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PROJECT FINAL REPORT

Grant Agreement number: 312815

Project acronym: STAMAS

Project title: Smart Technologies for artificial muscle applications in space

Funding Scheme: Collaborative Project

Period covered: from 01/01/2013 to 31/12/2015

Name of the scientific representative of the project's co-ordinator[1], Title and Organisation:

Mr. Marcelo Collado

Project Manager

ARQUIMEA INGENIERÍA S.L.U.

Tel: +91 689 80 94

Fax: +91 182 15 77

E-mail: mcollado@arquimea.com

Project website¡Error! Marcador no definido. **address:** www.stamas.eu

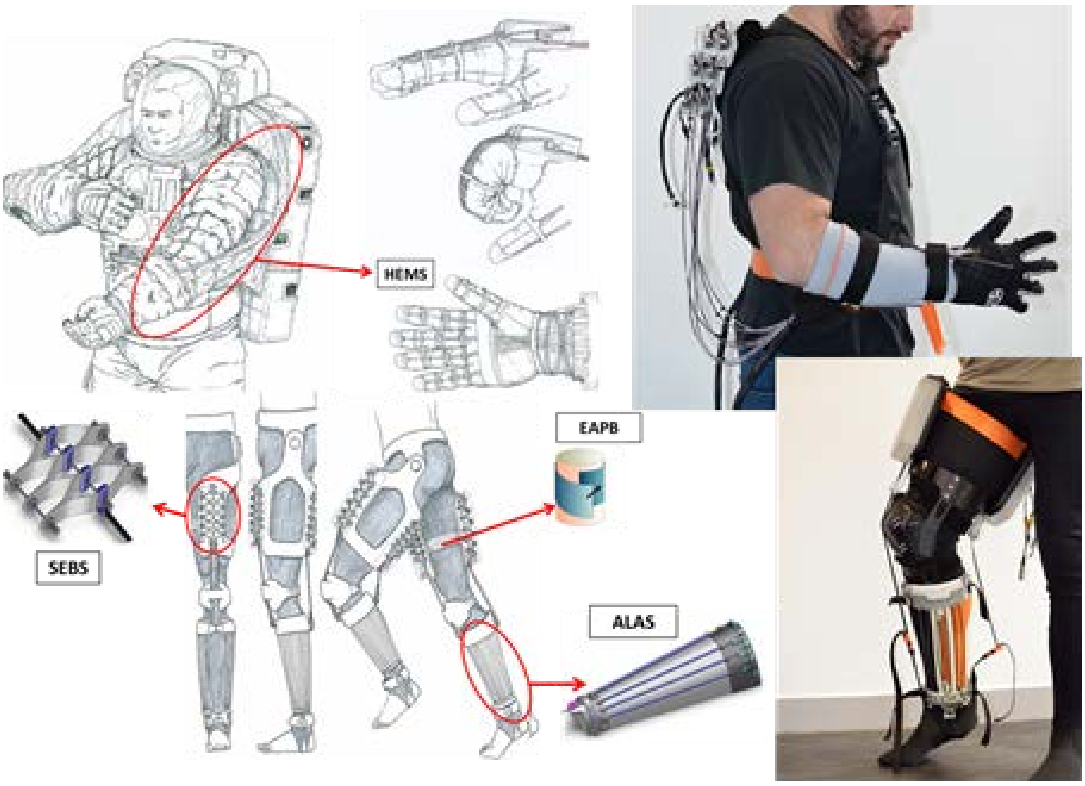
[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

4.1 Final publishable summary report

EXECUTIVE SUMMARY (1 page max)

The STAMAS has been a great and successful conducted effort focused on joining several incipient and promising terrestrial technologies to pose and demonstrate its suitability and accuracy in the space domain. Due the expertise of the participants in the project, the project has been focused in enhancing the life in space by improving the performance of the space suits and diminishing the health effects of the gravity absence.

In a 36 month duration project, two different technologies have been put in the spotlight: SMA (Shape Memory Alloys) and EAP (Electroactive Polymers). Thanks to the efforts devoted, these two present terrestrial applications have been handled to research in new concepts of artificial muscle systems for biofeedback suits for astronauts, as an alternative to currently used technologies. To this end, the project team has proposed to focus on designing, developing and testing both a lower and an upper limb biofeedback suit demonstrator. The lower limb demonstrator incorporate different types of artificial muscles subsystems in complementary configuration in order to attack the different pathologies originated due to microgravity (muscle atrophy, bone loss, and shifting of blood distribution). The upper limb demonstrator provides actuating systems for the assistance of astronauts while wearing space gloves during Extra-Vehicular Activities (EVA). In practical terms, biofeedback leg and hand suits have been developed. These parts of the human body have been selected for being the most critical and representative – in terms of engineering complexity and as key elements that require particular solutions to known problems of human space flights. In other words, a successful demonstrator of those devices for sure represents an important achievement for the design and development of a whole *smart suit*. The results have been very promising, being materialised in two functional prototypes, which have been validated in operational simulated conditions (TRL 4) opening a promising R&D landscape and awakening the interests of several key stakeholders with whom there has been a continuous feedback.



SUMMARY DESCRIPTION: Project Context and Objectives (4 pages max)

STAMAS is an European Project developed by Arquimea Ingeniería, DLR, ETH Zürich, Sensodrive, Universidad Carlos III de Madrid and Universitá di Pisa.
The main goal of the project is to create innovative exo-robotic hands and legs, using Shape Memory Alloys (SMA) and Electro-Active Polymers (EAP) actuators which aim is to support astronauts exercising to mitigate the effects of microgravity on the body and to assist the astronaut's fingers movements during Extra Vehicular Activities (EVAs).

General Objectives

- To generate the scientific basis to provide a smart suit for on-board spacecraft use which is able to control, mitigate and even treat the health problems that could arise owed to microgravity and lack of mobility, as well as to the stiffness of the space suit during EVAs.
- To bring experience on SMA/EAP technologies in the space domain, adapting the existing terrestrial technologies to space domain contributing to the substitution of conventional actuators.
- To adapt different biometric sensors to the on-board space requirements to promote their applicability as an integral part of the astronaut's equipment, improving its functionality and safety.
- To adapt and develop sensors to be embedded in the suit for the control of the mechanical behaviour of the suit and its actuators.
- To develop a control architecture able to process and interpret the information of the biological parameters of the astronaut, his/her movement intentions and the status of the suit and the actuators in order to provide the corresponding orders to the suit subsystems and feedback to the user.
- To develop a functional prototype of bio-feedback leg and hand which can be set over the astronaut's space suit, and react to his/her actions.
- To create a demonstration prototype of a light weight, flexible exoskeleton robotic system based on SMA and EAP actuating technologies, to be test on human beings.
- To obtain a significant technological demonstrator that will enable partners to show their technological capabilities, which will represent an important advantage at commercial level.
- To enlarge the scope of the project to applications other than space specific, such as healthcare or rehabilitation robotics.

Introduction – Problem description

When astronauts return to Earth after a long period in space, their organism shows several signs after living in microgravity, such as loss of muscles mass and bones density, increase of body length, blood distribution problems, heart dysfunction and orthostatic intolerance. Other functions such as proprioception or the capability to react quickly to recover body stability are also degraded by the effect of microgravity.
Currently, on the International Space Station (ISS), countermeasures are taken in the form of exercise plans to prevent the severity of the symptoms. These plans include three phases comprising pre-flight, in-flight and post-flight exercise programs in order to prepare, maintain and adapt the astronaut's physical condition during the whole length of the mission. A leg exoskeleton has been developed in this project for the exercising during in-flight phase.
A further problem encountered by astronauts on the ISS occurs during EVAs. EVAs performed by astronauts are limited by several factors. One of these limitations is the duration of the space walks due to the hand fatigue that astronauts suffer when performing manual tasks. This fatigue is mainly caused by the stiffness of the spacesuit gloves. The gloves are internally pressurized, as the rest of the spacesuit, to protect the astronaut from the vacuum of Space. The pressure inside the gloves increases the stiffness of each joint of the glove, making the astronaut to exert great forces to overcome this stiffness and mobilize the fingers.
In addition, the astronaut has to operate tools or other installations which have to be carefully designed to be gripped or handled in special ways. The resistance force of the glove due to air pressure and stiff

materials and the additional space and distance between the fingers and the grasped object translates in loss of touch feeling and dexterity. Thus, the astronaut has to fight against high forces when performing manipulation tasks during spacewalks. These forces disturb the intended tasks thus reducing efficiency, and causing dramatic fatigue of the astronauts' hands and fingers. A hand exo - muscular system demonstrator has been developed with the aim of assisting the astronauts in these manual tasks, reducing the extra amount of force required to move their hands.

LEG DEMONSTRATOR

One of the main objectives of the STAMAS project is to design an actuated device for the lower limb – the leg demonstrator – to be used for exercising inside the ISS, to address the problem of weightlessness that results in a loss of bone density and of muscular mass. The objectives of these measurements are to improve the exercising in orbit, to explore new countermeasures and to develop exercising devices that can be worn for long periods of time in order to exercise the legs during normal life in the ISS as well as provide a complement to current exercising devices. The leg device imposes several difficulties to the astronaut's movement and performs oppression and release forces over the user's thigh in order to modify the blood distribution. The leg demonstrator is divided into three different actuating subsystems, each one designed to tackle different problems associated with prolonged stays in a microgravity environment. These subsystems are:

- **Ankle Lateral Actuating System · ALAS**

It exerts lateral forces over the ankle, in order to generate sudden little deviations on the ankle position. The user has to use his proprioceptive abilities to keep his/her own balance.
This help to maintain the good state of all the secondary muscles, which usually support the main muscles. The lateral forces generated by this system are created by a set of actuated SMA wires.

- **Smart Elastic Bands System · SEBS**

It is intended for generating a resistance to the knee movement. This device can vary the degree of resistance and the point of the leg that has to perform a greater effort on the flexion-extension movement. The resistance force is generated by a device formed by thermally controlled SMA superelastic bands.

- **Electro-Active Polymer Bands · EAPB**

They are placed surrounding the lower limbs. Their function is to generate alternative compressions, thus improving the blood flow in the lower limbs, replying the effect of pumping muscles. This way the blood flow might be improved in the lower limbs, mitigating the muscular volume loss in microgravity.

HAND DEMONSTRATOR

The Hand Demonstrator is driven by the Hand Exo-Muscular System (HEMS), which is an actuated device used to compensate the stiffness of the space suit by counteracting the force exerted by the pressurized glove, in such way that the force demanded to the astronaut to flex the fingers is reduced. These forces are generated by aims of several SMA linear actuators, which are connected to the gloves by thin tendons connected to the actuators. Several thin rings are placed over the glove in order to guide and fix these elements. The actuated system is called Hand Exo-Muscular System (HEMS) and the proposed solution is based on a bio-inspired principle formed by flexible muscle-like systems as an alternative to state-of-the-art rigid exo-skeletons.

The device detects the movement of each of the user's fingers and acts over the glove helping the user to flex them, so that the apparent stiffness of the glove is reduced and the astronaut's dexterity is improved. An important fact to be taken into account is that the demonstrator is intended to be integrated within an EVA glove. The device is light and low volume. The SMA wires are the basis of the actuating system, thanks to their high force to volume rate characteristics and thus, providing a biomimetic design.

PROJECT TEAM

ARQUIMEA, leader of the project, is an engineering company specialized in the development of customised sensors, actuators and microsystems. The company was founded as a Spin Off of the “Departamento de Ingeniería de Sistemas y Automática” of the Universidad Carlos III de Madrid. ARQUIMEA`s design department is currently composed of 24 engineers, with demonstrated experience in aerospace and electronics (such as EADS Astrium, Analog Devices, Bell laboratories and Motorola, among others).
The most relevant business area of ARQUIMEA strategy is related to the development of SMA based actuators. In fact, the origin of the company six years ago was the development of SMA actuators for artificial muscles; project called EURISMA. This project consists in the application of a SMA based actuator to control the urethra in cases of incontinency.
Key personnel: **Mr. Marcelo Collado** has degree in Telecommunications Engineering by the UC3M (Madrid) and Master in Space and Satellite Technologies by the UPM (Madrid). He has been working for years in the development of SMA applications in the aerospace, automotive and biomedical industry. He has a wide knowledge of the field, supported by many publications in specialized journals as well as communications in scientific congresses.

