FITS

Force-feedback with Immersive Technologies Suit

Title : Executive Report

Abstract : This document is the executive report for the FITS study conducted for ESA by Space Applications Services.

FITS is an ESA study that ESA initiated with the intention of investigating potential use of immersive VR and force-feedback technologies in support to astronaut training.

Contract Nº : 4000102107/10/NL/AF

Technical Officer : F. Didot **ESA/ESTEC**

DISTRIBUTION LIST	
Customer	
Name	**Email**
Frederic Didot	Frederic.Didot@esa.int
Space Applications Services	
Name	**Email**
Michel Ilzkovitz	michel.ilzkovitz@spaceapplications.com
Jeremi Gancet	jeremi.gancet@spaceapplications.com
Pierre Letier	pierre.letier@spaceapplications.com
Keshav Chintamani	keshav.chintamani@spaceapplications.com
Stephane Ghiste	Stephane.Ghiste@esa.int
Lionel Ferra	Lionel.Ferra@esa.int
Olivier Lamborelle	olivier.lamborelle@spaceapplications.com
Dmitriy Churkin	Dmitriy.Churkin@esa.int
Partners	
Name	**Email**
André Preumont	andre.preumont@ulb.ac.be
Joseph McIntyre	joe.mcintyre@univ-paris5.fr

DOCUMENT APPROVAL SHEET			
	Name	**Company**	**Signature and Date**
Prepared by :	K. Chintamani P. Letier	SpaceApps SpaceApps	
Reviewed by :	J. Gancet	SpaceApps	
Checked by :	M. Ilzkovitz	SpaceApps	16 Nov 2012
Approved by :	L. Steinicke	SpaceApps	
Accepted by :	F. Didot	ESA/EAC	

Space Applications Services SA/NV
Leuvensesteenweg 325
B-1932 Zaventem, Belgium

Tel: +32-(0)2-721.54.84
Fax: +32-(0)2-721.54.44
URL: www.spaceapplications.com

Table of Contents

List of Figures

1 Introduction

1.1 Objective and Scope

FITS is an ESA study that ESA initiated with the intention of investigating potential use of immersive VR and force-feedback technologies in support to astronaut training. This document is the executive report for the FITS study. It aims at giving an overall understanding of the project's motivations, challenges, and main results obtained.

1.2 Document Structure

This document has been organized into the following sections:

- Section 2: Presents the motivation and main challenges of the project
- Section 3: Gives an overview of the proposed concepts and main outcomes
- Section 4: Concludes this executive report

1.3 Applicable Documents

AD1 Statement of Work, Force-feedback with immersive technologies Suit, reference: FFS-SOW-001-07_09, Issue: 1, Revision 1, 29.07.2009, Appendix 1 to AO/1-6270/09/NL/AF

AD2 FITS-SA-D1: State of the Art FF & VR Technology Use in Training Applications

AD3 FITS-SA-D2: Force Feedback and Immersive Technologies Suit for ISS Crew Training

AD4 FITS-SA-D3: Force Feedback and Immersive Technologies Suit for Moon and Mars Exploration

AD5 FITS-SA-D4: Preliminary System Requirements

AD6 FITS-SA-D5: FITS Preliminary Concept for an On-Ground Facility

AD7 FITS-SA-D6: FITS Preliminary Concepts for an On-Board Facility

AD8 FITS-SA-D7: FITS Preliminary Concept for Ground Facility (and Roadmap)

AD9 FITS-SA-D9: FITS Final Report

1.4 Reference Documents

RD1 ECSS-E-ST-40C- Software General Requirements

RD2 ECSS-E-ST-10-11C Human Factors Engineering

RD3 Man-Systems Integration Standards, NASA-STD-3000 Rev. B, July 1995

1.5 Acronyms and Abbreviations

COTS	Common Off the Shelf

DOF	Degrees-of-Freedom
EVA	Extra-Vehicular Activity
FITS	Force-feedback Immersive Technologies Suit
HMD	Head Mounted Display
HLA	High Level Architecture
ISS	International Space Station
IVA	Intra-Vehicular Activity
OB	On-board
OG	On-ground
VR	Virtual Reality

2 Motivations and main challenges

2.1 Motivations

FITS study mainly originated from 2 main considerations:

1. ESA astronauts training is costly, complex and has limitations, due to several factors including the limited availability for training facilities around the world, the maintenance cost for (some of) these facilities (e.g. neutral buoyancy pool), astronauts agenda, etc.

