

International Workshop  
“Mars, new Earth for local agriculture”

Robotics and Automation to Support Large Greenhouse  
Infrastructures on Mars

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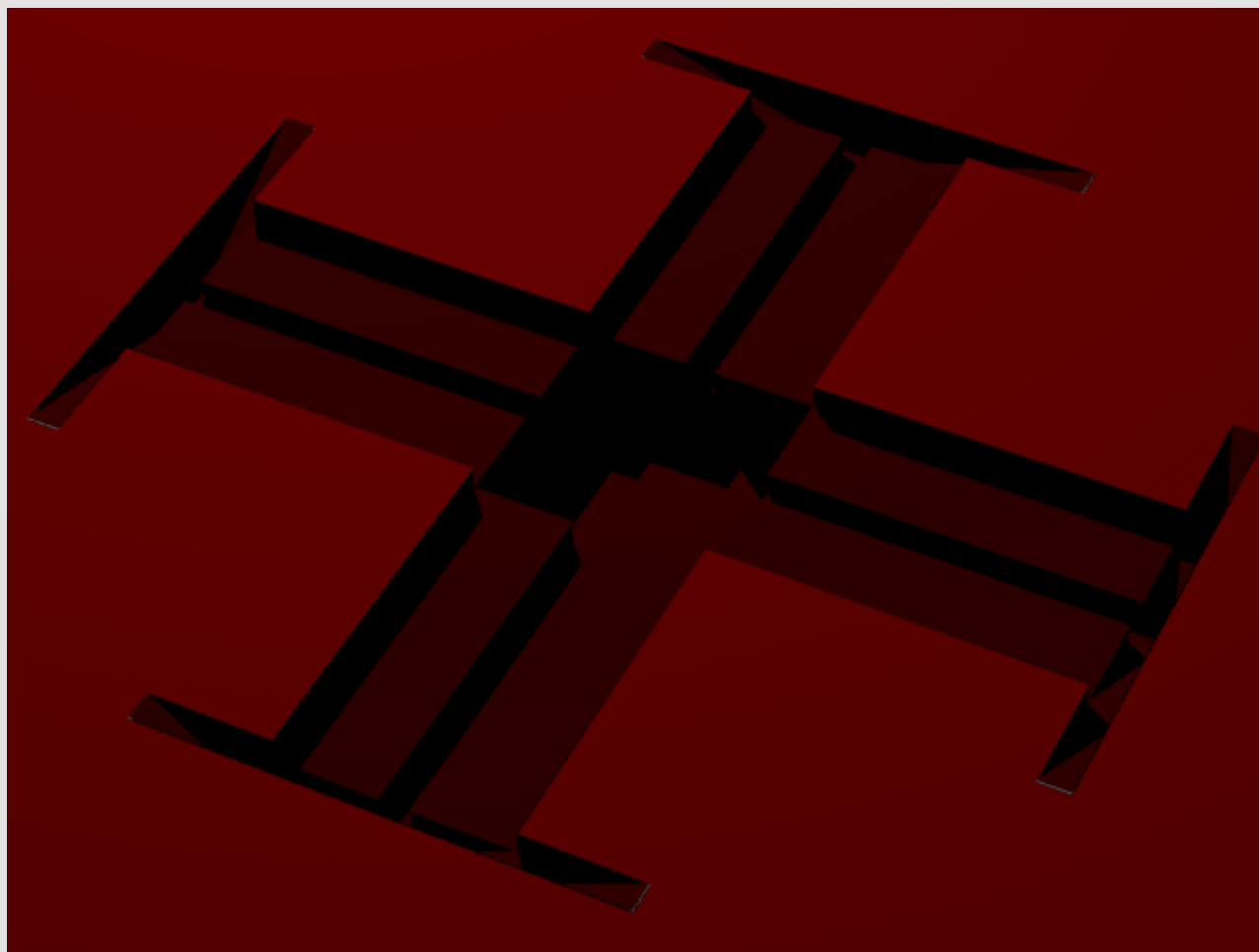
## 1. Introduction

The process of Mars colonisation is strongly related to ways for a correct balance between cost, technological advancements and dependability from earth.

One of such a way is certainly to reduce the mass requirement and dependability from earth by implementing on Mars a food and life support system through bio-regeneration (e.g. a greenhouse).

The assembly and running of a greenhouse on Mars is a very ambitious task which, depending on the final requirements to comply with, will require an adequate robotic infrastructure in order to keep the system as autonomous as possible.