DLR (Deutsches Zentrum Für Luft Und Raumfahrte), is an Aerospace Research Center as well as the German Space Agency. It is one of the biggest and most acknowledged Institutes in the field worldwide. The institute contributes to several international projects in FP6/FP7 (IP, STREP) as well as space projects and many national research projects. To mention in relation to STAMAS are the FP6 IP SKILLS Multimodal Interfaces for Capturing and Transfer of skills, FP7 IP DEXMART DEXterous and autonomous dualarm/ hand robotic manipulation with smart sensory-motor skills and FP7 STREP GeRT Generalizing Robot Manipulation Tasks. DLR provides its high-competence in designing, building and controlling robots, that sustains the hard conditions of space flight to STAMAS project. Besides that DLR has made use of its experience in the control of haptic human machine interfaces.
Key personnel: **Mr. Thomas Hulin** received his degree as electrical engineer from the Technical University of Munich, Germany, in Sep. 2003. Since 2003 he is scientist at the German Aerospace Center, Institute of Robotics and Mechatronics. His research interests, in which he has (co-)authoredmore than 30 publications, include control theory for haptic rendering, haptic rendering algorithms, multimodal human machine interfaces, skill transfer, and virtual reality.

ETH (Eidegenössissche Technische Hochschule Zürich). Founded in 1855, ETH Zurich has come to symbolize excellent education, groundbreaking basic research and applied results that are beneficial for society as a whole. Nowadays, it offers researchers an inspiring environment and students a comprehensive education as one of the leading international universities for technology and the natural sciences. ETH Zurich has more than 16,000 students from approximately 80 countries, 3.500 of whom are doctoral candidates. More than 400 professors teach and conduct research in the areas of engineering, architecture, mathematics, natural sciences, system-oriented sciences, and management and social sciences. One of ETH Zurich’s primary concerns is transferring its knowledge to the private sector and society at large. It has succeeded in this, as borne out by the 80 new patent applications each year and the 215 spin-off companies that were created out of the institute between 1996 and 2010. ETH Zurich is a leading global natural science and engineering university, and plays an important role in the Swiss economy. ETH transfer supports collaborations with ETH Zürich, licensing of ETH technologies, contacts to ETH Zurich Spin-off companies and innovation and start-up support programs, among others.
Key personnel: **Robert Riener**, leader of the Sensory-Motor Systems (SMS) Laboratory, holds a “Double-Professorship” affiliated to the Mechanical Engineering Department of the ETH Zurich andthe Spinal Cord Injury Center, University Hospital Balgrist, University Zurich. The SMS Lab has broad experience in several areas that are relevant for the development and dissemination plans of STAMAS. The innovative control strategies allow a rehabilitation robot for the first time to “cooperate” with the patient. From 1998 till 2004, Riener did participate in the EU funded projects “Neuros” and “NeuralPRO”. Riener was the leader of the

German network project “VOR”. Currently, he is subproject-leader within the Swiss National Science Foundation project “NCCR Neuro”. Prof. Riener did successfully coordinate the EU-Project MIMCS.

UNIPI (University Of Pisa). The Interdepartmental Research Center "E. Piaggio" is an institute of the University of Pisa devoted to multidisciplinary research in the fields of Bioengineering and Robotics, and to training of research personnel. In this project, the Center was represented by the Bioengineering Group which has a longstanding and internationally recognized expertise in the field of Electroactive Polymer (EAPs) as smart materials for electromechanical transducers. In this field, the Group is an international reference and coordinates the “European Scientific Network for Artificial Muscles”, entirely focused on EAPs (www.esnam.eu). In this project, the Group performed the following activities: design and manufacturing of new kinds of electroactive polymer actuators based on dielectric elastomers; mechanical, electrical and electromechanical characterization of materials and testing of the actuators; cooperation to the design, development and demonstration of the intended application.
Key personnel: **Dr. Federico Carpi** (Ph.D. degree in Bioengineering at University of Pisa). Currently is Postdoc researcher at this University. Coordinator of the “European Scientific Network for Artificial Muscles (ESNAM)”. His main research activities concern the development of novel materials and actuators for electroactive polymer-based artificial muscles and their applications.

SD (SENSODRIVE GmbH) is a spin-off company from the German Aerospace Centre DLR. SD main goal is to bring the latest drive, sensor, and control technology into the industry. Customers from the air- and space-industry, medical technology, simulator manufacturers, as well as the automotive branch rely on SENSODRIVE technology. The special mechatronic know-how enables the SD engineers to develop customer specific products as well as own products with unique features. Therefore, the company counts with a wide range of products among which sensor actuators, motion controllers and special actuators can be identified. All products are designed with the latest concurrent engineering methods; being the integration of mechanics, electronics, sensor technology, and advanced controllers the company’s specialty.
SENSODRIVE servo actuators are based on the ideas of the DLR light-weight robot. The unique compactness and performance are achieved by optimizing each individual component.
Key personnel: **Norbert Sporer** studied electronics at the Fachhochschule München. He got a degree from the technical University of Munich. Besides his studies in Automation and Control” Mr. Sporer worked as development engineer at the Institute of Automatic Control Engineering. He is currently working in the Institute of Robotics and Mechatronics at the DLR as project manager for the light-weight robot. With the light-weight robot development the team has been able to set new benchmarks in robotics. As requested by the head of the Institute, Mr. Sporer is still in charge of the light-weight robot project.

UC3M (Universidad Carlos III De Madrid). Founded in 1989, the Carlos III University of Madrid (UC3M) is a public university whose main goal is to provide specialised training in Law and Social Sciences and Engineering, as well as to become a prime European research centre. UC3M has strived to make research one of the fundamental pillars of its activity, both for the enhancement of its teaching and for the new knowledge and new areas of research. ROBOTICSLAB was founded in 1981 when participated in the development of one of the first robots in Spain, the DISAM-0. This centre has evolved and become one of the most representative robotics research group in Spain
Key personnel: **Dr. Luis Moreno** (Degree in Automation and Electronics Engineering in 1984; Ph.D. in 1988 from the Universidad Politécnica de Madrid). From 1988 to 1994, he was an associate professor at the Universidad Politécnica de Madrid. In 1994 he joined UC3M, from 2007 is the head of the Departament of Systems Engineering and Automation. He has been involved in several mobile robotics projects in Robotics Lab of the UC3M. His research interests are in the areas of mobile robotics, mobile manipulators, environment modelling, path planning, learning problems in robotics and mobile robot global localization problems.

MAIN S&T RESULTS/ FOREGROUNDS (25 pages max)

HAND SUIT

- Extra Vehicular Activities (EVA) performed by astronauts are limited by several factors. The gloves are internally pressurized to protect the astronaut from the vacuum of Space. The internal pressure increases the stiffness of each joint of the glove, making the astronaut to exert great forces to overcome this stiffness. The stiffness also leads to other problems, such as premature hand fatigue, damages in the nails, difficulties to move with dexterity and lack of control about the applied strength on the objects.
- The objective of the **hand demonstrator** o is to <u>reduce the effect of the stiffness of the glove</u> by counteracting the force exerted by the pressurized glove. These forces are generated by aims of several linear actuators connected to the gloves.
- The device predicts the user's movement intention and acts over the glove to reduce the stiffness.

It is composed by the following modules:

- **Hand Exo-Muscular System (HEMS)** – actuating system that reduces the stiffness of the spacesuit glove. 6 SMA flexible actuators connected to the fingers (1 for each finger and 2 for the thumb).
- **Finger Sensors (FS)** – 6 force sensors located on the fingertips (2 for the thumb)
- **Central Control Unit (CCU) / GUIs** – overall behaviour of device, monitor of parameters, security and safety.
- **Sensor Module (SM)** – transmitting information from sensors to other components.




General description:

- The FS register force information to detect the movement intention of the user. This information is sent to the CCU through the SM FS to monitor the user movement intention to decide the adequate actions (sending control signals to the actuating system) when using the device.
- The sensors of the HEMS measure information about position and force. All this information should be transmitted to the CCU to check the status of the actuating system and to send the required control actions.
- The SMs are responsible of coordinating the data acquisition and transferring sensor signals to the upper control layers.
- The CCU sends command signals to the actuating system via the Microcontroller and Driver block. The required control actions are also sent to the actuating system module (HEMS) using the SMs.

- The Platform is formed by the Power Unit and the Suit Structure. A Power Unit is required to feed each module of the device in a direct or indirect way. The suit structure gives mechanical support to the demonstrator, providing a suit demonstrator for the hand. It contains fixations for the different subsystems and blocks and connections for the transmission of forces to the user.

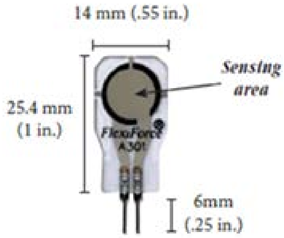
HAND EXO-MUSCULAR SYSTTEM

- Shape memory effect to perform the required actuation. When heated, the SMA wires contract, thus causing the flexion of the fingers. Upon cooling, the wires gradually return to their initial length thanks to the opposition force produced by the stiffness of the EVA glove, which also cause the extension of the user's fingers.
- Force applied on the fingers, allowing a more comfortable flexion while wearing a stiff glove. The amount of force is controlled by the user by changing the pressure applied in the fingertips.
- Mechanical structure – glove with a series of tendons attached to the fingertips and tendons routed through the underside of the fingers and the palm of the hand.
- The index, middle, ring and little fingers have only one tendon each, while the thumb has two tendons.
- Tendon system attached to the output of the HEMS actuators through an interface consisting of a series of pulleys to multiply the linear displacement of the actuators.
- Rigid tendons allows to flex the wrist without affecting the actuators performance.
- HEMS actuating system fixed end in the shoulder, where it is linked to Bending Beams force sensors.
- Sensors: fingertip sensors (FlexiForce #A201), force sensors (Bending Beam), and position sensors (Rolin linear).

HEMS Specifications		
Linear stroke		25 mm
Maximum force		35 N
Technology		SMA actuator
Max. Frequency of complete cycle		0.125 Hz
Lifetime		50,000 actuating cycles
Aggregated mass		< 1500 g
Power consumption		300 W
HEMS Controller	Performances	Control of fingers
	Resolution	> 0.025 Nm
	Freq.	1 kHz
Position Sensor	Range	0-40 mm
	min. res.	1 µm to 250 µm
	Freq.	> 100 Hz
Force Sensor	Range	> 50 N
	min. res.	> 0.5 N
	Freq.	1 kHz

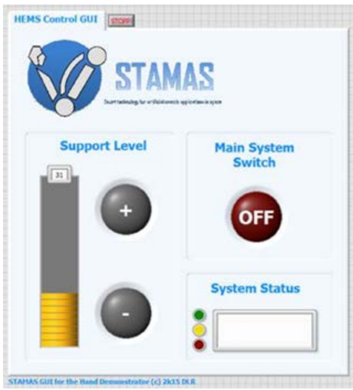
FINGER SENSORS

- The FS are formed by six force sensors located on the fingertips.
- One sensor is placed on each finger except in the thumb, which has two of them because two degrees of freedom have been analysed/controlled.
- Each sensor is a force sensing resistor (FlexiForce #A201 capacity sensor) that obtains analogic signals.
- These sensors are connected to the SM FS.

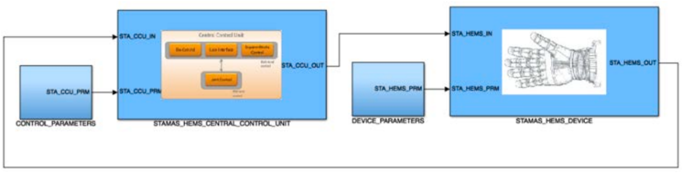


FS Specifications	
Range	Sensitivity towards 20N able to withstand 110 N
Power Consumption	0.1-0.5 V
	2.5 mA max
Resolution	12 bit
Output signal	Digital over Sensor Module

CENTRAL CONTROL UNIT - GUIS



- Overall control of hand demonstrator: upper control hierarchies, and two GUIs, one for the astronaut, and the other one for an expert or engineer.
- Monitors user parameters measured by the FS and information from actuating system.
- In case of an error, safety strategy that deactivates the device.
- Checks with regard to: timeout (delay between device and controller), status (actuating system), plausibility (sensor data), and range (control commands).
- Setting the required force to support the astronaut in manipulation tasks.
- Expert GUI: visualization of commanded and measured data, input and control of control parameter values, and data logging.
- Astronaut GUI: intuitive and easy-to-use interface that offers the astronaut access to the selected parameters and that displays information on the device state.