2. Recent technological progress with virtual reality, including immersive technologies and force feedback technologies, is interesting opportunity for astronaut training.

With FITS, ESA wanted to evaluate how feasible and useful can force feedback and immersive technologies be in support of, or in replacement of standard astronaut training facilities. Concept design of a FITS system for a ground setup and for an on-board setup, as well as early specification and roadmap for actual implementation of the proposed concept, are also part of the FITS study.

2.2 Main challenges

FITS contains many challenges, though the most preeminent one deals with microgravity (and various levels of gravity) simulation. The only way to reproduce weightlessness feeling on Earth is to experience falling. This can be done under Earth gravity either in free fall, or in parabolic flights. It is otherwise possible only with real space flights - while being in orbit in particular. Although microgravity cannot be reproduced (more than a few seconds) on Earth, human perceptions can however be tricked in order to give the sensation of weightlessness. In astronaut training centers, an approach frequently used to reproduce feeling comparable to microgravity is the water immersion within a neutral buoyancy facility (NBF). NBF however are rather huge facilities that are expensive and demanding for maintenance. Mockups of spacecraft are moreover needed so that astronauts can train in relevant IVA or EVA like conditions. FITS concept addresses this concern, and proposes an approach enabling perception tricking, that could prove to be far less costly and less demanding than NBF.

Another major challenge is the need for geographically distributed, collaborative astronauts training. Multi-astronaut simultaneous training is very difficult to organize and perform. In practice, for a given international crew or mission, it often happens that astronauts meet together only once, if not at all before the mission. This would be however very relevant and useful to have collaborative training sessions made possible on a more frequent basis, e.g. for scenarios like IVA emergency training that requires a lot of interaction and synchronization among teammates. FITS addresses this concern, and the proposed concept is scalable to multiple crew training (up to 6) and even mix in-orbit / ground training.

Finally, an additional challenge in FITS is the need to design concepts both for ground and for on-board usage that should at the same time rely as much as possible on the same common baseline (for the sake of cost effectiveness in the concept implementation).

The proposed FITS solution was designed to address all these challenges, and is further introduced in the next section.

3 Main results

3.1 On-Ground (OG) concept

Base on collected user requirements and elicited system requirements, the OG FITS concept was driven by the following factors and rationales:

- Make the concept flexible and scalable. This concern has been carefully considered regarding the potential need for geographical distribution of FITS setup's components.
- Keep overall setup price affordable, while having the setup modular and upgradeable (this may allow customer purchasing elements progressively).
- Keep required space for the setup reasonable.
- Rely on COTS in a large extent.
- Find a near optimal trade-off regarding training effectiveness (which for us implies training realism or transparency vs. solution complexity).
- Factorize as much as possible of the concepts for OG and OB FITS setups

Figure 1: Artist impression of the OG FITS concept

On the trainee side, the proposed OG FITS concept consists of a full body exoskeleton along with an HMD for visual VR immersion of the user. The setup is mounted horizontally on a 6 degrees of freedom parallel actuator (Stewart platform), that is used to initiate vestibular feedbacks. The horizontal position was considered an interesting approach to simulating microgravity. Along with the full body exoskeleton suit and the actuation platform, the proposed solution is expected to be very effective at tricking the user's perception of gravity.