## **2. Robotics and Automation needs**

The settlement of a large greenhouse infrastructure on Mars needs a very strong support of Robotics and Automation techniques for the following major areas:

- survey of candidate sites for final selection;
- selected site preparation;
- recovery of landed units/modules and transportation to site;
- placement of units/modules at the site and deployment/inflate;
- automation of internal greenhouse operations.

The astronaut intervention shall be kept to a real minimum during the settlement phase and limited to emergency conditions during the operative phase.

## 2.1 Survey of candidate sites for final selection

Candidate sites need be surveyed prior to final selection in order to:

- check subsurface consistency and boulder absence;
- check potential presence of water in deep subsurface.

Robotics techniques are needed in the frame of:

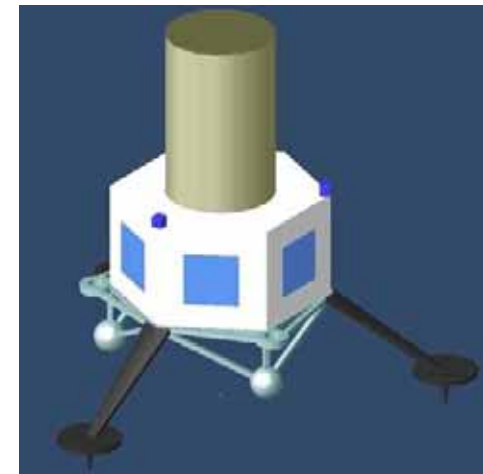
- surveyor rovers with subsurface drilling and sounder capabilities (in the 1-2 m range);
- deep drilling stations (in the 100 m range).

[1] Rover Pasteur (ESTEC running contract)

[2] Architectural Design of the AROMA Reference System (ESTEC)



Pictorial of surveyor rover [1]



Pictorial of deep drilling station [2]

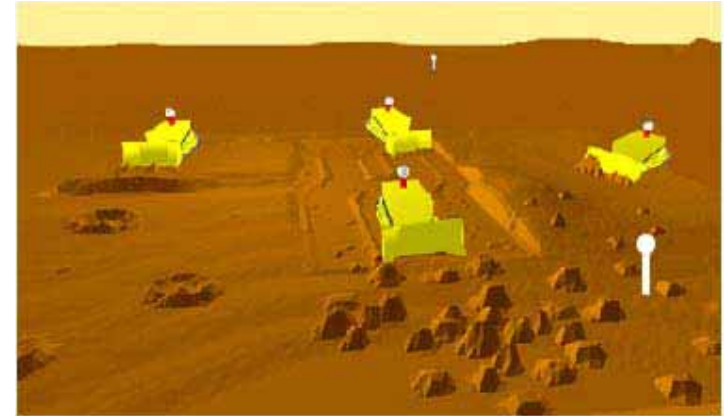
## 2.2 Selected site preparation

Selected site needs be prepared for:

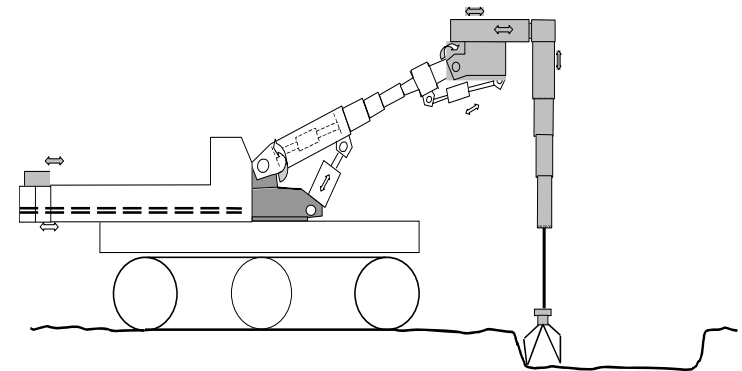
- access paths;
- surface preparation and levelling;
- excavation for parts deposition and logistics.

Robotics techniques are needed in the frame of:

- surface terrain displacement tractors with laser levelling capabilities;
- excavator cranes with meters arm class and hundereds of kilograms loads capability.



