# THE ADAH PROJECT: AN ASTRONAUT DEXTEROUS ARTIFICIAL HAND TO RESTORE THE MANIPULATION ABILITIES OF THE ASTRONAUT

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## INTRODUCTION

Pressurised gloves worn by astronauts during Extra Vehicular Activities (EVA) affect hand manipulation ability. This project is aimed at providing the astronaut with a system intended to enhance his/her limited dexterity in performing manipulation tasks.
The ADAH (Astrnonaut Dexterous Artificial Hand) will be controlled by the astronaut with an appropriate HMI (Human/Machine Interface) able to transmit motor commands to the hand, to receive sensory signals, and to stimulate astronaut fingers for providing tactile and force feedback
In order to design an artificial hand able to fulfill the requirements, the typical EVA ad the related tools to be manipulated during EVA will be critically analysed. The kinematic structure and the actuator and sensor systems will be designed according to the results of this analysis. The ADAH system will be designed following a biomechatronic approach with the aim of obtaining an intelligent hand able to adapt to different object shapes and weighs.
The extra-vehicular safety is improved by the usage of this device. In fact higher dexterity allows to reduce tasks execution time and to increase the quality of the completed tasks.

## APPLICATION SCENARIO

An EVA occurs when a crewmember leaves the protective environment of a spacecraft's pressurised cabin and moves out into the vacuum of space wearing a space suit.
With reference to the most recent manned space systems (Space Shuttle, International Space Station, Russian MIR Space Station), the EVA plays a basic role in the following categories of tasks:

1) tasks related to unmanned spacecraft's (typical of the Space Shuttle missions):
   - deployment;
   - repair / maintenance / upgrading;
   - retrieval.
2) tasks related to the space station:
   - servicing of structures and subsystems of the station;
   - servicing of payloads.

EVA tasks related to spacecraft / payload servicing can require the astronaut to perform fine manipulation operations. Examples of such tasks are:

- exchange of containers for fluids (e.g. Helium bottles);
- handling of thermal blankets;
- exchange of detectors / sensors;
- fluid connections;
- un-damping of tether system;
- wire-cutting;
- de-jamming of mechanisms;
- cleaning of optical components.

Pressurised gloves of the space suit limit hand manipulation ability, basically for the following reasons: large fingers size, reduced fingers mobility and reduced tactile feedback.
Hence this project aims to investigate the feasibility of an Astronaut Dexterous Artificial Hand (ADAH) capable to restore the manipulation abilities of the astronaut.

## SYSTEM DESCRIPTION

The objective of the project is to analyse an hand-interface system able to fulfill the EVA tasks. The hand design methodology is based on a biomechatronic approach, and microenginering technologies will be extensively applied in order to integrate on board microsensors and microsystems for providing dexterity, controllability and tactile feedback.
Different concepts of hand-interface systems can be analysed and compared in order to make a trade-off of the best solution to support astronaut hand in performing EVA tasks.
The possibility to control the ADAH system with different teleoperation modalities will be analysed: one modality is based on the local direct control of the astronaut who can "wear" the hand and control it by means of his/her fingers, the second modality is obtained when the hand is located on an external manipulator, and the astronaut control it from the ISS by means of an appropriate HMI.

Concerning the interface, the project will focus on the possibility to integrate the astronaut's glove with a biomechatronic structure (external or internal to the space suit), that detects simple movements of astronaut's fingers, and stimulates them with tactile and contact feedback originated by dedicated microsensors integrated in the artificial hand. The HMI senses/detects the *movements* (or tactile pressures) of the astronaut fingers, and provides proper feedback signals to the fingers, for example based on microvibrations.

**Artificial Hand**

*General Description*

The analysis of the state of the art begins from the analysis of three artificial hands presently available at ARTS Lab. These prototypes have been designed to satisfy to the typical requirements of a hand prosthesis (light weight, integrated actuators, low energy consumption, simple control system and dimensions and shape close to the human hand).

