, knees, elbows and wrists of the astronaut. By using specific, pre-programmed spatiotemporal patterns, the astronaut can get the feeling of whole body stimulation. This will support the astronaut in sensing and locating his extremities in space. This application is hypothesised to compensate for the sensory deprivation of the proprioceptive system during weightlessness, resulting in increased comfort for the astronaut.

1 Introduction

In everyday life, we gather information about the world around us via different sensory systems, including our proprioceptive and cutaneous senses. When the information that comes through one of our senses is degraded, for example when wearing protective earphones, our performance and comfort will be negatively affected. A micro-gravity environment not only degrades but even lacks specific sensory information. Especially the proprioceptive and cutaneous senses are affected. For example, there is no pressure on the sole of the feet when standing, and there are no G-forces to overcome when positioning limbs or that pulls clothing to the skin. This sensory deprivation affects the way astronauts perceive their subjective vertical. In Earth's 1G environment, we use four cues to determine the subjective vertical: visual cues, vestibular cues, proprioceptive cues and our ideotropic vector (i.e., we are inclined to see our own body axis as vertical). On board the ISS, vestibular and proprioceptive cues are absent.

Data indicate that during an adaptation phase, astronauts predominantly use visual cues from the ISS and colleagues to orientate themselves. During this adaptation phase, the unexpected visual cues of colleagues (e.g., colleagues oriented 'upside-down') can be very disturbing. The same holds for entering a different ISS module in an unexpected orientation due to sub-threshold rotation in the channel between the modules.

The present research project introduces artificial cutaneous (or tactile) stimulation to support the astronaut. Stimulating specific locations on the skin can be used to present the observer with useful information. Of course the Braille alphabet for visually handicapped individuals is a well-known example in which stimulus location is used to present (abstract) information via the skin. The first examples of presenting non-abstract information on the skin date back to the 1970-s when high density pin displays on the torso of observers were used to convey real life images from a video camera. Technological developments in vibrotactile displays allow stimulating the skin with elements located all over the body. Recent applications of this development hint at more intuitive ways of using the skin as an information channel. In this respect, tactile torso displays deserve specific attention.

Tactile torso displays consist of numerous vibrators attached to the torso in a linear array or in a matrix arrangement (Figure 1). They convey information by presenting localised vibrations to the torso. Since these stimuli are directly mapped to the body co-ordinates, tactile displays are able to present spatial information in an intuitive way [1-3]. For instance, Van Erp [3] showed that a vibro-tactile stimulus on the torso immediately leads to a percept of external direction, an effect which we call the "tap on the shoulder" principle. Such an intuitive perception of external direction can be very useful in applications that require a sense of spatial awareness, such as orientating and navigating in the ISS and performing extravehicular activity.

We designed a multi-purpose tactile torso display that uses this intuitive perception of spatial information. Possible uses of the displays include:

- Support the astronaut's orientation awareness, i.e. his orientation in space. We will discuss the application in more detail below,
- Support the astronaut's body awareness. The application is focused on compensating for the deprived sensory stimulation caused by the micro-gravity environment. For example, tactile patterns can be generated that stimulate the whole body. This is even possible with a limited number of vibrating elements spread over the body [5-8]. This will support the astronaut in sensing and locating his extremities in space, which may compensate for the sensory deprivation of the proprioceptive system during weightlessness, resulting in increased comfort for the astronaut.
- Present orientation information during Extra Vehicular Activity (EVA),
- Guide the astronaut, for example during an emergency evacuation,
- Support the localisation of objects and other astronauts,
- Display warning messages or use for cummunication.

In the present project, we concentrate on the possibilities of employing a tactile torso display to present direction information, more specifically to present an artificial gravity vector. This means that the astronaut wears a vest with a dense matrix of vibrating elements, see Figure 1. The *location* of vibration indicates the *'down' direction* in the station (the modules and the equipment in the ISS have a standard orientation), see Figure 2.

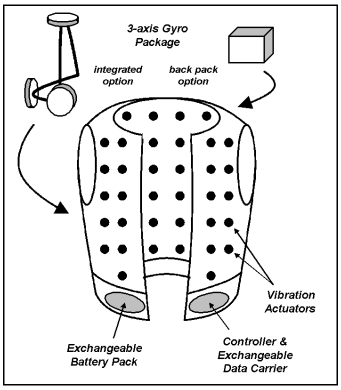

Fig. 1. Schematic lay-out of the multi-purpose vibro-tactile vest designed for use in the International Space Station (design by Dutch Space and TNO Human Factors, The Netherlands).

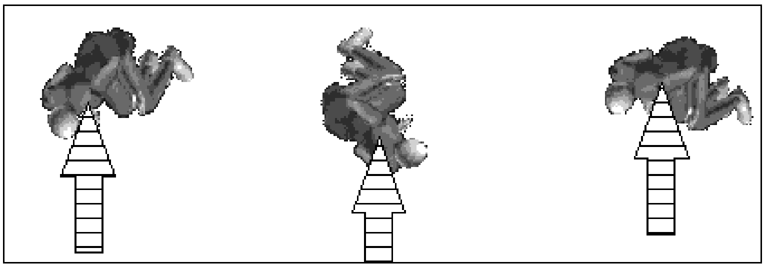

Fig. 2. Principle of projecting the artificial gravity vector as a localised vibration on the torso. A straight-up orientation will lead to no stimulation. For example, when oriented upside-down, the astronaut would receive a vibration on the shoulders. When the astronaut floats horizontally with his belly 'down', the vibration would be on the belly; and when floating on his back, the vibration would be on his back, etc.

2 In-flight experimentation

The tactile vest is scheduled to be tested by Dutch astronaut André Kuipers during a Soyuz taxiflight in 2004. The vest will be evaluated in different situations, but The main focus is on orientation awareness. Presenting an artificial gravity vector is hypothesised to help the perception of the user's current orientation, the perception of (unintended) changes in orientation, support the astronaut in reaching a desired / optimal orientation, and reduce the occurrences of space sickness caused by lack of orientation awareness (e.g., when moving from one unit of the ISS to another). Evaluation will be done by gathering both subjective and objective data. For the latter, we developed a taskbattery, consisting of the following four tasks: 1. rotation illusion in which the astronaut is brought into a slow rotation in the pitch plane with the goal to determine the effect of tactile stimulation on the shift from a stable ISS (i.e., visual

cues are dominant) towards a stable self (i.e., ideotropic vector being dominant) which is normally observed during adaptation to weightlessness; 2. mother Earth, in which the astronaut indicates his orientation after being rotated with his eyes closed with the goal to measure the effect of the tactile vest on orientation awareness and path integration; 3. rotation adaptation, in which the astronaut is brought in a constant rotation and indicates the time the rotation sensation dies out, and 4. Straight and level, in which the astronaut has to recover from a random orientation.
Furthermore, the effect of the vest will be evaluated when the user is involved in other tasks.

3 Closing remarks

The data gathered in the project are not only relevant for designing future support systems for astronauts. Of scientific importance is the study of orienting in 3D without confounding with Earth's 1G environment. The data gathered in a microgravity environment are of key importance to establish the role of tactile information presentation on orientation behaviour without the sensory information from otoliths and the proprioceptive system. The experimental results therefore contribute a unique datapoint for theoretical models on path integration, spatial orientation, tactile orientation information processing, and multi-sensory integration. This may increase the success of tactile display application in other domains such as for pilots and visually handicapped individuals.

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