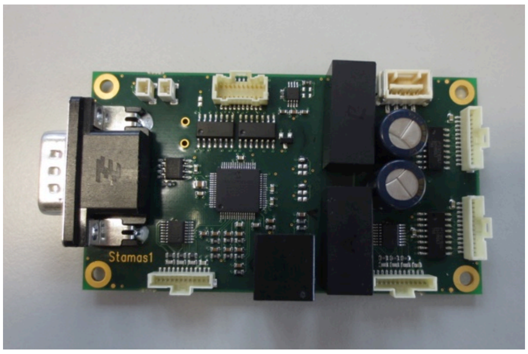
PLATFORM

- The Power Unit and the Suit Structure are included in the Platform.
- The Power Unit feeds each module of the device in a direct or indirect way. It feeds directly the CCU, the Microcontroller and Driver and the SMs.
- The Suit Structure gives mechanical support to the demonstrator, providing a suit demonstrator for the hand. It contains fixations for the different subsystems and blocks and connections for the transmission of forces to the user. It also provides protection to the user.
- The Bending Beam is attached to a mechanical interface that is used as its structure. This interface provides an easy system for attaching and detaching the HEMS actuators to the shoulder structures when putting on and off the suit.

Platform – Power Supply Specifications of each module	
CCU	European electrical standard, 230 V, 50 Hz
Microcontroller	Micro-USB to USB A
Drivers	0-40 V, 0-20 A (banana connectors)
SM	12 V, 0-0.5 A (banana connectors)
HEMS actuators	Molex 22-27-2021 with two pins
FS	0.1-0.5 V, 2.5 mA

SENSOR MODULES

- There are different types of sensors in the actuating systems of the hand demonstrator. The SMs have been designed to coordinate the data acquisition and to transfer signals to the upper layers.
- The SM board is able to read all the sensors and is connectible with the SMA Controller.
- A CAN Bus system is used to coordinate the information provided by the set of SMs because of the quantity of sensors and the spatial distribution.



LEG

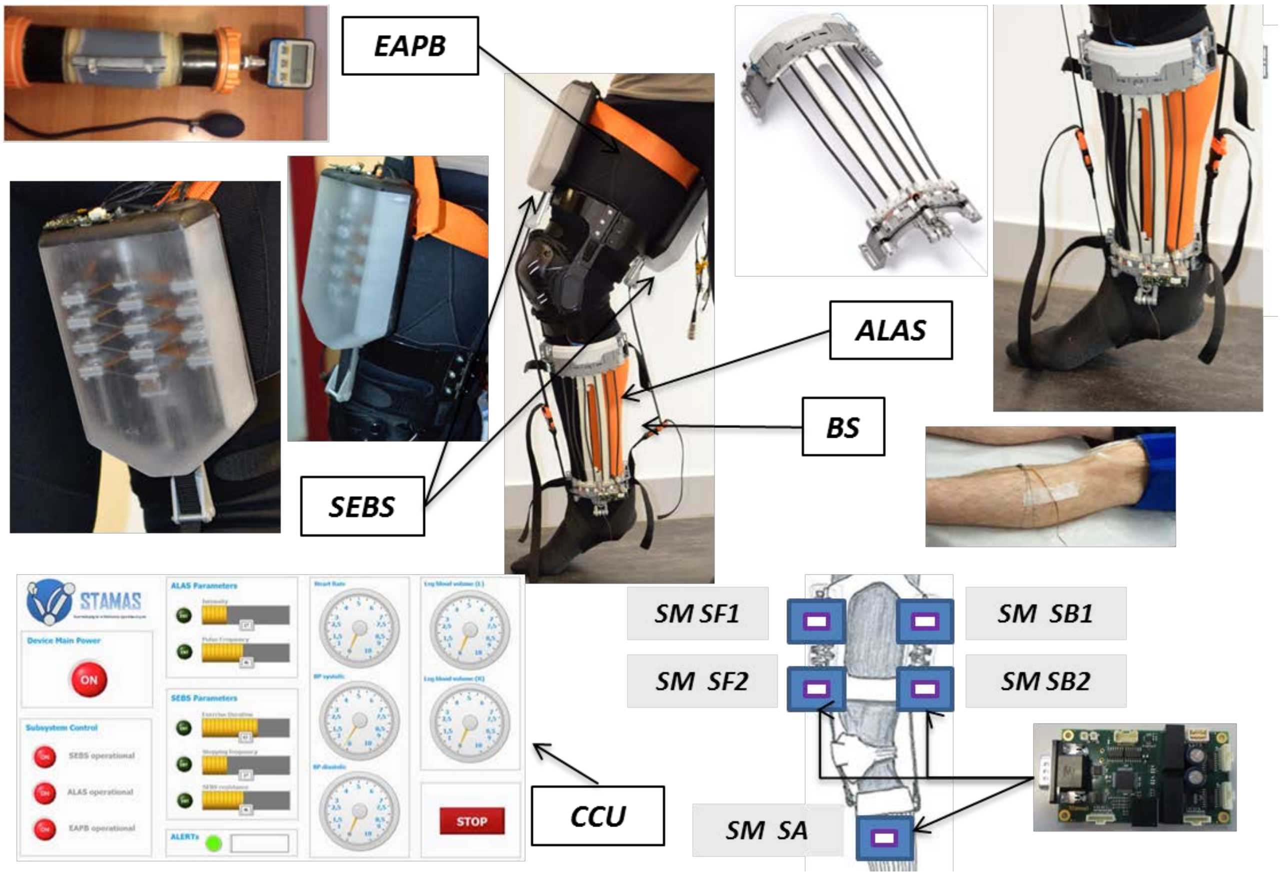
- The effect of microgravity during prolonged stays in space causes different problems. Astronauts suffer from several health problems, such as bone loss, muscle atrophy or a change of blood circulation and distribution.
- The leg demonstrator is an an advanced exercising device that can be used individually or complementing the existing exercising devices on board.
- It imposes several difficulties to the astronaut's movement and performs oppression and release forces over the user's thigh to modify the blood distribution.
- The main objective of the actuating systems is to mitigate the consequences caused by microgravity in space.
- The leg suit contains three different actuating systems (ALAS, SEBS and EAPB) based on different technologies that rely on smart materials: Shape Memory Alloys (SMA) and ElectroActive Polymers (EAP).

It is composed by the following modules:

- **Ankle Lateral Actuating System (ALAS) -** lateral forces over the ankle joint to exercise the ankle's lateral muscle.
- **Smart Elastic Bands System (SEBS) -** variable resistance to the knee movement in flexion-extension movement.
- **ElectroActive Polymer Bands (EAPB) -** alternative compressions, improving the blood flow in the lower limbs, replying the effect of pumping muscles.
- **Body Sensors (BS) –** information about blood pressure and heart rate.
- **Central Control Unit (CCU) / GUIs –** overall behaviour of device, monitor of parameters, security.
- **Sensor Module (SM) –** transmitting information from sensors to other components.

General description:

- The BS measures blood pressure and heart rate. This information is sent to the CCU to monitor the user parameters to decide the adequate actions (sending control signals to the actuating systems) when exercising.
- The SEBS and ALAS sensors measure information about position, force, and temperature. This information is transmitted to the CCU to check the status of the actuating systems and to send the required control actions.
- The SMs are responsible of coordinating the data acquisition and transferring sensor signals to the upper control layers.
- The CCU sends command signals to the actuating systems. The required control actions are also sent to the actuating system modules (SEBS and ALAS) using the SMs.
- The EAPB module has its own driver electronics, which feeds the EAP with the high-voltage signal required for its actuation. This driver is directly connected to the CCU, performing an ON/OFF control of the device.
- The Platform is formed by the Power Unit and the Suit Structure. A Power Unit is required to feed each module of the device in a direct or indirect way. The Suit Structure gives mechanical support to the demonstrator, providing a suit demonstrator for the leg. It contains fixations for the different subsystems and blocks and connections for the transmission of forces to the user.



ANKLE LATERAL ACTUATING SYSTEM

- Lateral forces over the ankle joint to exercise the ankle's lateral muscles.
- Options:
    - Maintained forces with low variation rate to perform a passive-active exercising of the user's ankle.
    - Fast sudden impulses to emulate the loads appeared when a person changes its direction or the ground is tilted.
- Two symmetrical devices linked by straps, internal and external ALAS, in charge of exerting inversion and eversion forces, respectively.
- Lateral forces created by a set of actuated SMA wires.
- On its top end, ALAS mechanically attached to the SEBS system. On the bottom end, linked to the astronaut's foot by a semi-rigid element.
- Sensors: force (Sensodrive Bending Beam) and position (RM08 Rolin). All sensors needed twice (internal and external).

ALAS Specifications		
Linear stroke		15 mm
Maximum torque		1.5 Nm
Maximum force		50 N
Technology		SMA actuator
Max. Frequency of complete cycle		0.25 Hz
Lifetime		50,000 actuating cycles
Aggregated mass		< 500 g
Power consumption		100 W
ALAS Controller	Performances	Control of load to the ankle
	Resolution	> 0.025 Nm
	Freq.	1 kHz
Position Sensor	Range	0-360°
	min. res.	> 0.5°
	Freq.	> 1kHz
Force Sensor	Range	> 50 N
	min. res.	> 0.25 N
	Freq.	> 1kHz

SMART ELASTIC BANDS SYSTEM

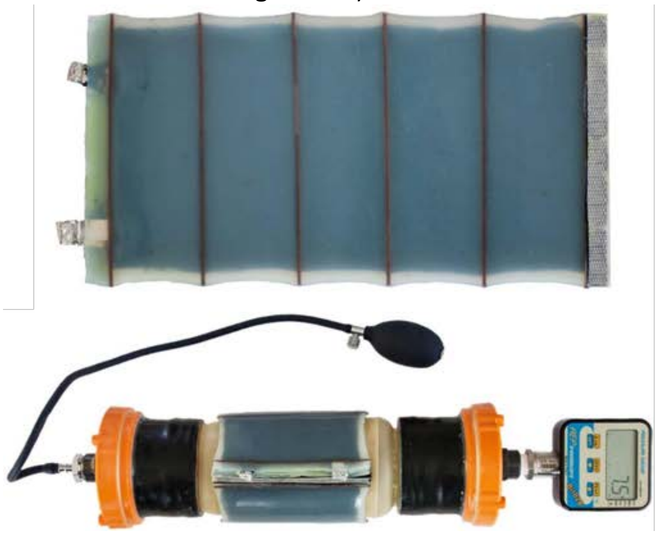
- Produces a resistive force to the knee movement, able to change the degree of resistance on the flexion-extension movement.
- Two SEBS devices united by straps (SEBS front and SEBS back). Each actuating system is in charge of exerting the flexion and extension forces, respectively.
- Mechanical interface to the suit structure, ensuring structural integrity and a proper force transmission from the actuator to the leg.
- Structure connected to the user hip, user leg guided through his knee and the rest of the suit properly to ensure the force transmission. It allows the user to make his/her whole range of movements of the knee.
- On its top end, the SEBS device is mechanically attached to the hip. On the bottom end, the device is connected to the ALAS device.
- Opposing force produced by a set of SMA sheets working on the superelastic region. The stiffness is modified by adjusting the temperature of the SMA elements using heaters.
- By varying the amount of resistance produced by the SEBS, it is possible to train a wide range of the leg's muscles, allowing the user to prevent the loss of muscle weight.
- Sensors: force (K100), position (Rolin magnetic encoder), and 16 temperature (16 PT1000) in each SEBS device.

