MOBILE TESTBED FOR THE DEMONSTRATION OF A MANIPULATOR ARM

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ABSTRACT

Astro- und Feinwerktechnik Adlershof GmbH (Astrofein) together with its partner Robo-Technology GmbH is currently developing a Flexible Orbital Manipulator (FOM) for various On-Orbit Servicing (OOS) tasks feasible for small satellite platforms. Within the development, Astrofein is responsible for the electromechanical manipulator arm design as well as the Mechanical Ground Support Equipment (MGSE).
One important task in development of a manipulator arm for space is the verification of the system. Since the dimensioning of the required load capacity, i.e. sizing of the joint drive units and mechanical strength of the links is optimized for space conditions, on ground testing is a major challenge. In addition, a facility is often required where testing can take place, making a demonstration site-bound.
The paper provides a short summary of the manipulator arm itself before describing the approach of designing the MGSE that ensures functional demonstration of the manipulator arm under gravity. Apart from meeting the requirements in terms of functionality, the MGSE was designed to allow for mobile testing. The resulting constraints will be presented and design solutions are described.

1. MANIPULATOR ARM DESIGN

FOM is designed to fulfil one (or more) of the following tasks:

- Monitoring and diagnostics as a basic functionality,
- Grappling of small client spacecraft,
- Replacing ORU's (Orbital Replaceable Units) or other prepared components,
- Deployment and assembly assistance for small/ medium structures.

Since the required servicing platform has been defined to be at the range of a small satellite, i.e. below 300 kg, resources were a main driver for the robotic arm design. The main parameters of the designed manipulator arm are provided in Tab. 1.

Table 1.FOM main parameters

Parameter	Value
Degrees of Freedom (DoF)	Arm: 6 Tool: 2*
Max. workspace radius	1,500 mm
Min. workspace radius	450 mm
Mass (excl. margin)	40 kg
Load capacity	Grappling: 4 N / 3 Nm Handling: 8 N / 8 Nm Connector plugging: 90 N / 2 Nm
Max. end effector speed	50 mm/s
Max. power consumption	300 W

* Task/mission specific.

To achieve a design that is feasible for small satellites regarding mass as well as stiffness and dynamical behaviour, structural design is done by using Additive Layer Manufacturing (ALM) [1]. The FOM manipulator arm is depicted in Fig. 1. Due to the lightweight design optimized for space, the manipulator cannot lift itself in a 1G environment, being one aspect that is driving the design concept of the MGSE.

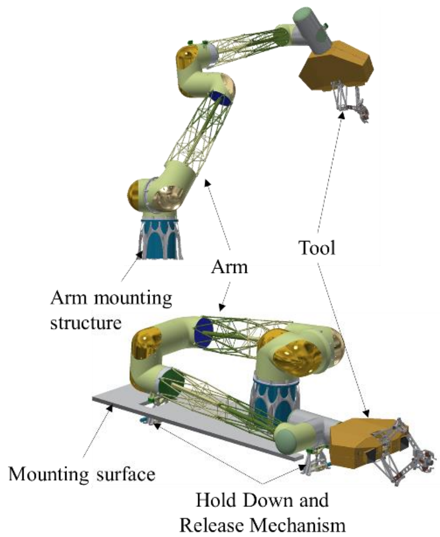

Figure 1. FOM design using ALM (top: operational, bottom: launch configuration)

2. MANIPULATOR TASK VERIFICATION TESTBEDS

As space manipulators have become indispensable for construction and maintenance of the ISS, space agencies have built testbed facilities for their verification and validation [2].
A major challenge of testing a robotic system designed for space is simulating a Zero-G environment on ground. There are different experimental methods to achieve that, such as suspension testing, air-bearing supported testing, neutral buoyancy testing and hardware-in-the-loop

simulations [2]. Regardless of the chosen method, testbeds are necessary which are often located in a facility and therefore site-bound. The DLR On-Orbit Servicing SIMulator (OOS-SIM) is shown in Fig. 2.

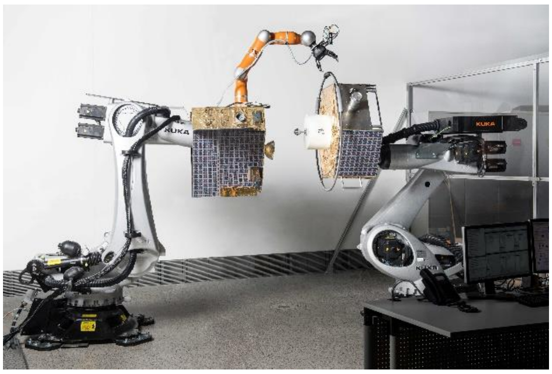

Figure 2. OOS-Sim Facility (DLR) [3]

3. MGSE DESIGN AND DRIVING REQUIREMENTS

To verify that the manipulator arm can fulfil its tasks, different scenarios are to be tested with a demonstrator. The demonstrator's design is a full representative of the space system. The needed MGSE must ensure the following functions:

- Operation of the manipulator arm in the presence of gravity by using a mass compensation device,
- Simulation of the space background with the help of a display screen,
- Simulating a tumbling client satellite with the ability of adjusting the client's rotation speed,
- Providing a connector mock-up (simulating the client's external power/communication interface) whose position can be adjusted within the test compartment.