Pictorial of displacement tractors [3]



Pictorial of excavator crane [4]

[3] Cooperative Robot Teams Applied to Site Preparation Task  
L.E.Parker, Y.Guo, D.Jung, Oak Ridge National Laboratory

[4] Concept adapted from Architectural Design of the AROMA  
Reference System (ESTEC)

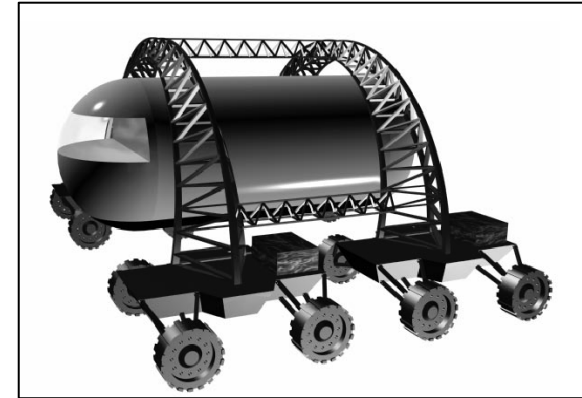
## 2.3 Recovery of landed units/modules and transportation to selected site

The landed units needs be:

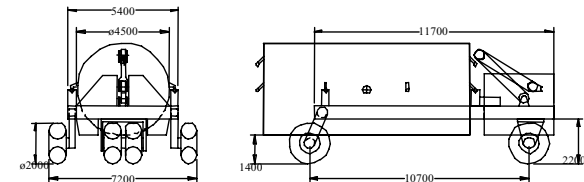
- recovered from the landing place;
- transported to the infrastructure site;

Robotics techniques are needed in the frame of:

- safe reaching the landing site (e.g. several tens of kilometers apart) with large vehicles;
- automatic grasping of large units (meters size and hundereds kg mass);  
levelling capabilities;
- safe transportation of units to infrastructure site following safe routes.



Pictorial of a large transportation system [5]



Pictorial of large track [6]

[5] Conceptual Design of a Mars Surface Transportation System (MSTS)  
C. Collins, W.T.Fowler et Al. University of Texas

[6] Architectural Design of the AROMA Reference System (ESTEC)

## 2.4 Placement of units/modules at the site and deployment/inflate

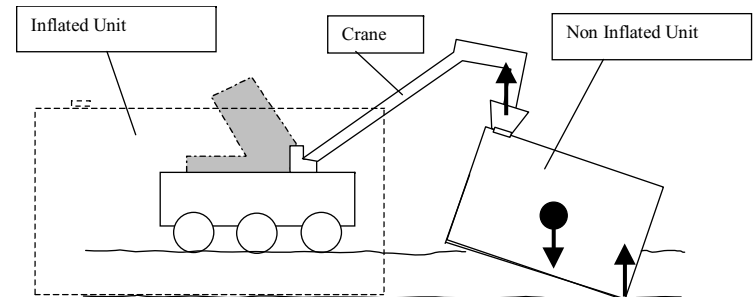
The units/module needs be:

- correctly placed (in terms of relative distance and relative orientation) to allow inflatability procedure;
- deployed and inflated;

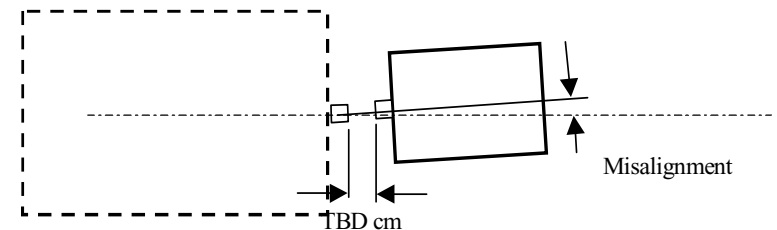
Robotics techniques are needed in the frame of:

- handling of large objects (meters size and hundreds kg mass) with ease of grasping/releasing;
- accurate relative displacements with tolerancing of few centimeters;
- accurate relative reorientation with tolerancing of the degree.

Operation such as anchoring of inflated structures to ground (as needed) can be performed by astronaut or robot.