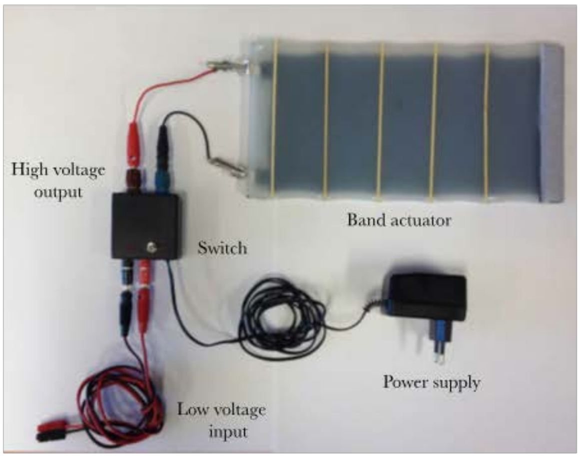
SEBS Specifications		
Max. Deformation		> 60 mm
Max. Force		> 300 N
Total load applied		[40%,60%] muscle load
Technology		SMA – Superelastic elements
Lifetime		50,000 actuating cycles
Aggregated mass		< 400 g
Power Consumption		< 160 W
SEBS Controller	Performances	Adjustment of elastic behaviour (resistive load)
	Freq.	> 50Hz
Temperature Sensor	Range	-50°C to 150°C
	Resolution	12 bit
Position Sensor	Range	[0,60] mm
	Resolution	1 µm to 250 µm
Force Sensor	Range	[0,1000] N
	Resolution	> 5 N



ELECTROACTIVE POLYMER BANDS

- Generation of alternative compressions, improving the blood flow in the lower limbs, replying the effect of pumping muscles. Surrounding the lower limbs.
- Three hardware components: EAP band, mock up limb simulator and high voltage power unit.
    - EAP band: multilayer stack of several dielectric elastomer films coated with compliant electrodes. The stack is coupled to soft passive elastomeric layers, which represent a suitable mechanical interface with the limb and, at the same time, ensure proper electrical insulation of the user and protection of the device.
        - Electrical connections by means of metal stripes, one end connected to the band's electrode and the other one to a voltage lead.
    - Mock-up limb simulator: soft tubular structure pressurized by air. A pressure gauge allows for reading the variation of pressure inside the air chamber.
    - High voltage unit: electrical interface consisting on a High-voltage step-up converter driven at low voltages (0-5 V) via a buffer (simple operational amplifier in voltage follower configuration).

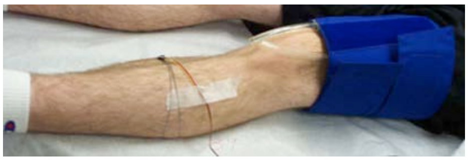




EAPB Specifications	
Lifetime	100,000 actuating cycles
Pressure Range	[0,33] kPa
Max. Compression Freq.	0.5 Hz
Compression duration Range	[1,300] s
Band dimensions	270x140x6 mm
Radious (limb simulator)	40 mm
Longitudinal length of air chamber (limb simulator)	180 mm
Power supply	0-5 V
High voltage unit power supply	0-10 kV
Safe limit (high voltage unit)	7 kV

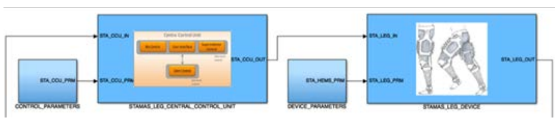
BODY SENSORS

- CNAP monitor (two air cuffs): first one applied to the upper arm of the user, and second one to their index and middle fingers. An external device controls the pressure of these cuffs, and calculates blood pressure and heart rate.
  - Hand where the finger cuffs are placed should be at the level of the heart.
  - Arm movements avoided.
- Strain gauge: elastic tube that changes electrical resistance based on its elongation. Wrapped around the leg to monitor changes of leg diameter due to changes of blood volume.
  - Requirement: no occlusions to blood flow.




BS Specifications		
BLOOD PRESSURE	Range	[4, 33.3] kPa ±0.6 kPa
	Power Consumption	18 VDC
		3 A Imax
BLOOD VOLUME	Range	[0; 10] mm ±0.001 mm
	Weight	< 500 g
	Power Consumption	15 VDC
		3 A Imax

CENTRAL CONTROL UNIT – GUIS



- Overall control of leg demonstrator: upper control hierarchies, and two GUIs, one for the astronaut, and the other one for an expert or engineer.
- Monitors user parameters measured by the BS and information from actuating systems.
- In case of an error, safety strategy that deactivates the device.
- Checks with regard to: timeout (delay between device and controller), status (actuating systems), plausibility (sensor data), and range (control commands).
- Setting the training intensity of the astronaut.
- Expert GUI: visualization of commanded and measured data, input and control of control parameter values, and data logging.
- Astronaut GUI: intuitive and easy-to-use interface that offers the astronaut access to the selected parameters and that displays information on the device state.

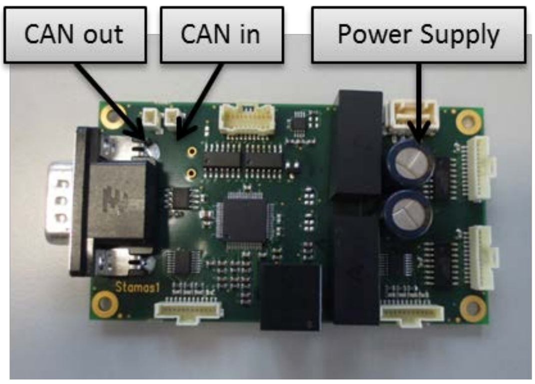
PLATFORM

- Power Unit and the Suit Structure included in the Platform.
- The Power Unit feeds each module of the device in a direct or indirect way. It feeds directly the CCU, the Microcontroller and Driver (which feeds the SEBS and ALAS SMA actuators), the EAPB, and the SMs.
- The Suit Structure gives mechanical support to the demonstrator, providing a suit demonstrator for the leg. It contains fixations for the different subsystems and blocks and connections for the transmission of forces to the user. It also provides protection to the user.

Platform – Power Supply Specifications of each module	
CCU	European electrical standard, 230 V, 50 Hz
Microcontroller	Micro-USB to USB A
Drivers	0-40 V, 0-20 A (banana connectors)
SM	12 V, 0-0.5 A (banana connectors)
SEBS and ALAS actuators	Molex 22-27-2021 with two pins
EAPB	Europeanelectrical standard, 230 V, 50 Hz
BS (amplifier of strain gauge)	±5 V, 50 mA
BS (strain gauge)	10 V, 100 mA

SENSOR MODULES

- There are different types of sensors in the actuating systems of the leg demonstrator. The SMs have been designed to coordinate the data acquisition and to transfer signals to the upper layers.
- The SM board is able to read all the sensors and is connectible with the SMA Controller.
- A CAN Bus system is used to coordinate the information provided by the set of SMs because of the quantity of sensors and the spatial distribution.



SOCIOECONOMIC IMPACT, DISSEMINATION AND EXPLOITATION

Potentially exploitable products and technologies

The main challenge of this project is the adaptation of mature SMA and EAP based technologies to develop new concepts of feasible artificial muscles integrated in a biofeedback suit for astronauts. The main system to be developed is formed by two subsystems: biosensor subsystem and artificial muscle subsystem. From both the overall system and the subsystems, project developers have taken the necessary heritage and knowledge in order to develop new potentially exploitable products and technologies:

Biosensor subsystem

The set of sensors is a key part of the biofeedback suit. This provides constant feedback to the control system, which connect or disconnect the SMA/EAP actuators. The set of sensors consists of:

- O_2 saturation (reflective pulsoxymetry) two channels ECG, temperature.
- Blood pressure meter based on the oscillometric method.
- Volume sensors for big groups of muscles (i.e. legs, chest, abdomen).

Apart from its use in space, potential terrestrial applications of the proposed biosensor system are very clear, especially in the field of medicine. It is possible to implement an innovative customizable sensing system for patients' online monitoring. Thanks to the possibility of setting custom configurations, users could monitor different parameters according to their needs.

For this project, no new sensors have been developed. However, ARQUIMEA experience in microelectronics design for space has been used within the project to assess the possibility to integrate the overall sensor acquisition electronics in a single chip, enabling smooth integration into the biofeedback suit, as well as lower consumption in the overall biofeedback sensor subsystem. The implementation of this chip in a further project continuation would be beneficial for optimizing both the space and terrestrial applications of the proposed sensing system.

Mechanical sensors subsystem

A set of sensors was included in the active biofeedback suit for the measurement of the status of actuators and mechanical parts of the suit. The signals obtained from these sensors are used by the different controllers to handle the actuation of the artificial muscles and to take decisions from the status of the user joints. These sensors include:

- Position sensors for the actuators (artificial muscles).
- Force sensors for the actuators (artificial muscles).
- Torque/position sensors to obtain the state of the joints
- Temperature sensors for controlling the temperature of actuators.

Apart from its use in the propose application, potential terrestrial applications of these sensors can be found in different sectors, such as industrial, robotics…

Artificial muscle subsystem

The active biofeedback suit is able to exert resistance stress in order to force human body to exercise and train. The forces to be applied at the legs target two levels: resistance forces in order to induce the skeletal muscle operation, simulating gravity forces and massage forces in order to stimulate the lower limb and induce the blood circulation from upper to lower limb. For the resistance forces an artificial muscle with high power/mass ratio, high resilience, low relative deformation (muscles are very large) and low speed is sought. To this end, according to the preliminary technology trade-off, SMA fibers are considered the best candidate. For the massage forces, the most suited technology is EAP, since large relative deformation and low forces are required. The stockings must apply annular forces around the thigh, small forces (massage force requirements are very low). Recent developments based on dielectric elastomer bands for active bandage have shown feasibility of this approach.

The SMA/EAP technology validated in the frame of the project boosted a further development of actuating systems for both space and terrestrial applications. In the space field, besides the proposed artificial muscle applications, STAMAS has eased the improvement on the performance of already existing SMA based actuators, such as hold-down and release mechanisms, pin pullers or rotary and linear actuators. Specifically, the knowledge acquired by ARQUIMEA in SMA manufacturing, characterization and control allowed the company to use these materials for a more efficient actuation of its low-shock, low-weight, non-explosive space devices. Such characteristics are also very positive for other terrestrial applications, such as medicine (smart implants, artificial muscles…) or nuclear (radiation immune tools and devices for remote handling…).

Section 6 of the present document describes the expected potential products and the exploitation strategy to be implemented per each partner of the STAMAS consortium with regard to its own particular foreground to be obtained.

EAP dynamic limb compression bandage

The innovative EAP compression bandage developed in this project is expected to lead to potentially exploitable products and technologies not only suitable for space suits but also for different applications. In particular, the EAP-based compression bandage might find applications in the following specific examples of products:

1) **Massage devices for patients suffering of malfunctioning of the lower limbs circulatory system:** pathological or gravity-induced malfunctioning of the lower limbs circulatory system are currently addressed with both static or dynamic compression systems such as compression stockings and pneumatic compression sleeves. In particular, such compression systems are utilized as a treatment for the prevention of deep vein thrombosis, orthostatic hypotension and other venous-return related problems. However, the static compression offered by compression stockings was proved to be less effective than the time-dependent one provided by intermittent pneumatic compression systems. On the other hand, the latter require the use of bulky pneumatic cuffs and a pumping box, resulting impractical in many conditions.
   The developed EAP compression bandage overcomes the shortcomings of both compression stockings and pneumatic compression systems, allowing for the development of conformable, light-in-weight, low-power consuming, and noise and heat free wearable systems or garments able to provide dynamic compression actions distributed over different body portions.

2) **Haptic devices for man-machine interfaces (e.g. for virtual reality systems):** in this case, evolutions of the devices might be used to develop soft, conformable, light-in-weight, low-power consuming, and noise and heat free wearable systems aimed at providing man-machine interfaces with actuating functions, either at low or at high frequencies. Virtual reality systems are just an examples of possible systems that might benefit of these new technologies.

3) **Safety systems for drivers or other operators (e.g. use of vibrations as an alarm integrated within wearable systems):** in this case, evolutions of the devices might be used to develop soft, conformable, light-in-weight, low-power consuming, and noise and heat free wearable systems aimed at allowing different kinds of operators to perform tasks more safely. A specific example is represented by drivers of vehicles. Here, the driver’s suit/garment or gloves might be fitted with conformable alarm systems alerting the driver with vibrations in case of need or danger (e.g. warning systems in case of incipient sleeping detected by external sensors).

SMA actuators

SENSODRIVE has gained knowledge on the application of SMA actuators in force/torque controlled systems including the sensors needed for those applications. The combination of SMA actuators with existing control know-how enables SENSODRIVE to offer engineering services in a wide range of potential applications and possibly enter new markets.

Furthermore, SENSODRIVE developed bending beams with a digital electronic interface (SPI) that can be used in upcoming projects.
A miniature PCB to amplify and digitize the low-voltage signals from the bending beam was developed. It was used in the STAMAS-Project to connect the bending beams to the sensor module and to the controller. SENSODRIVE will use this PCB in other projects and will continue to do so.
The sensor module, a PCB connecting various sensors (temperature, bending beam, incremental encoder, etc.), with diverse interfaces (analog, SPI, RS485) to the controller via CAN will be used in other projects where distributed sensing and digitizing is required.