3.2 On-Board (OB) concept

Base on collected user requirements and elicited system requirements, the OB FITS concept was driven by the following factors and rationales:

- Make the concept flexible and compatible with multiple users training, including mix ground / board training sessions.
- Keep mass, volume and energy consumption budgets reasonable for such a training payload.
- Rely on COTS in a large extent (though trade-offs are required with mass, volume and power constraints)
- Find a near optimal trade-off regarding training effectiveness (which for us implies training realism or transparency vs. solution complexity).
- Factorize as much as possible of the concepts for OG and OB FITS setups

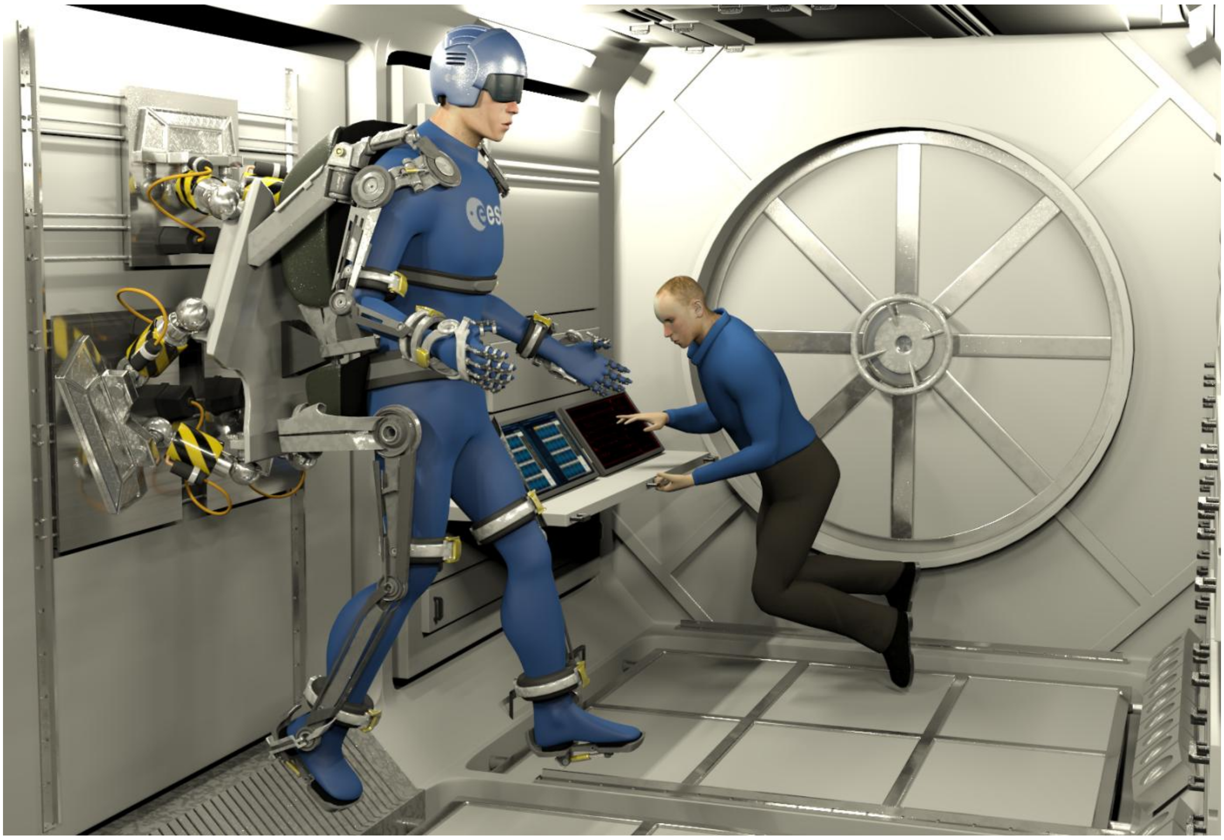

Figure 2: Artist impression of the OB FITS concept

The proposed OB FITS concept shares a lot with the OG setup. It consists in the same manner in a full body exoskeleton along with an HMD for visual VR immersion of the user. The setup is mounted on a 6 degrees of freedom parallel actuator (Stewart platform), that is typically fixed to a standard rack slot. The overall setup is expected to be able to trick user's perception with a feeling of gravity (e.g. Moon, Mars and Earth levels of gravity).