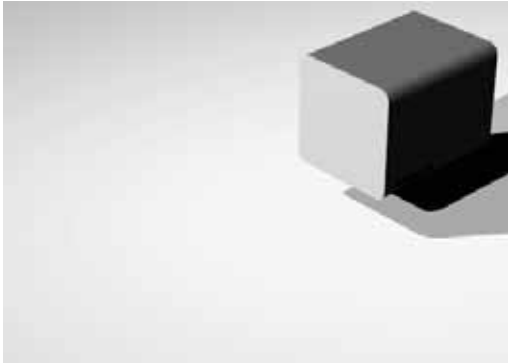
Pictorial of unit placement via crane [7]



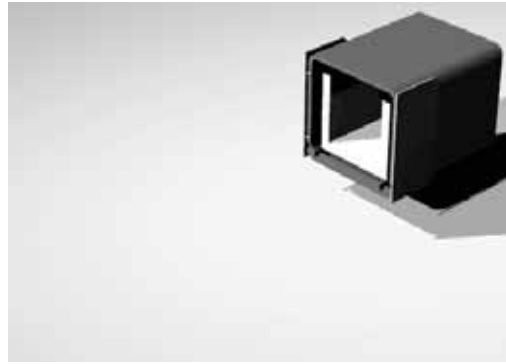
Pictorial of misalignment between placed units

[7] Adapted from Architectural Design of the AROMA Reference System (ESTEC)

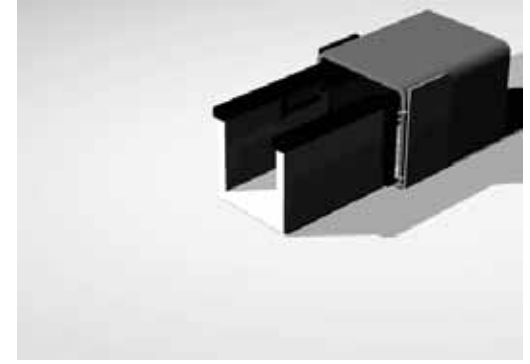
## Schematics of deployment sequence



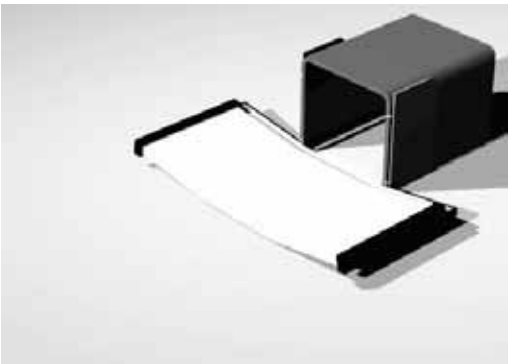
Basic module ( $\approx 3 \times 3$  m)



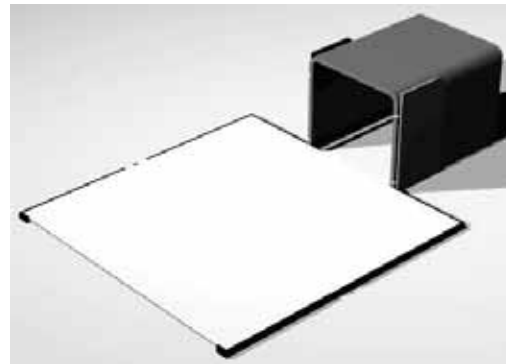
Front side opening



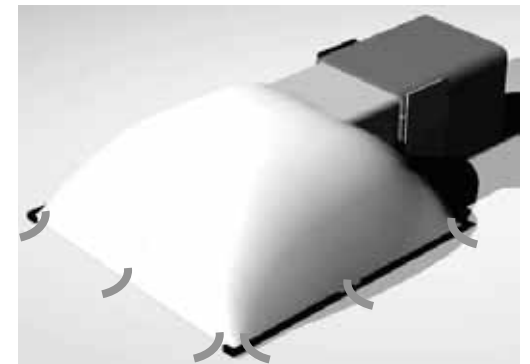
Sliding of core structure



Unfolding of deployable part (1)