One goal was to have a mobile testbed, which allows an easy (dis-)assembly and transport, e.g. for presentation at trade fairs. Required security mechanisms are foreseen to ensure safety of personnel and fair visitors. A detailed description of the individual elements follows in the next paragraphs.

3.1 Frame Design

To allow a flexible and cost-effective design, the demonstrator cell is built with aluminium profiles. Usual door heights and widths are considered when defining the dimensions of the testbed, to have fewer restrictions on storage and transport sites. In order to ensure a sufficient motion range of the manipulator arm as well as the accommodations of the Electrical Ground Support Equipment (EGSE), retractable covers are provided to increase the motion range in extended configuration. Moreover, the cell consists of two frame halves that can be divided easily to meet the requirements regarding the width. For accessing the test compartment, security doors are foreseen at the back of the cell. When the doors are open, no movement of the arm is allowed to prevent injuries. In case of an unexpected movement of the arm an emergency stop was placed between the two doors, which is easily accessible. The EGSE is accommodated in pull-outs at the bottom of the frame, which are equipped with flaps. The back of the cell can be seen in Fig. 3.

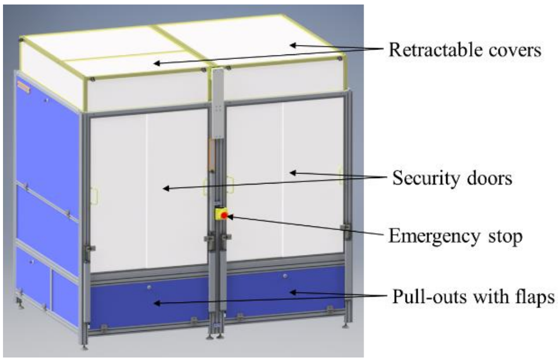

Figure 3. Back of the cell

At the front and left side of the cell, large observation windows are foreseen to provide the personnel with a good view of the demonstration. These are also a safety feature to ensure that a malfunction does not cause harm or injury to the people around. It is also possible to interact with the mock-ups during the demonstration by adjusting controls for the different tasks. To make different states of the demonstration visible, signal lights were installed on all four sides of the cell. The front of the cell is shown in Fig. 4.

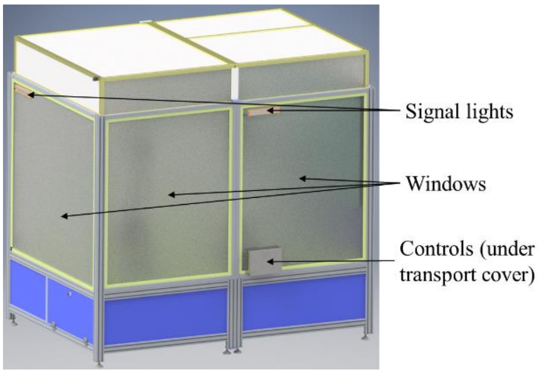

Figure 4. Front of the cell

3.2 Inner Design

Since the cell can be divided in two halves for transportation, it was decided to place the manipulator arm on one side, while the mock-ups for the tasks are located on the other side. This leads to a convenient transport configuration, which will be presented in section 5. The arm cannot lift itself in 1G environment, leading to a mass compensation that carries the gravitational load. The lifting point was chosen to balance the gravitational loads of the forearm of the manipulator, i.e. it is positioned close to the Centre of

Gravity (CoG) of the forearm assembly. The counterweight is located in rail between the two cell halves. The joint of the suspension allows greater movements to the right half of the cell to ensure the widest possible range of movement during the tests.
To simulate an external power/communication interface to a client satellite a socket is placed on a rotating setup located on a linear axis. The orientation and position of the socket can be adjusted via the controls.
A client satellite mock-up is suspended via a cable attached to a motor representing a tumbling satellite. The rotation speed can also be adjusted via controls placed beside the ones for the socket. Therefore, the manipulator control algorithm can be verified for different rotational speeds of the client satellite, which are observed while testing. For grappling of the satellite, there are cameras equipped at the manipulator tool to detect the motion of the satellite. To simulate the space background, a display screen is mounted on the right side of the cell. That is necessary for the detection of the edges and therefore the prediction of the satellite's motion. In addition to the observation windows, two wide-angle cameras are placed inside the cell to get an overall view of the demonstration. All cameras included in the testbed are functional representatives of the vision system that is designed for the space system. Therewith, functional verification of the closed-loop manipulator control is possible with the derived test-setup. The inner design of the cell is depicted in Fig. 5.