3.3 VR simulation setup and communication channels

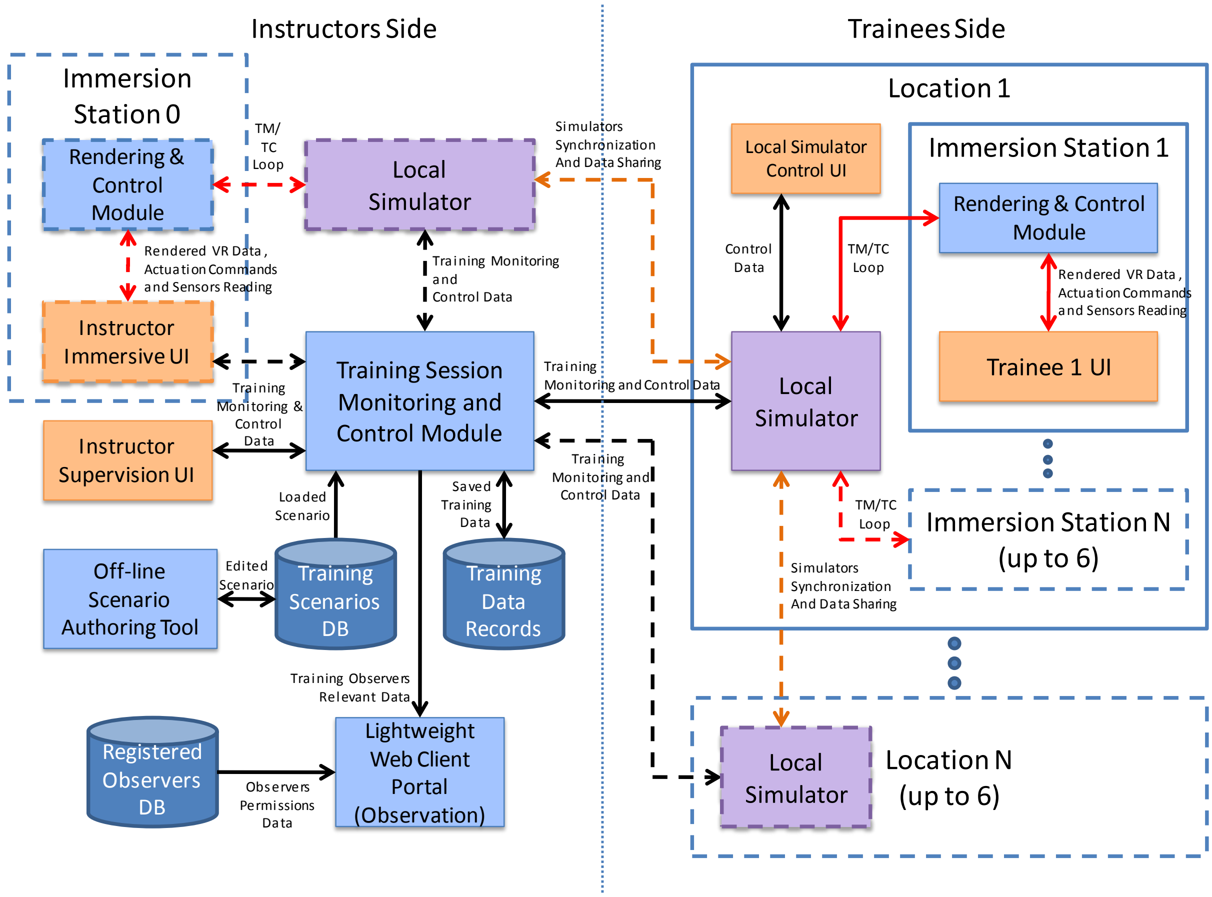

Figure 3: OG FITS functional architecture - big picture

Figure 3 above depicts the OG FITS overall system functional architecture. Dash lines and boxes mean that they are optional in the setup. Red arrows represent haptic performances links, i.e. with at least 1 kHz data transmission (haptic relevant TM/TC). Orange arrows represent communication links that should allow high performance communication (bandwidth, data transmission frequencies) but that may be subject to latencies (due to distance). Black arrows represent standard communication links that do not have to provide high performance in data handling and transmission.

With the proposed concept, in the case of a multiple users / multiple locations setup, a local simulator locally manages the simulation in order to feed local training stations with high performance simulation data, without latencies. Collision detection in the virtual environment, in particular, is handled locally with high performances (compatible with haptic requirements). Local simulators (that are geographically distributed) share data about their state and status, so that state discrepancies can be mitigated locally, and so that simulations are always kept locally as consistent and as transparent as possible for the users. The training session is monitored and controlled centrally (e.g. at EAC) by one instructor having in charge the supervision of the overall training session.