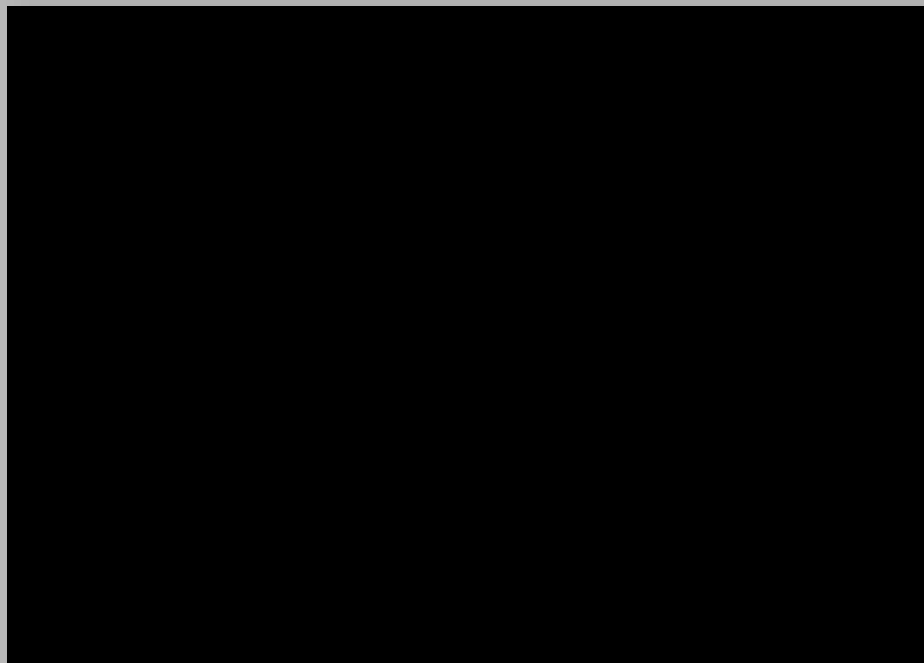


Unfolding of deployable part (2)



Deployment of inflatable dome  
( $\approx 9 \times 9 \times 3$  m)





## 2.5 Automation of internal greenhouse operations

The operations to be carried out inside the greenhouse can be automated so to be performed by ‘farmer robot’.

The operations to be performed include:

- surveillance;
- detailed inspection
- cutting of leaves and weeds
- replacement of plants/herbs from nursery and detachment of replaced;
- progressive harvesting of fruits and vegetables;
- transport of crops to storage/’freezing’ site;
- transport of parts and ordinary maintainance;
- contingency operations.

## 2.5 Automation of internal greenhouse operations (cont.)

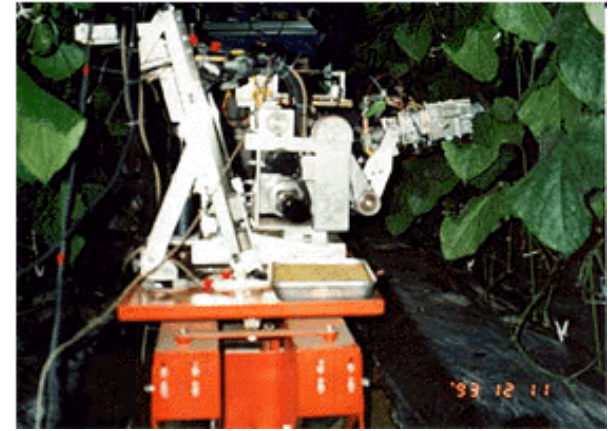
The internal characteristics of the greenhouse allow the ‘farmer robot’ to move and operate from along the aisle (between the inclined trays), to serve the crops/products, to access to the connected facilities.

Two typology of robots can be conceived:

- wheeled robots;
- walking/crawling robots (farmer robot).

The robot is equipped with:

- manipulation capability (arms 2 m class with interchangeable dedicated End Effectors);
- high sensoriality (stereo vision, force/torque perception, proximity perception, ....)
- high autonomy (sensor based control, techniques, scene/environment perception capability, decision making capability, ....)