The first one, called RTR I hand, is based on the use of brushless microactuators directly integrated in the mechanical structures of the hand, i.e. the phalanxes. It is composed of three fingers: index, middle and a thumb in opposition, with 6 independent active DOF (see Figg. 1 and 2). It is able to perform the tasks represented in Figg. 3, 4, 5.

Fig. 1. RTR I Hand

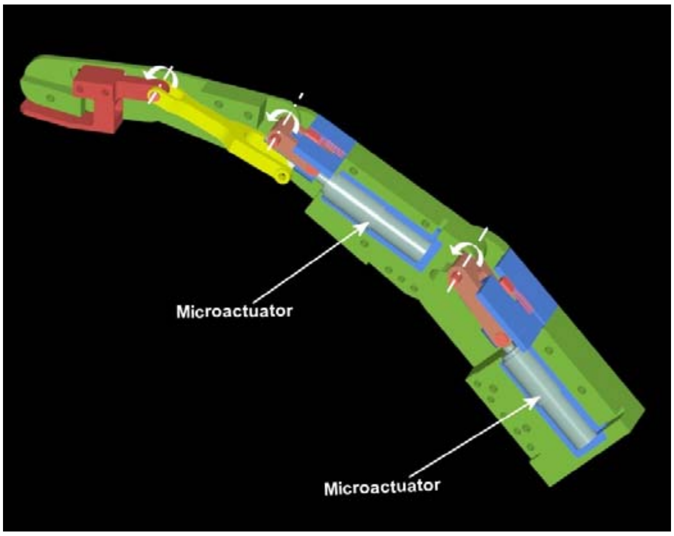


Fig. 2. RTR I finger

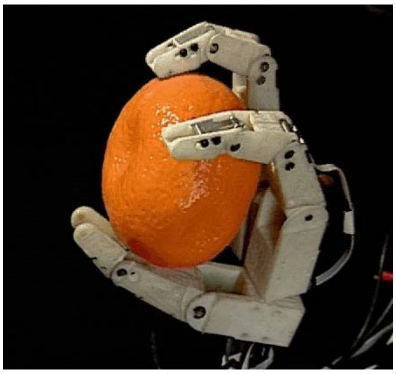

Fig. 3. Task I

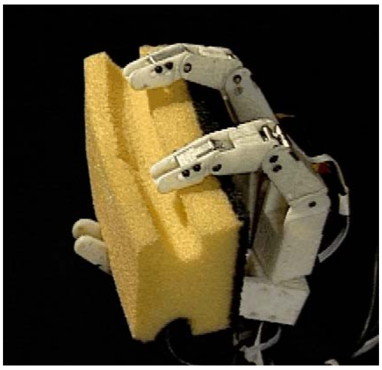

Fig. 4. Task II

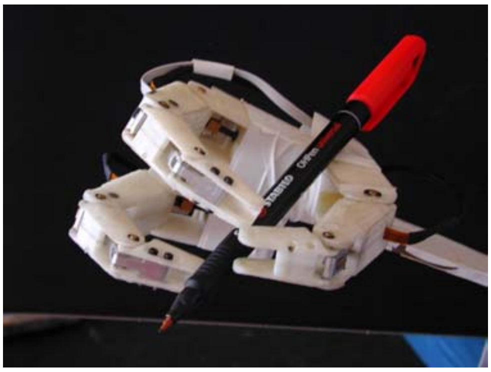

Fig. 5. Task III

The second one, called RTR II hand (see Fig. 6), is underactuated. In other words, the fingers can self-adapt to the object shape with a simple movement of a slider linked to the finger through a steel wire. The thumb can also abduct and adduct thanks to a four linked mechanism. In this way the hand can perform two type of grasps (see Figg. 7 and 8): cylindrical grasp and lateral pinch. Two DC MINIMOTOR, integrated in the palm, actuate the hand: the first moves the slider and pulls the wires, the second is used only for the thumb positioning.