Communication between the local simulators dealing with discrepancies mitigation aspects, rely on a distributed simulation framework. High Level Architecture (HLA) is proposed (which is a solution already exploited in existing ESA simulators like SIMSAT).

3.4 Instructor setup

The instructor side setup gathers tools to prepare, perform and debrief training sessions. Two main components are introduced for the instructor: a scenario authoring component, and a training session monitoring and control component.

3.4.1 Scenario authoring (off-line)

The scenario authoring tool allows instructors to design training sessions, including:

- the importation of required VR models (e.g. spacecrafts, payloads, objects…),
- the scenario cut from a temporal perspective (events occurring along the scenario timeline),
- the training objectives for the trainees, etc.

Edited training scenarios can be loaded by the training instructor in the Training Session Monitoring and Control, to perform a training session.

3.4.2 Training Session Monitoring and Control (TSMC) (online)

The TSMC is a central node in the FITS setup. Once a training scenario is loaded, it paces the overall simulation (communicating with the geographically distributed simulators, in the case of a multi-site session), collects training results and offers supervision tools for the instructor.

In addition, the TSMC also allows debriefing, through post-training data replay and analysis capabilities.

3.4.3 Instructor immersive training station

The availability of an immersive training station for the instructor is seen as optional.

If available, one instructor has the possibly to wear the FITS training suit and get immersed in the VR environment along with the trainees. This allows virtually collocating with them, and to perform instruction in a similar way as physically collocated instructor and trainees could do. Alternatively, the instructor wearing the FITS suit can perform specific movements that can guide the trainee’s movements (master / slave setup), or reversely the instructor can feel the movements performed by the trainee.

3.5 Potential FITS applications

The ground FITS (OG) is first intended to substitute to, or complement existing training facilities at ESA. As such, FITS could allow more flexible crew training and enable new training paradigms such as multi-crew, geographically distributed joint training configurations.

OG FITS may for instance allow crew training for EVA with simulation conditions and sensations reflecting aspects that cannot be properly handled with the Neutral Buoyancy Facility – e.g. feeling accelerations when moving, and perceiving the inertia of objects being manipulated.

As another example, OG FITS may be exploited for IVA emergency training: with standard facilities, such training typically calls for the co-location of the whole ISS crew increment, which is not always feasible, or is otherwise performed a single time due to the constraint and cost of having multiple crew members jointly attending a collocated training session. With the FITS paradigm, one can imagine having FITS setups located in the different crew training centers worldwide, and having the joint training performed in a distributed manner.

The on-board FITS (OB) may serve several purposes. It may be used to fill a gap as refresher training (or proficiency training) enabler, which traditional implementation so far essentially relies on paper or laptop based training refresher of sessions having occurred on Earth weeks or months before (e.g. in the case of 6 months long ISS mission increment). Sometimes instructors can support the O/B crew refresher training from Earth in addition. OB FITS would allow more efficient refresher sessions, with perceptually more realistic conditions. FITS may even go one step further, allowing on-the-fly training with new skills, that could not be trained on Earth before the mission.

Considering long distance and long duration flights (e.g. flight to Mars), OB FITS would be even more valuable: refresher is even more critical, as the extent of the different skills to train would be much larger with such missions than with ISS ones. Moreover, delays in communication may prevent direct communication with Earth-located instructors. In such setups, it is also foreseen that cross-training (or cross-certification) paradigm could be implemented: crew being proficient with certain skills would act as instructors for crew having less proficiency for these skills, and the other way around. Cross-training would therefore allow all the crew to progressively become proficient with the skills of (some of) the other crew. This approach may help saving crew training time on Earth, while giving the crew an opportunity to keep busy with training activities during the flight.

OB FITS could typically be used to refresh planetary operations, starting e.g. a few weeks before descending on Mars.

In addition OB FITS design may be provisioned to also include countermeasure mechanisms and capabilities, in order to be exploited as a mean to maintain crew health over long flight durations – ensuring in particular that the crew will not suffer from impairing conditions once descending on a planetary surface.