Potential users of the technology

As stated before, STAMAS project pretends to extend the use of some fairly mature terrestrial actuation technologies into new innovative space applications. Nevertheless, project foreground also shows attractive potential non-space usage. In this section, both markets – space and non-space – are discussed identifying potential users and advantages provided by the technology. Apart from the specific applications described below, STAMAS works have provided a deep knowledge in new configurations and control of SMA materials in force and position. This allows a wide bunch of new potential uses for these materials for both space and terrestrial, such as more accurate devices, flexible actuators, "snake" robotics, super elastic elements with variable and controllable elasticity, etc.

Space applications

The main project result is the technology necessary to develop a future astronauts' suit, a "smart-suit" using SMA and EAP, to mitigate the effects of weightlessness and motor inactivity on astronauts during the space missions. Therefore, the use case of STAMAS in space is restricted either to long manned missions (i.e. long stays at the ISS and future missions to Mars and similar) or for training and preparation on Earth. In addition, in most of the cases one single device will be used by several astronauts, so no high amounts of units per customer or mission are expected to be sold.
The following table lists the target groups that are potential buyers or stakeholders of STAMAS technology and thus, at which the exploitation activities will be addressed:

TARGET GROUP	REASON FOR DISSEMINATION EXPLOITATION	OFFERED BENEFITS
Policy and decision makers (government agencies engaged in activities related to outer space and space exploration)	Awareness Understanding	Suggestions for new legislation and barriers to development
Space research community	Involvement	Research topics. Take up of innovations and adaptations
European Space Industry	Involvement Action	Information and solutions that can adapt terrestrial products and services for space applications New ways of working and collaborating Efficiency and innovation
End users: worldwide space agencies	Awareness Action	Driving innovation for space missions through technical competence and a strong customer focus
Other stakeholders	Involvement Action	Information and solutions that can improve products and services. New ways of working and collaborating Efficiency and innovation
Media	Awareness	Further dissemination

Public sector actors such as Space Agencies and Policy Makers are considered as a priority, due to the applicability that STAMAS results may have in their programs and future actuations. Other interesting target of the exploitation activities will be the mass media, thanks to their potential to spread the results.

Non-space applications

SMA/EAP based actuation systems are quite extended in different terrestrial sectors, such as: automotive actuators (low-weight actuators for opening the trunk, adjusting the rear view mirror, etc.), robotics (such as robotic fingers and hands), aeronautics (morphing flaps and engine parts) or instrumental, stents and implants in medical field. All those sectors are also potential stakeholders, so the developed technologies will be also disseminated and exploited with them.

More specifically, within the STAMAS project two devices have been developed so far – hand and ankle – that can be commercialized as standalone products mainly for medical purposes:

physiotherapy/rehabilitation and support to elderly or people with reduced mobility are the most promising applications. Another one is the use of the technology for elite sport training; here we can find a twofold application: to get recovered from an injury in hands or ankles, or to train and strengthen those parts.

The following table shows some of the main players to be reached in order to tackle this potential market:

TARGET GROUP	REASON FOR DISSEMINATION EXPLOITATION	OFFERED BENEFITS
Governmental decision makers	Awareness Understanding	Approval of the devices for medical use
Hospitals, specialized clinics and rehabilitation centers	Awareness Understanding	New devices for more effective treatment
Nursing homes	Awareness Understanding	Technology to ease the life of the elderly
Sport centers and sport clubs	Awareness Understanding	New training and injuries recovering systems
Medical laboratories	Involvement	New potential products to be commercialized

The fact of involving specialized medical companies as commercial partners is mainly due to the complex and costly process required to validate a new technology for medical human applications. Furthermore, a strategic commercial partner will certainly ease accessing hospitals, clinics, distributors and end users.

In the industrial sector, SMA actuators could, for instance, be used as valve actuators. Another field is augmented reality where force feedback solutions with miniaturized actuators are required. The actuators could also be used for training or supportive systems in health care.

For controlling these systems knowing the sensor signals are mandatory. With the help of Sensor Module, signals of various sensors can be read and digitalized locally and sent to the control. The system is less sensitive and can be used in areas with high electric magnetic field disturbance. (i.e. plant engineering and construction). Another advantage is the reduction of harness due to a bus system leaving space for other possibilities.

Socioeconomic impact of the project

The entire foreground involved in the execution of this project is in line with the premises and objectives detailed in the European 2020 Strategy and in the last published European Space Policy “Towards a Space Strategy for the European Union that Benefits its Citizens”. According to these objectives, it is crucial to build a competitive European Community and contribute to the smart, sustainable and inclusive growth of Europe, taking the premise of knowledge and innovation as a starting point; STAMAS perfectly fits in this target. One of the essential initiatives included within these strategic objectives for European Community is to develop an effective space policy to provide the tools to address some of the key global challenges. Hence, the

STAMAS project is expected to directly or indirectly provide part of the necessary technology to improve space initiatives and innovations and place Europe in a better competitive standing.
The European Space Policy basically considers a few priority actions conceived for giving response to three type of needs: social (combating climate change, civil security, humanitarian and development aid, transport and information, etc.), economic (generating space knowledge and products, promoting innovation, competitiveness, growth and job creation), strategic (cementing the EU's position as a major player on the international stage and contributing to the Union's economic and political independence).
According to this Policy, the improvement of the European Space Industry Competitiveness will significantly contribute to the overall European Competitiveness. Space is a key sector for supplying independence to the economy in Europe. A plausible deficiency of this sector is the low concentration of SMEs. One of the main objectives of this sector is the steady, balanced development of the industrial base as a whole, including SMEs, greater competitiveness on the world stage, non-dependence for strategic subsectors such as launching, which require special attention, and the development of the market for space products and services. On the other hand, this Space Policy requires also a solid technological base and competitive space industry. This Policy also points out the need for developing key generic technologies. So that, according to this, the STAMAS project contributes to the fulfillment of the strategic objectives of the European Space Policy, providing disruptive and innovative research into the space domain and increasing the number of competitive SMEs operating in the space sector.
With regard to its contribution to the European Space Work Programme 2012, STAMAS primarily helps reaching goals set within the Theme 9 (Activity 9.3) as the development proposed in STAMAS contributes to translate terrestrial technologies into the space domain. Specifically, STAMAS project has adapted SMA and EAP actuators based technologies for its utilization in a smart space suit. As explained before, these actuation technologies are commonly used in the last few years in numerous of industrial, non-industrial and medical applications.
The STAMAS project is also considered as high-impact research due to the very innovative character of the developments involved. Artificial muscles have never been considered for its utilization in space environment and consequently, several technical risks are associated, however, the background expertise and commitment of the partners involved has contributed to the success of the project.
Additionally, the targets of the STAMAS project are in line with the Europe 2020 Strategy. This policy puts forward three main priorities: an economy based on knowledge and innovation; promotion of an efficient, greener and more competitive economy; and fostering a high-employment economy. Among these general targets, special attention is paid to strengthen knowledge and innovation. Currently, R&D spending in Europe is below 2%, compared to 2.6% in the US and 3.4% in Japan, mainly as a result of lower levels of private investment. The fostering of private investment in R&D is essential to cover this gap and make Europe a more competitive area. Under this target, numerous initiatives have been proposed in the Europe 2020 Strategy.
On the other hand, building a sustainable and competitive economy through developing new processes and technologies, including green technologies, are key actions that contribute to the improvement of the competitiveness of Europe. Under this general target, various initiatives have also been proposed, standing out in the frame of this project "the development of an effective space policy to provide the tools to address some of the key global challenges".
STAMAS indirectly contributes to the achievement of objectives within the 2020 Strategy. It mainly helps increasing the percentage of private investment in R&D, especially by SMEs with the participation of ARQUIMEA and SENSODRIVE. Furthermore, STAMAS is a challenging project studying the utilization of efficient and innovative technologies in the space domain. Therefore, STAMAS project provides technological tools for improving European space competitiveness as it is claimed in the Europe 2020 Strategy.
So that, STAMAS project is part of the private investment on R&D coming from SMEs that will partially mitigate some fundamental weaknesses of the actual European economy. STAMAS project gives evidence of the new business conscience implanted in the SMEs business structure focused in increasing R&D and innovation investment as an effective measure for fighting actual crisis.
Finally, STAMAS project has also contributed to the generation of high-skilled personnel across scientific and technical disciplines that will contribute to the aerospace field. The personnel employed on this project has

received from their respective employers and the rest of consortium member's world-class technological training that enable them to compete on an international stage when the project reaches its conclusion. Therefore, the European Union has gained a highly skill and well-trained workforce of personnel specialized in aerospace, microelectronics, systems engineering, automation, etc. An increase in employment in related areas is expected if project achieve successfully the objectives that have been established.
The STAMAS consortium considers this project as an important step necessary to bring SMA and EAP based actuation technologies into the space market. The nature and main features of this type of technology makes these actuators appropriate for space applications.
After the project, partners are expected to continue working on further fundamental knowledge and optimization of artificial muscles to create a more feasible, high performance and more durable technology with more applicability in the space domain. The industry partners are large and well established companies with the required capacity to drive this towards full commercialization, while R&D partners will continue the more basic and fundamental research.

Socioeconomic impact: terrestrial applications

Out of space, the terrestrial applications identified for STAMAS foreground will mainly have a positive socioeconomic impact in the healthcare and wellbeing areas. The use of SMA- and EAP-based artificial muscles in physiotherapy, prosthetics, injuries recovering and assistance to impaired people allows the implementation of new treatments and solutions that will improve the currently available technics, in terms of performance and recovery time. This will not only have a significant social impact in the life quality of the users, but also economic, thanks to the expected cost reduction due to shorter-time treatments and the use of more efficient technologies.
Regular training with the STAMAS suit will improve the astronaut's health condition in orbit by reducing (or avoiding) amyotrophia and bone antrophy. On earth, the results of the STAMAS-project can be used to support elderly and impaired people by reducing bone abrasion and avoiding injuries. In medical institutes training capabilities for people who are in recovery after a stroke might be improved using the results of the STAMAS-project.
Furthermore terrestrial exo-skeletons enable people to take part on life in an active way, while reducing stress in people's occupational activities so that they are able to stay longer in their profession and gain a high recreational value.
On the other hand, the wide expertise acquired in STAMAS with regards to the control of the SMA materials in force and position also supposes a clear breakthrough that will help boosting the use of this technology in general for terrestrial applications to replace less effective technologies. New configurations of SMA based devices will be possible. The main advantages of these materials (memory effect and super elasticity) can be better exploited, not only for medical, but also for general applications, such as industrial, automotive or avionics. Altogether represents a clear economic impact.

CONTACT DETAILS

Public project webpage:
www.stamas.eu

Contact details:

ARQUIMEA (Project Coordinator)
Mr. Marcelo Collado**:** mcollado@arquimea.com

DLR (Deutsches Zentrum Für Luft Und Raumfahrte
Mr. Thomas Hulin: Thomas.Hulin@dlr.de

ETH (Eidegenössissche Technische Hochschule Zürich)
Mr. Robert Riener: robert.riener@hest.ethz.ch

UNIPI (University Of Pisa)
Dr. Federico Carpi: f.carpi@qmul.ac.uk

SD (SENSODRIVE GmbH)
Mr. Norbert Sporer: norbert.sporer@sensodrive.de

UC3M (Universidad Carlos III De Madrid)
Dr. Luis Moreno: moreno@ing.uc3m.es

USE AND DISSEMINATION OF FOREGROUND

Section A (Public)

This section should describe the dissemination measures, including any scientific publications relating to foreground. ***Its content will be made available in the public domain*** *thus demonstrating the added-value and positive impact of the project on the European Union.*

Knowledge distribution plays an important role not only facilitating the development of other projects, but also exploiting the business strategy. The present document has the purpose of presenting and explaining the planned dissemination activities and publication of the STAMAS project results after the project end.
This document is divided into five main parts describing the entire dissemination strategy according to the project results: chapter 2 focuses on the planned scientific publications after the project end, which are based on the studies performed and results obtained during the project. Chapter 3 focuses on planned patents after the project, related to different fields of the Project. This chapter includes the outline of these patents. Chapter 4 focuses on future planned projects and funding opportunities based on the STAMAS project results. Finally, chapter 5 focuses on organization or participation in seminars, talks, workshops, studies within STAMAS partners, as well as future media and online activities for the STAMAS project.