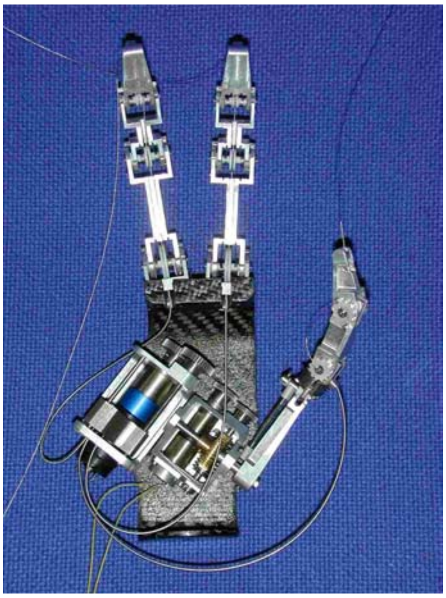

Fig. 6. RTR II Hand

Fig. 7. Cylindrical grasp

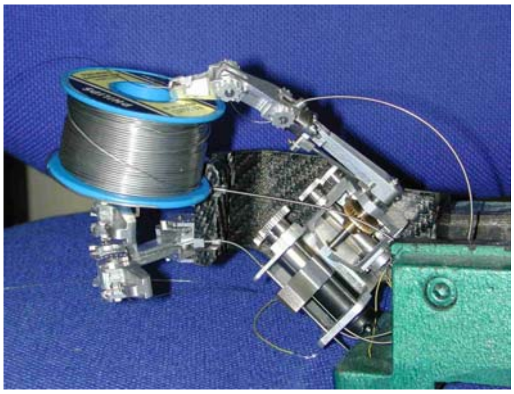

Fig. 8. Lateral pinch

The third one, called RTR III hand (see Fig. 9) is also underactuated but it implements a different transmission mechanism; furthermore the thumb is fixed in the opposing position and only one DC MINIMOTOR actuates a slider that pulls the fingers wires. This hand can perform only one task (cylindrical grasp) even if it is able to adapted to every object shape (see Figg. 10 and 11).

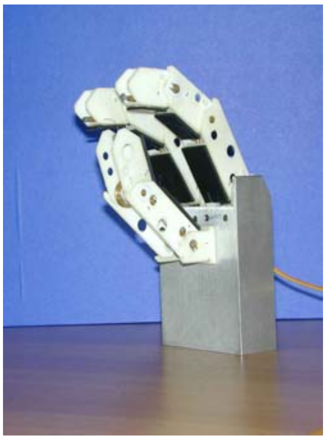

Fig. 9. RTR III Hand

Fig. 10. Cylindrical grasp

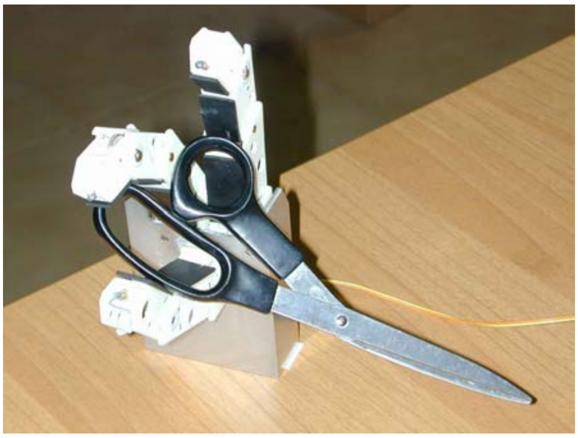

Fig. 11. Adaptive grasp

Table 2 shows a comparative analysis of some artificial hands reported in recent robotics literature. The parameters selected to compare different hand concepts and prototypes are the number of degrees of freedom, the number of actuators, the size, the weight and the resulting force. The hands are compared to the natural human hand that represents the "model". It is evident that presently available knowledge and technology are able to produce hand

prototypes which are far to provide similar performance to the natural hand. Nevertheless, recent achievements and progresses indicate that there is a positive trend in producing better hands concepts and prototypes. It is clear that due to technological limitations it is necessary to make some compromises in mimicking the abilities of the human hand and to define some priority "specifications" according to the intended application, as for example when higher resulting force are obtained causing higher weight and larger size.
Based on the results of this analysis, the concept of an innovative hand is presented. The hand is designed to assist the astronaut performing the EVA tasks defined in the ADAH project. According to state of the art technology the artificial hand can be composed of five fingers with in total 11 DOFs independently controlled.