With the same long trips perspective, OB FITS could also be used for leisure and as psychological condition countermeasure too – contributing in the success of the mission.

4 Conclusion

The FITS study has been initiated by ESA with the intention of investigating potential use of immersive VR and force-feedback technologies in support to astronaut training.

The FITS study resulted in force feedback and immersive training facility concepts both for ground based (OG) and on-board (OB) applications. The 2 concepts have a lot in common, though specific constraint for a space setup resulted in trade-offs regarding the mass, power and volume budgets.

Challenges like microgravity simulation capability and multi-site, geographically distributed training implementation have been taken into account in the proposed concepts.

Although being an early study, proposed FITS concepts give evidences that a FITS facility is not only technologically feasible, scientifically interesting but also economically viable and pertinent. The FITS roadmap envisages concrete, progressive OG setup implementation over a four years long period and a 3 phase breakdown, each phase resulting in exploitable outcomes for astronaut training (illustrated on Figure 4 below).

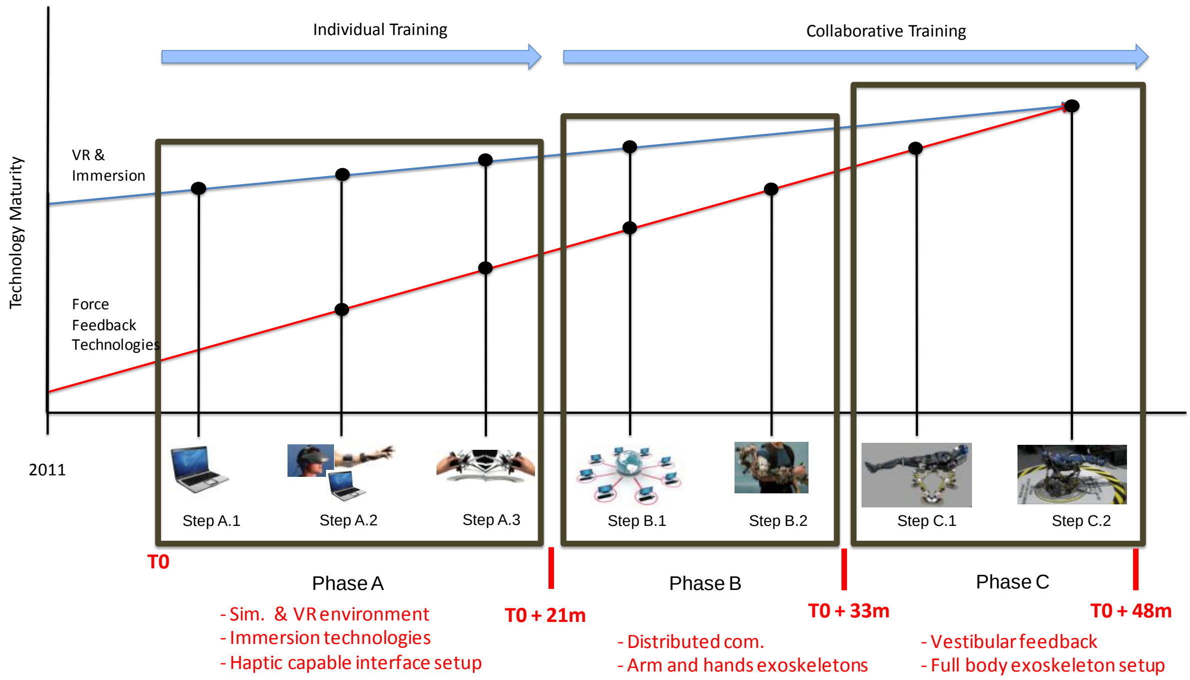

Figure 4: OG FITS implementation indicative roadmap

With the ISS use being promoted for future exploration mission technologies experimentation, unique conditions are getting gathered in a short term horizon, to create opportunities that may eventually turn FITS early concepts into essential ESA astronauts training asset. Furthermore, in the case of exploration mission, FITS could be a unique asset with provision both for crew training (including proficiency training and cross-certification) and for microgravity induced health condition countermeasure – all in one, thus minimizing required space and mass.