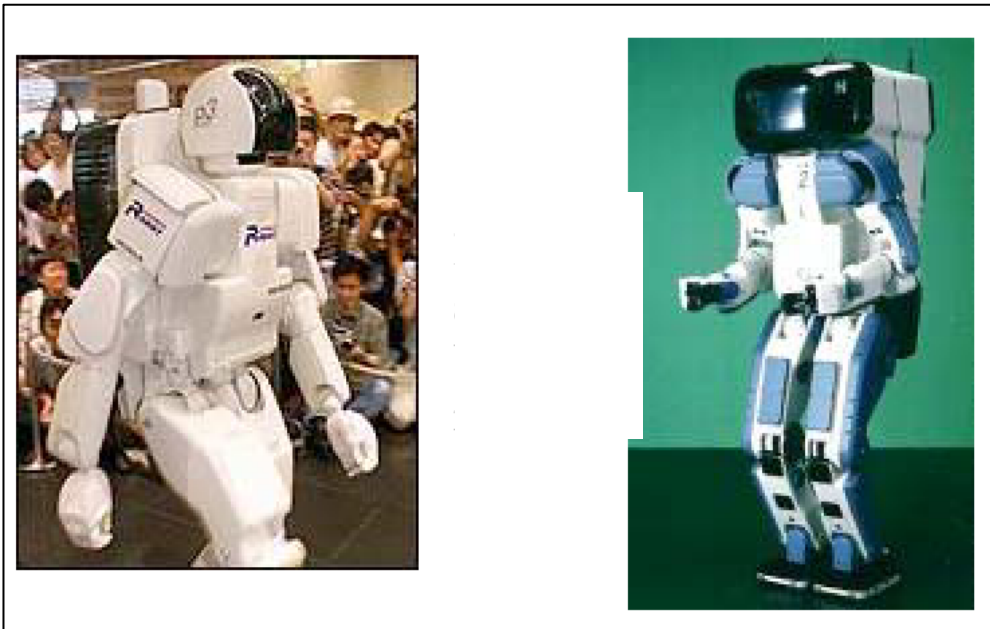


[8] Laboratory of agricultural system engineering, Kondo et al.(Okayama)

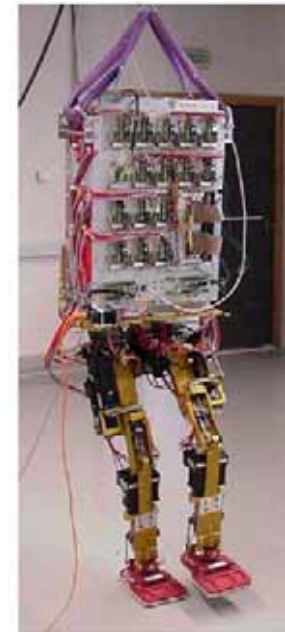
Pictorial of wheeled robot concepts [8]

## 2.5 Automation of internal greenhouse operations (cont.)

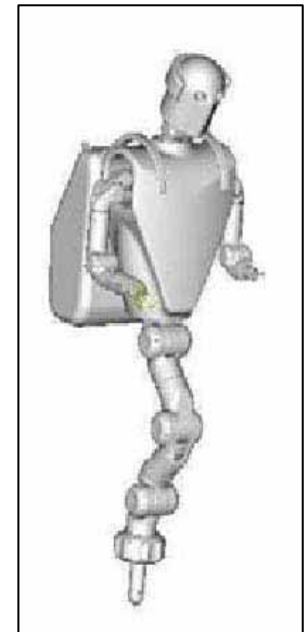
Examples of walking robot concepts and Nasa Robonaut Telerobot (from [9])



Honda P3 advanced bipedal robot



<sup>B</sup> BIP-2000  
bipedal robot concept



Robonaut  
Telerobot

[9] Human Robotic Cooperation, G.A.Landis, NASA Glenn Research Center

## 2.5 Automation of internal greenhouse operations (cont.)

Examples of dexterous arms



SPDM bi-arm system[MD Robotics]  
3.5 m class arms



SPIDER Arm [Galileo Avionica]  
ASI Contract  
1.5 m class arms



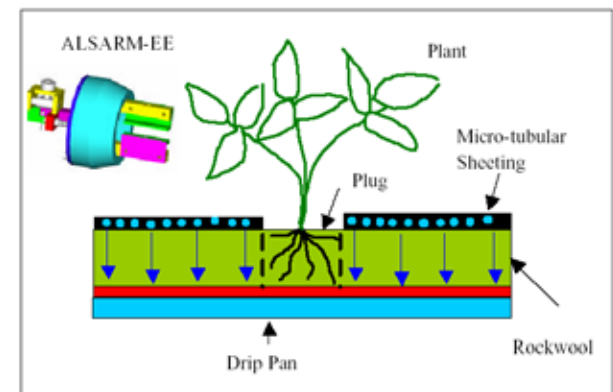
Robonaut Arm Hardware [10]

[10] Human Robotic Cooperation, G.A.Landis, NASA Glenn Research Center

## 2.5 Automation of internal greenhouse operations (cont.)

### End Effectors/Grippers

- ⇒ EE/Grippers are key elements in order to efficiently perform the necessary operations on plants, herbs and vegetables;
- ⇒ the operations to perform are complex due to the non deterministic nature of the objects on which operate and the surrounding environments/obstacles;
- ⇒ delicate object handling need be envisaged;
- ⇒ two approaches may be considered for the design:
  - compliand passive based approach;
  - high sensoriality/control approache.