Table 2. State of the art in the field of artificial grasping systems: a comparative analysis

| HANDS | n° fingers | Size Hand/Human Hand | DOF | n° actuators | weight [Kg] | force [N] |
|---|---|---|---|---|---|---|
| Human hand [1] | 5 | 1 | 22 | 38 ext+int | about 0,4 | >300 |
| Salisbury hand [2] | 3 | 1,2+control | 9 | 12 ext | 1,1 (+5,5drive assembly ) | 44 |
| Utah/MIT hand [2] | 4 | 2+control | 16 | 32 ext | | 31 |
| DIST hand [3,4] | 4 | 1,5+control | 16 | 20 ext | 1 | |
| Sugiuchi hand [5,6] | 5 | | 17 | | | |
| Anthrobot hand [7] | 5 | 1+control | 20 | 16 ext | 4,5 | |
| SDSU hand [8] | 5 | 1+control | 15 | 6 ext | 2 | 15 (finger tip) |
| NTU hand [9] | 5 | | 17 | int | 1,57 | |
| Shadow hand [10] | 4 | 1,2+control | 21 | ext | between 5 and 10 | |
| BUAA hand [11] | 4 | 1+control | 16 | int | 1,4 | |
| Goldfinger hand [12] | 4 | 1,5+control | 12 | est | 2,27 | |
| BarrettHand [13] | 3 | 1,2 | 8 | 4 int | 1,18 | 20 (finger tip) |
| Laval hands 1 [14-17] | 3 | 2 | 12 | 6 ext | 9 | 687 |
| Laval hands 2 [14-17] | 3 | 1,5 | 10 | 2 ext | | |
| Gifu hand II [18] | 5 | 1,5+control | 20 | 16 int | | 4,9 |
| Robonaut hand [19-21] | 5 | 1,2+control | 12 (+2wrist) | 12 (+2 ) ext | | |
| DLR II hand [22,23] | 4 | 1,5+control | 13 | 13 int | | 30 (finger tip) |
| RTR II hand [24,25] | 3 | 1 | 9 | 2 int | 0,32 | 16 |

The feasibility of using microactuators integrated in the mechanical structure of the hand in alternative to underactuated mechanisms will be studied, and suitable actuators to generate an adequate grasping force will be selected. In Fig. 12 it is depicted a simple schematic drawing of the proposed hand concept: each arrow is a controlled DOF.