Planned Scientific Publications

The planned publications based on the obtained results during the project are summarized below. They are divided into three categories: journal publications, conference publications, and theses.

Planned Journal Publications

Partner	Paper title	Authors	Journal	Field	Submission Date (Expected)
ETH	Effects of physical exercises on cardiovascular parameters during head-down tilt.	Cristiano Alessandro , Amirehsan Sarabadani Tafreshi , Robert Riener	To be decided.	SpacePhysiology	February, 2016
ARQUIMEA	Ankle Lateral Actuating System.	Cayetano Rivera, Marcelo Collado, Naiara Escudero, Fernando Martín, Álvaro Villoslada, Luis Moreno	Sensors & Actuators A: Physical	Multidisciplinary (Physics, Materials and Processing)	June, 2016
	Smart Elastic Bands System	Cayetano Rivera, Marcelo Collado, Naiara Escudero, Fernando Martín, Álvaro Villoslada, Luis Moreno	Smart Materials & Structures	Materials	June, 2016
	Leg	ARQUIMEA,	The	Aerospace	January,

	Exoskeleton for astronauts excercising	DLR, ETH SENSODRIVE, UNIPI, UC3M	International Journal on Aerospace Sciences		2017
UNIPI	Dynamic limb compression bandage made of electroactive elastomers as muscle-like actuators	Luigi Calabrese, Gabriele Frediani, Massimiliano Gei, Danilo De Rossi, Federico Carpi	Medical Engineering & Physics	Biomedical eng. & physics	Jan 2016
	Multilayer bandage made of electroactive elastomers as muscle-like actuators: design and optimization	Luigi Calabrese, Gabriele Frediani, Massimiliano Gei, Danilo De Rossi, Federico Carpi	Smart Materials and Structures	Materials	Feb 2016
UC3M	Hand Exo-Muscular System	Fernando Martín, Álvaro Villoslada, Luis Moreno, Cayetano Rivera, Marcelo Collado, Naiara Escudero,	Sensors & Actuators A: Physical	Multidisciplinary (Physics, Materials and Processing)	June, 2016
	Hand Exoskeleton for astronauts manipulation tasks	ARQUIMEA, DLR, ETH SENSODRIVE, UNIPI, UC3M	The Journal of the Astronautical Sciences	Aerospace	January, 2017
DLR	On Optimal Control for Haptic Rendering	Thomas Hulin	IEEE Transactions on Control Systems Technology	Control	30.06.2016

Planned Conference Publications

Partner	Paper title	Authors	Conference	Field	Country (year)

ETH	Increasing leg blood volume during head-down tilt by performing physical exercises, a preliminary study.	Cristiano Alessandro , Amirehsan Sarabadani Tafreshi , Robert Riener	the 6th IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob 2016)	Medical Robotics	Singapore (2016)
ARQUIMEA	Testing of superelastic bands for actuating system	Cayetano Rivera, Marcelo Collado, Fernando Martín, Luis Moreno	Shape Memory and Superelastic Technologies (SMST)	Materials	2017
	Leg exoskeleton for rehabilitation	Cayetano Rivera, Marcelo Collado, Álvaro Villoslada, Fernando Martín	International Conference on Rehabilitation Robotics	Rehabilitation, Robotics	2017
UNIPI	Design and optimization of EAP-based multilayer bandages	Luigi Calabrese, Gabriele Frediani, Massimiliano Gei, Danilo De Rossi, Federico Carpi	EuroEAP 2016	Electromechanically Active Polymer (EAP) transducers & artificial muscles	14-15 June 2016
UC3M	Testing of SMA-based actuating system for hand exoskeleton	Álvaro Villoslada, Fernando Martín, Cayetano Rivera, Marcelo Collado,	IEEE International Conference on Robotics and Automation	Robotics	2016

DLR	A Rule of Thumb for the Influence of Delay on the Optimal Performance of Haptic Devices	Thomas Hulin	International Conference on Intelligent Robots and Systems (IROS 2016)	Robotics	Korea, 2016

Planned Theses

Partner	Thesis type	Thesis title	Authors	Field	University	Submission Date (Expected)
UC3M	PhD	Design, modeling and control of SMA actuators for actuated space suit gloves	Álvaro Villoslada	Robotics	University Carlos III of Madrid	June, 2016
DLR	PhD	Control of Hybrid Systems Affected by Time Delay with Application in Haptic Rendering	Thomas Hulin	Haptics, Robotics	Leibniz Universität Hannover, Germany	31.03.2016

Planned Patents

No patents have been filed yet.

Future Projects and Funding Opportunities

There are no future projects or funding opportunities planned yet.

Other activities

Common workshops, seminars, talks and demos (as part of larger conferences)

Partner	Workshop or demo title	Collaborating partners	Conference or venue	Field	Expected date
ETH	Workshop on Wearable Body Sensor Networks for Motor and Cognitive Rehabilitation	None	The 2014 International Conference on Wearable and Implantable Body Sensor Networks - BSN 2014	Robotics, Rehabilitation	June 19, 2014 - Zurich, Switzerland

	Workshop on Motivational Patient-Tailored Therapy with Rehabilitation Robots	None	The 2015 IEEE/RAS-EMBS International Conference on Rehabilitation Robotics	Robotics, Rehabilitation	August 11, 2015 - Singapore
ARQUIMEA	Meetings to summarize results to possible users (astronauts, medical corps,…)	All	To be defined	Aerospace, Robotics, Rehabilitation	2016
UC3M	Robocity2030 Workshop	ARQUIMEA	Carlos III University Hall	Robotics	2016
DLR	DLR Booth at the Automatica	None	Automatica 2016 (Trade Fair)	Robotics	21.-24.06.2015
	DLR Open Day	None	DLR Oberpfaffenhofen	Robotics, Space, Aeronautics	09.10.2015

SENSODRIVE:
To get public attention for this new system and developed products, will be presented to our existing customers. Furthermore its application in customers' products will be discussed.

Organization of summer/winter schools
ETH is organizing a winter school on rehabilitation robotics (covering topics such as exoskeletons and the research work from STAMAS project) at Daegu Gyeongbuk Institute of Science and Technology (DGIST), Daegu, Korea, Jan 4-9, 2016.

Planned studies and experiments within continued collaborations

Partner	Study title	Collaborating partners	Field	Goal of the study	Expected date
ARQUIMEA	Possible applications of SMA exoskeletons for rehabilitation	UC3M	Rehabilitation, Robotics	New methods and devices for rehabilitation	2016-2018
UC3M	Possible applications of SMA exoskeletons for rehabilitation	ARQUIMEA	Rehabilitation, Robotics	New methods and devices for rehabilitation	2016-2018

Online activities (STAMAS website, Twitter, Facebook etc)

Project derives from STAMAS Project are promoted on the SENSODRIVE, ARQUIMEA, UC3M homepages. Example: http://roboticslab.uc3m.es/roboticslab/project/stamas

Furthermore, the STAMAS website (http://www.stamas.eu) will be updated with the final project achievements.

Future media activities

Partners will collaborate publish a final newsletter and a publishable summary about the STAMAS project activities and achievements.

This section includes two templates

- Template A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.
- Template A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

These tables are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project. Updates are possible at any time.

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	*Effects of physical exercises on cardiovascular parameters during head-down tilt*	*Robert Riener*	-	-	-	-	*2016*	-	-	-
2	*Ankle Lateral Actuating System.*	*Marcelo Collado*	-	-	-	-	*2016*	-	-	-
3	*Smart Elastic Bands System*	*Marcelo Collado*	-	-	-	-	*2016*	-	-	-
4	*Leg Exoskeleton for astronauts excercising*	*Marcelo Collado*	-	-	-	-	*2017*	-	-	-
5	*Dynamic limb compression bandage made of electroactive elastomers as muscle-like*	*Federico Carpi*	-	-	-	-	*2016*	-	-	-

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

	actuators									
6	*Multilayer bandage made of electroactive elastomers as muscle-like actuators: design and optimization*	*Federico Carpi*	-	-	-	-	*2016*	-	-	-
7	*Hand Exo-Muscular System*	*Luis Moreno,*	-	-	-	-	*2017*	-	-	-
8	*Hand Exoskeleton for astronauts manipulation tasks*	*Luis Moreno,*	-	-	-	-	*2016*	-	-	-
9	*On Optimal Control for Haptic Rendering*	*Thomas Hulin*	-	-	-	-		-	-	-

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities[4]	Main leader	Title	Date/Period	Place	Type of audience[5]	Size of audience	Countries addressed
1	*Conference*	*ETH*	*Increasing leg blood volume during head-down tilt by performing physical exercises, a preliminary study.*	*2016*	*the 6th IEEE RAS/EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob 2016)*	*Specialised*	-	*Singapore*
2	*Conference*	*ARQUIMEA*	*Testing of*	*2017*	*Shape Memory*	*Specialised*	-	-

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

			superelastic bands for actuating system		and Superelastic Technologies (SMST)			
3	Conference	ARQUIMEA	Leg exoskeleton for rehabilitation	2017	International Conference on Rehabilitation Robotics	Specialised	-	-
4	Conference	UNIPI	Design and optimization of EAP-based multilayer bandages	2016	EuroEAP 2016	Specialised		-
5	Conference	UC3M	Testing of SMA-based actuating system for hand exoskeleton	2016	IEEE International Conference on Robotics and Automation	Specialised	-	-
6	Conference	DLR	A Rule of Thumb for the Influence of Delay on the Optimal Performance of Haptic Devices	2016	International Conference on Intelligent Robots and Systems (IROS 2016)	Specialised	-	Korea
9	Meeting	ARQUIMEA	Meetings to summarize results to possible users (astronauts, medical corps,…)	2016	TBD	Specialised		
10	Workshop	UC3M	Robocity2030 Workshop	2016	Carlos III University Hall	Specialised		
13	PhD	UC3M	Design, modeling and control of SMA actuators for actuated space suit gloves	2016	University Carlos III of Madrid	Specialised		
14	PhD	DLR	Control of Hybrid Systems Affected by Time Delay with Application in Haptic Rendering	2016	Leibniz Universität Hannover, Germany	Specialised		

Section B (Confidential or public: confidential information to be marked clearly)

Exploitation strategy

In terms of exploitation strategy, the consortium partners have established two different approaches: one is regarding the shared foreground and the other is based on the resulting products and technologies belonging to every single partner. Discussion in this section is focused on the partners' common foreground.
Concerning the individual IPRs, each partner will define its own exploitation strategy, which approach is described in the Section 6 of this document. Research institutions will go in depth with the academic and scientific part, and will search for possibilities of licensing their resulting products and technologies. On the other hand, private companies choose to use the resulting IPR for improving and increasing their products and services portfolio.
The STAMAS exploitation strategy identifies the following priorities:

- To disseminate and expand project results within the aerospace industry and stakeholders across Europe as well as through different media and sources. Most of project results will be public in order to expand the base of knowledge. This would be achieved thanks to the previous elaborated project dissemination plan.
- To be aware of external advances and research performed by other projects or resources. In terms of risk management this will increase a fast reaction in case of objectives changing, redefinition, etc. Thus, it will be easier to identify opportunities for promotion and future projects opportunities.
- To promote networking activities with relevant partners of the aerospace sector. Special attention will be paid to participants SMEs networking activities.

STAMAS exploitation policy is based on three main points: market context, project results and partners' priorities and interests.

Market context

The market context helps consortium finding new business opportunities for a suitable exploitation of the expected project results. It also places the project with respect to other similar initiatives and will help the project guiding towards a strong market position against potential competitors and substitutes. The analysis of the market context will evolve in the same way of the project results and will be focused on the identification of clear areas for exploitation.

Space applications

As stated before, the proposed technologies are highly disruptive compared to the current existing solutions for space applications and they also improve their performance in most of the cases. Therefore, it is expected the foreground to awaken a great interest between worldwide space agencies, which are the main market context of the biofeedback suit.
On the other hand, space qualification of SMA- and EAP- based products will improve the performance and consolidate the use of these technologies for currently existing space applications, such as hold-down and release mechanisms, pin pullers, linear and rotary actuators and couplings, and will foster its use for new ones, such as artificial muscles or smart valves.
STAMAS will mainly contribute to the space industry with a better knowledge of SMA/EAP control systems, SMA/EAP characterization and manufacturing, power consumption reduction and an overall improvement on the performance of the SMA/EAP based actuators. This will allow technology owners to increase its market share.
No other competitors have been identified working on SMA/EAP based biofeedback suits, while there is another reference company commercializing SMA-based space actuators: the American TiNi

Aerospace is manufacturer of innovation mechanisms using SMA technology. Its main products are pin pullers and hold-down and release mechanisms. The improvements in new actuators configuration, control and accuracy will widen the range of space applications to be addressed with these technologies.
SMAs and EAPs can potentially replace other technologies currently used in space, such as pyro-actuators, thermal knives or electrical motors.