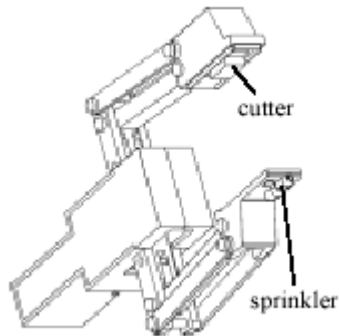


Schematic of operations [11]

[11] C.H.Ham, G.Ballmann et al., 'Mars deployable greenhouse', University of central Florida/Florida Space Institute

## 2.5 Automation of internal greenhouse operations (cont.)

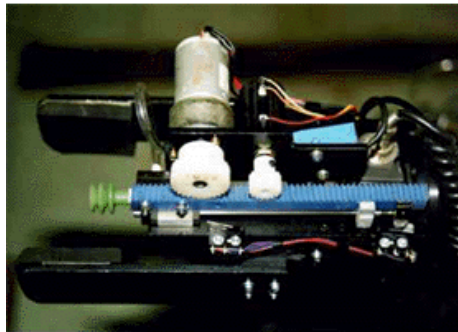
### Examples of End Effectors/Grippers



Schematic of EE for picking leaves [12]



Schematic of a grapevine harvesting EE [13]



Schematic of a (large) tomato harvesting EE [14]



Human like dextrous hand [15]  
(high sensoriality/control)

[12] G.M. Acaccia et al., 'Mobile robots in greenhouse cultivation: inspection and treatments of plants', PMAR Lab, University of Genova

[13] Laboratory of agricultural system engineering, Kondo et al.(Okayama)

[14] Laboratory of agricultural system engineering, Kondo et al.(Okayama)

[15] Architectural Design of the AROMA Reference System (ESTEC)

## Example sequence of ‘farmer robot action’: tomato harvesting



Inspection (shape, colour)



Grasping (tactility)



Cutting of ‘umbilical’



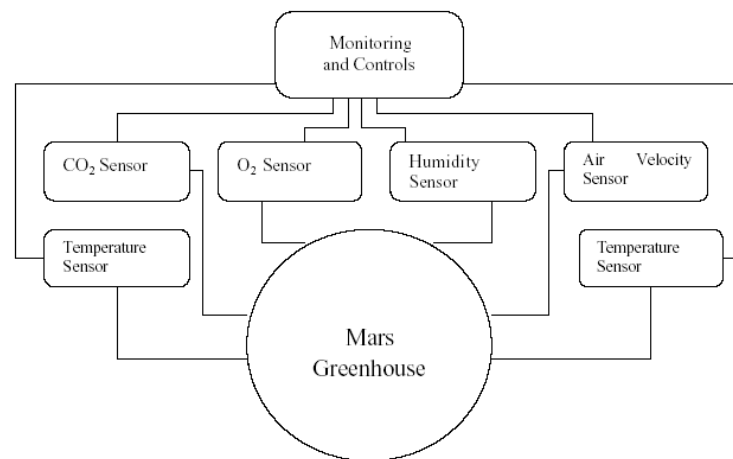
Deposition in conveyor

### 3. Control aspects

#### 3.1 Athmosphere control

Subsystem	Range of Operation
Air Revitalization System	
Oxygen	18.5 – 23.45 %
Carbon Dioxide	300 - 5000 $\mu\text{L/L}$
Chamber Pressure	101 kPa
Ventilation and Thermal Control	
Air Temperature	288.15 K – 308.15 K
Relative Humidity	70 – 85 %
Air Velocity	.1 – 1.0 m/s
Leak Detection and Control	1% of the chamber
Leakage Rate	volume/day

Athmosphere supply requirements [16]