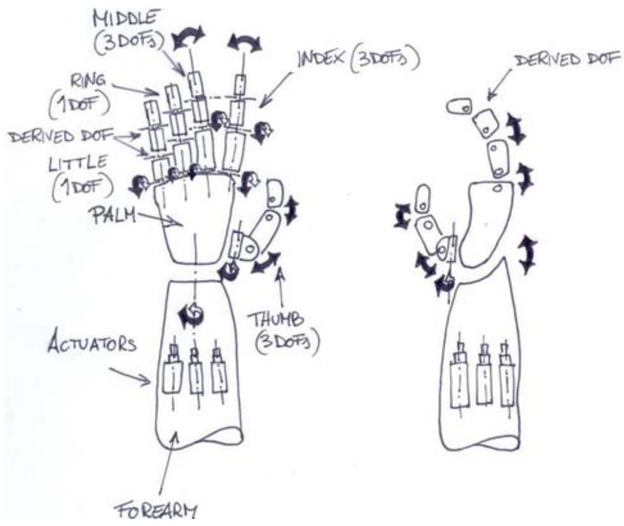


Fig. 12. Proposed structure of the ADAH hand

The first objective of the ADAH project is to define the kinematic structure and the number of active and passive degrees of freedom required to perform the desired tasks. In particular the feasibility and the effectiveness of introducing the degree of freedom of abduction-adduction DOF will be investigated, because this will provide the hand with higher grasping performance but it will require a more complex control system. In addition, the ADAH project will investigate the possibility to introduce a new DOF in the palm, which allows a better embracement of a tool of various shapes. In order to limit the hand weight, advanced material will be exploited as polymer-metal composites with low density but high mechanical strength. The second step of the ADAH project is to study dynamic properties required to the hand in order to effectively fulfill EVA tasks.

*Summary of General Technical Specifications*

The 11 DOFs of ADAH system can be distributed as follows:

- Index and middle will have two active (metacarpal and intermediate joint) and one passive (distal joint) flexion DOF and one active abduction –adduction DOF;
- Ring and little finger will have one active (metacarpal joint) and two passive (intermediate and distal joint) flexion DOF; they will be used to obtain a stable grasp;
- Thumb will have two active (metacarpal and distal joint) flexion DOFs and one active (carpal) abduction – adduction DOF.

**Glove Interface**

The artificial hand is controlled by the astronaut by an appropriate interface based on a sensorized glove which will translate *little movements* (or tactile pressure) of the finger tips – detected by proper sensors - into larger movements of the Artificial Hand fingers.

Furthermore the Glove will provide the astronaut fingers with proper feedback, e.g. of tactile type. Such feedback will be generated – by proper miniaturised devices close to the finger tips - using the signals provided by the sensors of the Artificial Hand and conditioned by the Control Electronics.

As regards the physical interface between the Astronaut hand and ADAH two different solutions can be envisaged:

1) The ADAH is just a tool for the astronaut wearing the complete space suit. Miniaturised devices which sense the fingers movements and provide the (e.g. tactile) feedback to the fingers should be in contact with the nude fingers of the astronaut. Hence such devices must be located inside the space suit glove, e.g. incorporated in a thin glove directly in contact with the astronaut nude hand .
2) The ADAH project will study also the possibility to control the hand from the ISS accessing to a special control unit. In this case, the ADAH system will be the end effector of a manipulator and will be teleoperated by the astronaut by means of a HMI.

The function of the HMI is to restore as much as possible the natural control strategy described above. For this reason the HMI should be made in order to:

- make possible an intuitive and not fatiguing control of the ADAH system during the different tasks the astronaut has to carry out;
- deliver a cognitive feedback about several sensory information (e.g., the position of the fingers of the artificial hand in the space, the force produced) to the astronaut during grasp.

In order to achieve these goals the following issues will be investigated:

- analysis of the residual manipulation abilities of the astronaut by using a sensorised system (“ADAH Glove”) which has to be donned under the pressurised one. The astronaut will be asked to carry out different hand movements and the ADAH Glove will record information about the kinematics of the hand by using several position sensors embedded in its structure. These experiments will allow us to understand what level of manipulation is still available to the astronaut to remotely control the artificial hand;
- study (according to the previous results) of an algorithm to control the movements of the artificial hand by means of the movements of the hand of the astronaut;
- definition and implementation of the strategy to provide the sensory feedback to the astronaut (e.g., by using microactuators embedded in the ADAH Glove). The necessity of avoiding any discomfort to the astronaut will be primarily taken into account;
- definition of the coding of the sensory information (i.e., how the microactuators can stimulate in order to provide the information about an increase of the force sensed) by testing the different possible approaches with several subjects in order to analyse their effectiveness.

**CONCLUSIONS**

The ADAH project is currently investigating the feasibility of an Astronaut Dexterous Artificial Hand capable to restore the manipulation abilities and tactile feedback of the astronaut, in order to enhance dexterity in performing EVA tasks. The most critical technologies are studied and assessed through the development of some prototypes of the system to perform functional tests in laboratory.

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