Non-space applications

In terms of technology transfer to other sectors, as it has already been mentioned, although SMA/EAP are fairly mature technologies for terrestrial applications, the progresses achieved in the frame of STAMAS will improve their performance and will strengthen their use for medical, and rehabilitation issues: active implantable devices, rehabilitation equipment, assistance to disabled people, training, health monitoring systems and so on.
Despite of its maturity in healthcare, most of the current medical applications of the SMA consist of passive elements using the superelastic properties or self-heating in contact with the body in different shapes (dental wires, coronary stents, bone staples…). The use of the materials in active configuration opens a new frame of potential applications. The better control and accuracy achieved in STAMAS will allow the replacement of other technologies showing worst performance, such as complex pneumatic, electric or electronic systems used in active implants, and exoskeletons.

Project results and constraints

Project results and constraints are clearly meaningful for the exploitation of the project. The performance, capabilities and limitations of the technology indicate what can be achieved, and the innovation of the components provides the uniqueness which will give the project results potential in a commercial environment.
Although SMA and EAP are relatively mature technologies, its use for space applications is far from being intensive. Besides, considering how innovative and disruptive the proposed developments are, it is very difficult to precisely define at this time the final project results and constraints.
However, the main strength of the proposed biofeedback suit, compared with other currently existing substitutive technologies, is related to its design as an active system constantly operating and actuating on the human body as a function of the information received from integrated sensors. The integration of a set of sensors, the actuators and a precise control system will allow the suit to counteract the irregular behavior of the organism during the mission. The use of SMA and EAP technologies will allow an innovative suit design, more flexible than conventional solutions based on hydraulic or electromagnetic technologies, providing a better platform for the astronauts training and exercising during their daily life in orbit. Besides, the possibility of providing continuous countermeasures with the smart suit would reduce the necessity of specific exercising and improve the astronauts' productivity.
It is also challenging the integration (through SMA/EAP actuation technology) of innovative and active functionalities into a space suit. Currently, space suits incorporate exclusively passive functionalities for the improvement and protection of the astronaut's health. In this sense, the biofeedback suit will have the necessary autonomy to exert compressing or decompression on soft tissues. The magnitude of the exerted effort, its periodicity and its segmentation will be previously determined by the active suit according to the parameters and information provided by sensors.
The objectives of the STAMAS project answers to detected needs that have not been satisfied yet. Therefore, as far as the project achieves the expected results, it is easy to expect a great success during the commercial exploitation phase.

Partners' priorities and interests

Partner's priorities and interests must drive the exploitation strategy. Although STAMAS consortium bets on prioritizing a collaborative exploitation instead of immediate opportunities or individual

goals, any commercial decision will reflect each partner position. The long-term vision is as important as the short-term vision for guiding the project towards maximum value and impact creation.
Since STAMAS is an R&D project, the main priority of the consortium is to analyze the suitability and bring experience on the SMA and EAP based actuation technologies addressing terrestrial applications to research in new concepts of artificial muscles for biofeedback suits for astronauts, as an alternative to currently used technologies.
Concerning the future commercial exploitation, it is established as one of the specific objectives of the project to generate innovative, valuable and beneficial results for the consortium and for the participating SMEs in particular. Therefore, any commercial strategy with regard to the obtained common foreground (specifically, the future commercialization of the biofeedback suit for space applications) will prioritize the interests of both ARQUIMEA and SENSODRIVE companies.
Each partner's priorities and interests concerning its own foreground are specifically described in Section 6 of this document.

Exploitation and technology transfer per partner

Industrial Partners

ARQUIMEA

ARQUIMEA has been working since the very beginning of its activity with SMA materials and its utilization in actuation systems. In fact, the origin of the company ten years ago was the development of SMA actuators for artificial muscles in the frame of another R&D project. Therefore, SMA-based devices are considered as a critical issue in the business strategy of the company.
Most important expertise to be acquired by ARQUIMEA in the frame of STAMAS is related to the preparation process of the SMA wires and the rest of elements composing a SMA actuator for its use as artificial muscles and actuators' triggers, as well as more efficient and reliable SMA control systems. ARQUIMEA has gained experience in different control philosophies for SMA actuators, such as control in position, control in force or torque or more complex approaches. This knowledge will allow the company to implement a new family of innovative, highly-reliable SMA actuators for different applications in and out of space, so several sectors and stakeholders will benefit the project results:

- Space: artificial muscles, radiation tolerant actuators for payload applications…
- Medicine: artificial muscles, smart implants, rehabilitation devices, devices for supporting elderly and impaired people…
- Nuclear: radiation tolerant remote handling devices…

SPACE APPLICATIONS
ARQUIMEA is European leading company in the development and commercialization of SMA-based actuators and mechanisms for space applications. Apart from custom developments of rotary and linear actuators, the company has qualified up to TRL6 two product families of devices using SMA: pin puller actuators and hold-down and release mechanisms (HDRM). The expertise acquired in STAMAS will allow ARQUIMEA improving the performance of its products in a second generation of actuators which is currently under development. This will help consolidating ARQUIMEA's position in the European space sector and also expanding commercial operations worldwide. The fact of owning a fully European SMA material technology is a clear advantage in some markets out of Europe and USA, such as China, India and South America, due to the export restrictions that affect American suppliers of this type of technology.
Additionally, STAMAS opens new business opportunities in space. The main one is the one already described, the use of exoskeletons for astronauts' training; but also more accurate rotary actuators for deployment and hinge mechanisms in satellites (antennas, booms and solar panels' release) or custom specific mechanisms replacing electric motors for scientific missions with low-power and

critical mass requirements (rover explorers, sensing systems, etc.). Besides, the experience acquired during the project can be applied to space robotics applications, with novel solutions to certain exploration challenges in scientific challenges.
Regarding competitors and similar technologies, up to now there are few companies working with SMA triggered actuators for space applications and most of them are from United States. Therefore, after STAMAS, ARQUIMEA aims to achieve a leading position as the main SMA based actuators' supplier in the European space market. There are other technologies, such as servomotors or pyro-actuators, which could replace SMA in certain applications, but none of them improve the performance of SMA, especially in terms of weight and dimensions, radiation tolerance and reliability. Consequently, thanks to STAMAS, the consolidation of SMA technology for space and terrestrial applications will have a meaningful impact for the stakeholders.
All SMA based new devices, mechanisms and control systems for space applications obtained from the project and belonging to ARQUIMEA will be directly marketed by the company. Any new actuators and performances will be introduced and discussed with the company's current customers. Since ARQUIMEA already commercializes space mechanisms, the same sales channels will be used for STAMAS foreground. Therefore, no extra needs or costs are foreseen for the commercialization.

NON-SPACE

In case of technology transfer to other sectors the company will make deeper market researches and business plans in order to evaluate the possibility of facing these new markets on its own or searching for added value partners. Some potential applications have been already described in prior sections, mainly related to medical rehabilitation, support and assistance to elderly and impaired people, and elite sport training.
Societal changes and progressive ageing of the world population bring new challenges related to accessibility, adaptability, general wellbeing and safety for elder and impaired people. Everyday more efficient treatments tailored for each specific patient and pathology are required (case-by-case approach).
SMA materials are homologated for medical uses, but their application is almost reduced to passive devices. Devices resulting from STAMAS use SMAs as driving element (artificial muscles), thus requiring power consumption and an accurate electronics and control system in order to achieve good actuation performances. No companies using SMA materials to control and actuate wearable devices for healthcare applications have been identified so far. Several trends and techniques are being investigated to solve the problems here detected, but none of the approaches analyzed provides as efficient solutions as SMA in terms of flexibility and lightweight.
SMA-based exoskeletons offer a series of advantages compared to other technologies, such as electric motors, hydraulic or pneumatic mechanism. Some of them are listed below:

- SMA-based wearables show to be more reusable and easily adaptable from one user to another than current solutions.
- SMAs are lighter and allow simpler architectures than servomotors.
- SMA actuators can be flexible, reducing the rigid parts of the system and improving its wearability.

Only in US, musculoskeletal products market accounts for more than USD 22billion (USD 7 billion is orthopedic reconstructive devices and 1.5billion is sports medicine). Worldwide Rehabilitation Medical Supplies and Assistive Products Market (excl. wheelchairs & scooters) accounted for USD 5.2 billion in 2012. The wide range of applicability of the proposed products and their innovative nature make possible to expect a high market share. The technology resulting from STAMAS addresses specific niche applications which may account for up to USD 10 million turnover during the first 3 years of commercialization.
Using the resulting technology from STAMAS, other potential products for healthcare using SMA are:

- Extra-urethral implant for severe urinary incontinence.
- Orthopedic implants using artificial muscles based on SMA.
- SMA-based structures and furniture helping children and elder people make exercise.

- Data mining from SMA wearables' users. Data acquired might be suitable for: physiology, behavior, sports, hobbies, habits, sneakers, etc.
- Stents, catheters and guide wires made by SMA.

Besides, other markets could be addressed with solutions based on some of the principles applied in the development of STAMAS actuators, such as automotive, robotics, industrial or civil. A very interesting application could evolve from the superelastic elements developed in the project: the application of the capabilities of SMAs to damp mechanical oscillations.

IP PROTECTION

Any new technologies, products and services resulting from the project and susceptible to become an IP will be duly protected by ARQUIMEA through international patents or other legal means. ARQUIMEA already holds two national patents and a European one (US extension is ongoing) related to SMA actuators:

- L.E. Moreno, P.V. Placer, M. Téllez, N. Felip, "Dispositivo de obturación intrauretral controlado a distancia", Spanish Patent (201030293).
- L.E. Moreno, P.V. Placer, M. Téllez, N. Felip, "Dispositivo de obturación extrauretral controlado a distancia", Spanish Patent (201030292).
- R. Cabás, N. Nava, R. Mena, M. Collado, "Linear actuator device", European Patent (11382333.0).

SENSODRIVE

SENSODRIVE will gain knowledge on the application of SMA actuators in force/torque controlled systems. This knowledge will be incorporated into control systems in various fields. The combination of SMA actuators with existing control know-how enables SENSODRIVE to offer engineering services in a wide range of potential applications and possibly enter new markets. Based on these sensor-actuator-units new "intelligent drives" for customer specific applications may be designed.

Apart from space agencies, terrestrial industry users will benefit from this technology. In the industrial sector, SMA actuators could, for instance, be used as valve actuators. Another field is augmented reality where force feedback solutions with miniaturized actuators are required. The actuators could also be used for training or supportive systems in health care.

With regard to the competitors of this technology, electrical, pneumatic and hydraulic actuators and force, torque and position sensors are readily available on the market. The use of SMA actuators within force/torque-controlled drive units is new and requires integrated and customized sensors. As far as actuators are concerned, EAPs and pneumatic muscles are available for research institutes, whereas industrial applications of these technologies are not known. Highly integrated force/torque controlled systems for industrial applications are not known to be readily available.

In terms of impact of the technology to be developed by SENSODRIVE in the frame of the STAMAS project, regular training with the STAMAS suit will improve the astronaut's health condition in orbit by reducing (or avoiding) amyotrophia and bone atrophy. On Earth, the results of the STAMAS project can be used to support elderly and impaired people by reducing bone abrasion and avoiding injuries. In medical institutes training capabilities for people who are in recovery after a stroke might be improved using the results of the STAMAS project. To get public attention for this new system, exhibitions and conferences will be attended. Furthermore this new system will be presented to our existing customers. Its application in the customers' products will be discussed. The project and its results will be promoted on the STAMAS and SENSODRIVE homepages.

To get public attention for this new system, exhibitions and conferences will be attended. Furthermore this new system will be presented to SENSODRIVE's existing customers. Its application in the customers products will be discussed. The project and its results will be promoted on the STAMAS and SENSODRIVE homepages.

Regarding IPR, any new products or applications resulting from the technologies acquired in the frame of the project will be submitted for patent protection. Torque sensors that are utilized in the project are already protected by patents held by SENSODRIVE. If new technologies arise, applications for patents will be submitted.