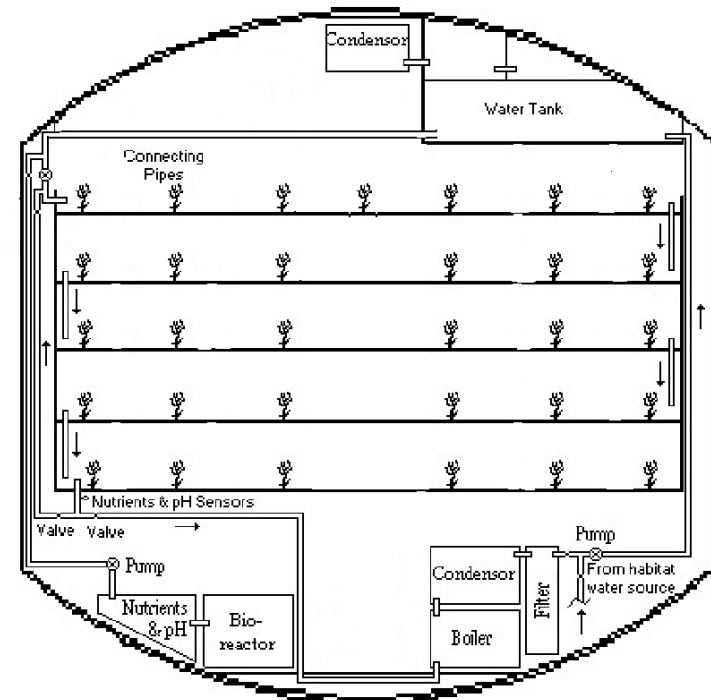
Athmosphere control flow chart [16]

[16] C.H.Ham, G.Ballmann et al., 'Mars deployable greenhouse',  
University of central Florida/Florida Space Institute

## 3.2 Nutrient subsystem

This subsystem provide the greenhouse with the appropriate quality and quantity of nutrients:

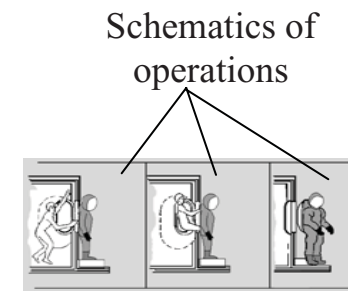
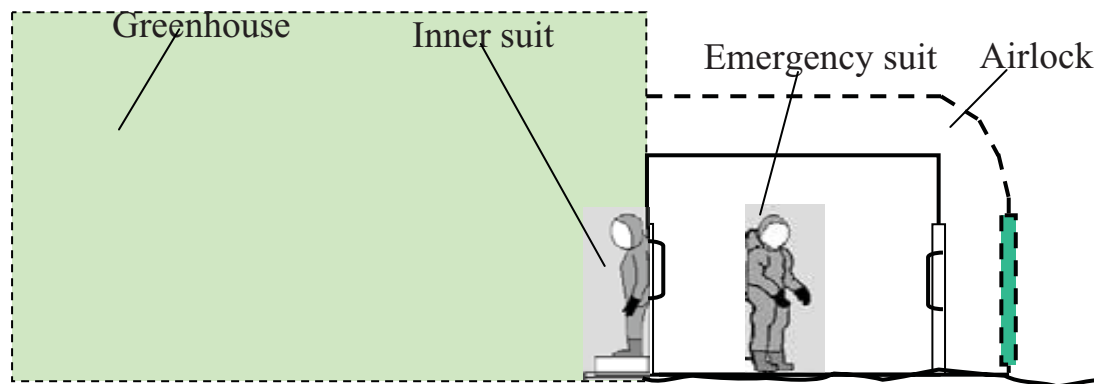
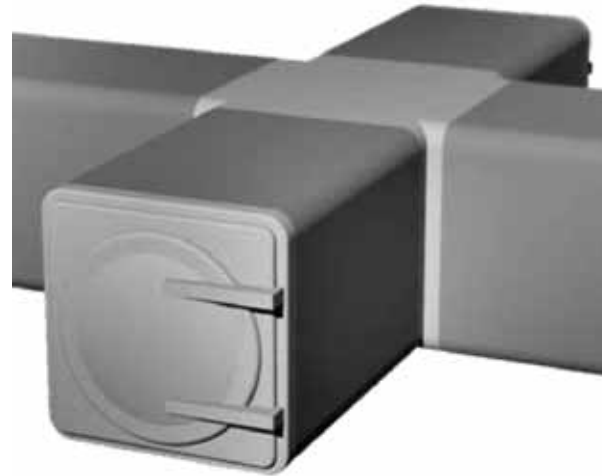
- Nutrient Production System
- Solution Circulation System
- Water Purification System
- Condensation System
- Sensing System



Schematics of Hydroponic arrangement  
(not to scale)

### 3.3 Astronaut survey-Airlock aspects

Possible concept for astronaut accessibility to the greenhouse (from [18])



[18] Transfer method from “Conceptual Design of a Mars Surface Transportation System (MSTS)”  
C. Collins, W.T.Fowler et Al. University of Texas