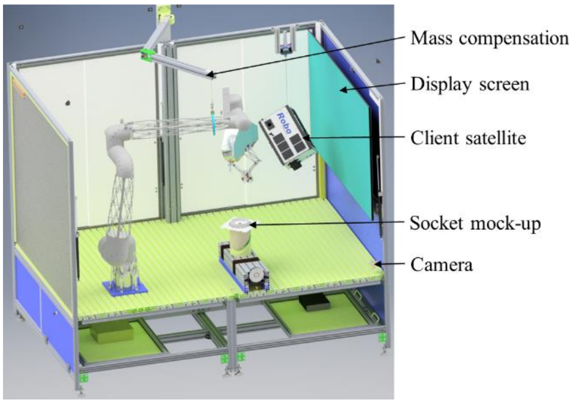

Figure 5. Inner design of the cell

4. TEST SCENARIOS

Two scenarios are to be tested. One is the plugging of a connector to the socket mock-up, simulating a power/communication interface. As described before, the orientation and position can be adjusted, making it possible to test different configurations. The connector plugging can be seen in Fig. 6.

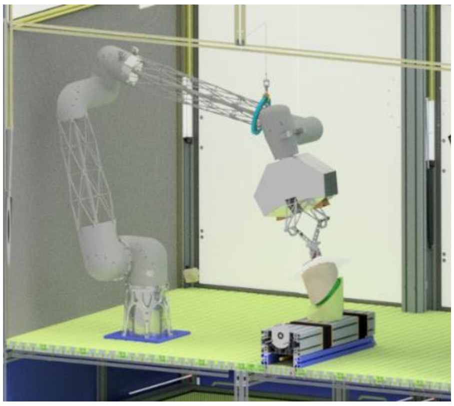

Figure 6. Plugging of the connector

In the other scenario, a tumbling satellite is grappled and decelerated. Its initial rotational velocity can be adjusted via a potentiometer. The controller predicts the movement with the help of the tool cameras. The grappling is depicted in Fig. 9.

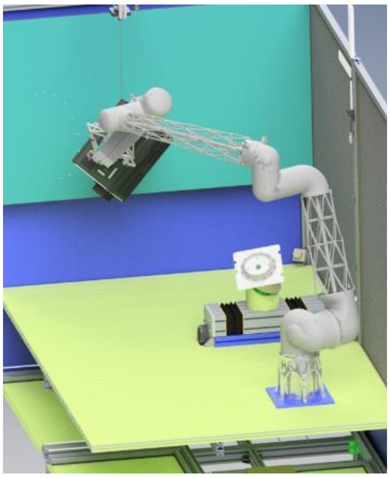

Figure 7. Grappling of the client satellite

5. TRANSPORT CONFIGURATION

When transporting the demonstrator cell, all assemblies can be mounted inside the cell, which makes additional transport containers not necessary. The manipulator arm can be stowed into a similar position as during the launch. The satellite as well as the mass compensation can be mounted in the right half of the cell. The transport configurations can be seen in Fig. 8 and Fig. 9.

Figure 8. Transport configuration left half

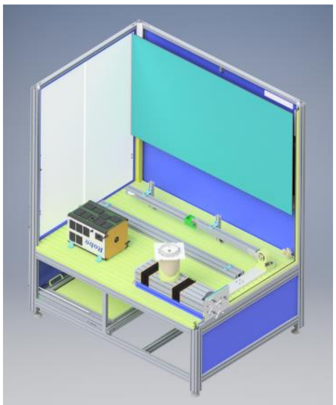

Figure 9. Transport configuration right half

6. ADVANTAGES AND DISADVANTAGES

The advantages of the solution are the mobile and simple design, allowing for an easy (dis-)assembly and transport. By providing controls, the manipulator arm can be tested and verified for different test parameters.
The mass compensation as well as the client satellite mock-up do not fully allow a demonstration under space condition, since there is an interaction with the suspensions that does not replicate the movement in space. Because of the limited motion range in the cell, the demands on the manipulator arm control are stricter than in space, which is a disadvantage compared to other testbeds.

7. CONCLUSIONS

A design for a mobile testbed was proposed, which allows the functional demonstration of the manipulator arm. It is not site-bound, allowing for demonstration at different locations, which is a main difference compared to other testbeds. Its design is simple and cost-effective. Control elements provide the possibility of direct interaction with the user.
Currently, the manufacturing and assembly of the manipulator arm and the demonstrator cell are ongoing.

Since the mass compensation was designed to balance the gravitational loads of the forearm, it does not support the arm in every configuration. Therefore, stay-out zones have to be carefully assessed during the upcoming test campaign. Even though simulations of the trajectories were carried out to identify the range of motion and the positioning of the different mock-ups, some uncertainties remain.

8. REFERENCES

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9. Acknowledgement

This work is been carried out under funding of Federal Ministry for Economic Affairs and Energy (Funding No. 50RA1714).