Research Institutions

DLR

Main tasks of DLR in the STAMAS project are related to the development of a high-level controller. The efficiency of the envisaged project demonstrators for the hand and the leg prototypes highly depends on a sophisticated control algorithm that intelligently controls the actuator signals. This controller will not only take into account the condition of the astronaut, but also react on desired movements and their intensity.

The high-level controller will rely on data of medical studies and on practical experience in order to sensibly adjust interaction forces with the human operator. It will have expectedly the following capabilities:

- Estimation of human limb configuration
- Compliance control in Cartesian and in joint coordinates
- Auto-adjustment to human fitness and physiological condition
- Interfacing to medial data-base containing processed data of medical studies

DLR will derive knowledge for controlling robotic systems from this second feature. Specifically, for controlling robotics arms that physically interact with human operators. The potential applications are not limited to the space domain, but also comprise rehabilitation of human limbs and optimal training of professional sportsmen.

The sophisticated high level control envisaged in the STAMAS project is promising for spatial and terrestrial applications. Potential users of this technology may be found inside and outside of the STAMAS consortium:

1. **Robotic Industry and Research**

A key technology of the DLR Institute of Robotics and Mechatronics are robots with integrated torque-sensors that aim at the delicate field of direct human-robot interaction. One exemplary robotic system, the DLR bimanual haptic device, provides interaction forces to both human hands. The fields of application of this device comprise robotic tele-manipulation, haptic interaction in virtual environments, and multimodal skill transfer and training. The high-level control technology of the STAMAS project will highly contribute to open a new field of application for this robotic system, namely rehabilitation.

2. **Rehabilitation and Medical Companies**

One vastly increasing research topic of medical companies and institutes is rehabilitation of human limbs. For example the Sensory-Motor Systems Lab of the ETH Zurich has set up two demonstrator platforms for gait and arm rehabilitation, e.g. the Lokomat and the ARMin. These two demonstrators would benefit from the STAMAS high-level control. This technology is expected to improve efficiency of the demonstrator platforms and thus reduce exercise durations.

3. **Space Agencies – Field of Application: Space**

A hot development and research topic for the largest space agencies (NASA, Roskosmos, ESA) is supporting astronauts for extra-vehicular activities (EVAs). Specifically, a supporting mechanism for the glove of a space suit would be of high value for the agencies. The control algorithms developed in the STAMAS project will be well suited to control such supporting mechanism. The benefits for the astronauts would not only be a reduction of physical exertion and thus higher comfort, but also a highly improved perception and tactile feeling of the manipulated objects.

The proposed high-level control technology will have diverse impact in the society, depending on the application. In the space domain the impact clearly aims at improving living and health conditions for the astronauts. The terrestrial applications are of high relevance especially to the ageing societies, in which there is an increasing need for reliable and efficient rehabilitation systems. Those sophisticated systems will help people to quickly recover their unrestricted mobility, increase their quality of life and enrich the research activities in this domain.

The novel findings and improvements of the high-level control approach are planned to be exploited by licensing to industrial partners of the DLR and also to other research projects within the DLR. DLR will benefit with respect to this activity by its long time and intensive contacts to robotic industry and national as well as international research institutions. Upon this, the DLR is a member of the German Helmholtz Association comprising 18 research centers, and will thus employ this wide scientific network.

With regard to potential competitors, there are numerous players in the field of robot control worldwide. Nevertheless, with many years of experience in the field of robot control, specifically for direct human-machine interaction, DLR has a great advantage over potential competitors.

The high-level control approaches of the DLR are protected by numerous international key patents. The developed technology in the STAMAS project will be applied for international patents and moreover published in international conferences and journals.

ETH

Together with SENSODRIVE, ETH will participate in the design and development of the sensing subsystem. Specifically, ETH will implement a set of closed-loop controllers that are capable of controlling heart rate, blood pressure and blood volume distribution in the astronauts' body. The following sensors are expected to be included in the suit:

- Two channels ECG
- Blood pressure meter based on the oscillometric method
- Volume sensors for big groups of muscles (i.e. legs, chest, abdomen)

No new sensors will be developed for this project. Sensors already tested and regularly used for the characterization of body in microgravity conditions will be used. Currently these sensors are composed of two elements: a small and flat transducer, which can be easily integrated in future suit, and the large electronics. In order to reduce the last mentioned ETH, helped by ARQUIMEA´s experience in microelectronics design for space, will address the possibility to integrate the overall sensor acquisition electronics in a single chip, enabling smooth integration into the biofeedback suit, as well as lower consumption in the overall biofeedback sensor subsystem.

As described before, sensing systems resulting from the biofeedback suit are not only supposed to be used by astronauts; this technology will be also transferred to other applications, such as rehabilitation clinics, fitness centers, entertainment and simulation, etc. The expected foreground could have a big impact in some of these areas. In the case of applications for rehabilitation, the sensing system will support patients with heart diseases (heart insufficiency), musculoskeletal diseases (myelitis, arthritis, and osteoporosis) and neurological diseases (hemiparesis after stroke, para/tetraparesis after incomplete spinal cord injury, paralysis/paresis after head traumatic injuries, children with cerebral palsy, multiple sclerosis, Parkinson disease, etc.).

Concerning the protection and exploitation of the foreground, ETH will identify the resulting project IPs (software, hardware, know-how, drawings, algorithms, patents), will apply for the corresponding patents before any dissemination, will make license agreements with potentially interested companies and/or will analyze the possibility of creating a new spin-off company for project results direct exploitation.

UNIPI

The industrialization of any possible product resulting from the project activities will be considered during the next years, as the prototypes demonstrated so far will continue to be developed in order to address the remaining technical challenges (especially the reduction of the driving voltages via the adoption of stacks of much thinner membranes). Such industrialization will require the selection of suitable potential partners with appropriate expertise and capabilities for the manufacturing and engineering of elastomeric devices. The group at UNIPI already cooperates with major multinational companies that might serve as the first interlocutors for any industrialization plan. Marketing will come as a natural consequence of the development of a product.

The UNIPI leads the development of an innovative EAP vibrating device, which is expected to lead to potentially exploitable products and technologies not only suitable for space suits but also for different applications. In particular, it is envisaged that the new configuration for dielectric elastomer artificial muscles to be designed and developed might find applications in the following specific areas:

i. Massage devices for bed-rest patients
   Development of soft, conformable, light-in-weight, low-power consuming and noise and heat-free wearable systems aimed at providing bed-rest patients with vibratory actions distributed over different body portions. This might help to improve microcirculation.

ii. Haptic devices for man-machine interfaces (e.g. for virtual reality systems)
   Development of soft, conformable, light-in-weight, low-power consuming and noise and heat free wearable systems aimed at providing man-machine interfaces with actuating functions, either at low or at high frequencies. Virtual reality systems are just an example of possible systems that might benefit of these new technologies.

iii. Safety systems for drivers or other operators (e.g. use of vibrations as an alarm integrated within wearable systems)
   Development of soft, conformable, light-in-weight, low-power consuming, and noise and heat free wearable systems aimed at allowing different kinds of operators to perform tasks more safely. A specific example is represented by drivers of vehicles. Here, the driver's suit/garment or gloves might be fitted with conformable alarm systems alerting the driver with vibrations in case of need or danger (e.g. warning systems in case of incipient sleeping detected by external sensors).

The state of the art of vibrating systems is heavily dominated by electromagnetic and piezoelectric motors. However, integrations of those technologies into suits/garments are still a mostly unsolved problem today, mostly because of the stiffness of the required materials (namely metals and ceramics, respectively). Overcoming this drawback requires a paradigmatic change with new technology based on soft and stretchable materials.
The dielectric elastomer actuators that will be developed in this project (as the most promising EAP technology) are expected to represent a major advance in this sense with respect to the state of the art. The examples of products mentioned above are clear example. Realistic evaluations in terms of perspectives of economic impact could be done at a later stage of the project, when the development of the prototypes will have reached an adequate stage.
With regard to IPR, any new design will be considered for possible intellectual property protection via patents applications that might be filed either at national or international level. The group at UNIPI already holds the following national patents that form a solid background for the specific activities performed in this project:

- F. Carpi, G. Frediani, D. De Rossi, "Sistema di ausilio per ipo- o non-vedenti, con funzione di display dinamico braille, tattile o aptico, o di stimolatore elettromeccanico tattile o cutaneo, basato su attuatori a polimeri elettroattivi ad accoppiamento idrostatico", Italian Patent, PI/2009/A/000148, 2009.
- F. Carpi, G. Frediani, "Attuatori, sensori e generatori a polimeri elettroattivi ad accoppiamento idrostatico", Italian Patent, PI/2008/A/000091, 2008.

Finally, regarding exploitation and technology transfer strategy, any resulting product will be industrialized by selecting the most suitable potential partners with appropriate expertise and capabilities for the manufacturing and engineering of elastomeric devices. Marketing will come as a natural consequence of the development of a product.

UC3M

The UC3M research group will study the implementation of an SMA-based exoskeleton for astronauts. Specifically, UC3M is responsible for the design and integration of the two technology demonstrators to be implemented:

- **Hand**: the main objective is to develop a training or assistance device for the astronauts to prepare for their work in Extra Vehicular Activities (EVA). Therefore, the SMA-based hand will reduce the force needed in handling tasks in EVA. This product can be also useful for industrial workers because fatigue and injuries could be reduced.
- **Leg**: the main purpose will be to perform countermeasure exercises inside the space station (rehabilitation). A SMA-based device that opposes resistance to joint movements will be developed. This will reduce the effects of microgravity on human body functions (bone loss, increase of body length, muscle atrophy, change of blood circulation and distribution, heart atrophy).

An associated technology/product that should also be mentioned is the knowledge and the experience that will be acquired with this type of actuators, easily exported when developing similar products (for rehabilitation and training) applied to different fields.
As the main objective of this project is to analyze the development of a smart space suit, the most important potential users will be the astronauts of the ESA and other worldwide space agencies. Moreover, the space suit will incorporate two different functionalities that make it possible to find potential users in other fields. First, the leg will be helpful for rehabilitation purposes. People with disabilities such as hemiparesis or hemiplegia can be included as potential users of this technology. Second, the hand is a training device that reduces the force needed in handling tasks. This fact can be useful for industrial workers, reducing fatigue and injuries.
Concerning the competitors and substitute products, in the specific case of hands exoskeleton, there are other organizations, mainly universities, working on technologies for similar applications:

a) Hands for rehabilitation (to oppose resistance to joint movement):

- POWERED HAND EXOSKELETON II (T.U. Berlin): multiples degrees of freedom, actuated by electric motors. Glove attached that is worn by a person.
- HEXXOR (Robotic Exoskeleton project of the Catholic University of America): people with disabling injuries such as hemiparesis or hemiplegia have great difficulties when controlling the movement of the wrist and hands. This project covers design tests, and clinical development of a robotic exoskeleton for hand therapies.

b) Assistance (training):

- K-GLOVE (NASA & GM): Robonaut2 is a humanoid robot (currently in the ISS) with an anthropomorphic robotic hand. A new device called K_GLOVE has been developed to reduce injuries and fatigue for the user (GM workers).
- Exoskeleton for astronauts (Vanderbilt University): In 1997, a group Vanderbilt U. wrote an article about the use of an anthropomorphic hand exoskeleton to reduce fatigue in your hand during extravehicular activities.

c) Others: PROJECT HAND (Carnegie Mellon University, controlled by EMG, electromyogram), HAND ACTUATED Exoskeleton (IIT HandLab), PNEUGLOVE (Hand Rehabilitation Laboratory), GLOVE SENSOR I & II (Tokyo University)

With regard to SMA, these actuation technologies have been commonly used in the last few years in numerous industrial, non-industrial and medical applications: automotive actuators (for opening the trunk, adjusting the rear view mirror, etc.), robotics (such as robotic fingers and hands), aeronautics (morphing flaps) or instrumental and implants in medical field. In aviation industry Boeing, General Electric Aircraft Engines, Goodrich Corporation, NASA, and All Nippon Airways developed the Variable Geometry Chevron that reduces aircraft's engine noise.

The technological advances expected to be obtained with the different products developed in the project will have a socioeconomic impact in different fields, as can be deduced from the stated potential users and applications. Particular implications will be also discovered with the development of the project.

UC3M plans to exploit its foreground according to the priorities of the Space Work Programme, which are: promoting relevant research among SMEs; supporting international cooperation; establishing effective dissemination actions; fulfilling cross-thematic approaches; and finally improving the understanding of space challenges and opportunities in Europe.