MODULAR ROBOTIC TOOLS FOR SPACE APPLICATIONS, THE MULTI PURPOSE TOOL (MPT)

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ABSTRACT

The next decades of spaceflight will be characterized by new services and cost-effective concepts for launch services and space systems. Robotics and automation will be a critical pillar to reduce costs and enable new services and system designs. Airbus Defence and Space is developing modular manipulators and tools for such robotic missions. The rationale for this approach lies in the ability to adapt quickly to new missions, reduce development and manufacturing costs by creating recurring building blocks, and enable missions with high duty cycles by replacing obsolete parts rather than relying on complex redundant architectures. The authors present in this paper a modular tool architecture and the first breadboard implementation.

1 MOTIVATION

Government and corporate roadmaps around the world point to the need for robotic manipulation in future orbital and planetary missions [1][2]. For planetary missions, manipulation capability is important for sample collection, sample container handling, and infrastructure construction. For orbital missions, capturing cooperative and uncooperative spacecraft, cutting and patching MLI, opening and closing FDVs, inspecting spacecraft, and reconfiguring spacecraft by attaching new payloads. In particular, for orbital missions targeting in-space manufacturing and assembly (ISMA), operations such as bolting, gripping, measuring position, welding, cutting, clinching, and bending represent important technological operations [3].
For a manipulation system, a positioning system (robot arm) and an end effector system are usually required. While a robotic arm can be considered as a generic device that provides the ability to position the EE relative to the environment, a robotic tool must interact with specific geometries to perform the tooling operations. There are two fundamentally different approaches for the end effector on a manipulation system. The use or operation of simple tools such as screwdrivers or pliers by a complex gripping tool with a high degree of freedom similar to the human hand, or the use of interchangeable specialized end effectors.

The advantages of complex end effectors are the use of very simple tools which are mostly very light and cheap and of comparatively low complexity. The disadvantages, however, are that the planning and coordination of such a gripper is comparatively complex [4]. This approach is therefore especially useful in environments made for humans and for teleoperation of the robotic system. The same tools can then be used by astronauts and robots, and the complex hand handling and coordination can be greatly simplified by an immersive tele operated approach. The advantages of special tools are mainly the simplified control, the safety of the operations, and the reduced actuation effort, which makes it possible to perform autonomous operations already in the medium term. A disadvantage is the higher complexity of the tools, which can lead to higher weight and thus higher costs for the rocket launch, especially for missions in which a large number of tools is required.

In this paper, an architecture and a realization of specific tools is presented and the important aspects of the design are presented in the next chapters. Figure 1shows the overall modular architecture. The figure also shows different configurations of a manipulator arm, since the whole manipulation system (arm + end effector + tools) should be considered as one system where harmoni-zation of related components is required.

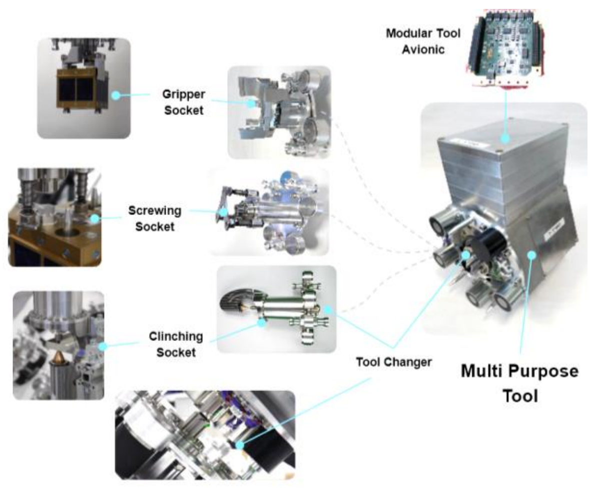

Figure 1 – The MPT Architecture

The concept is to use the Multi Purpose Tool (MPT) as the driving element when only one degree of freedom is required for the tooling operations. In this case, the MPT can be used, it is just necessary to develop a special tool attachment for the application. If a task requires more degrees of freedom or advanced avionics, the concept is open to customization by reusing elements such as the MPT's avionics and actuator. The MPT and the tool attachments are always interfaced. The limits of the concept are reached when the tool attachment becomes too complex, e.g., too many DOF, too many electrical connections (the capacity of the interfaces limited), or when the missions require special tools such as mass spectrometers or laser cutting tools. Such tools are not covered by the MPT architecture and a dedicated tool must be developed.

2 REFERENCE APPLICATION

The MPT and associated tool holders are being developed for orbital missions. There are two important areas to be mentioned here. One is In-Space Manufacturing missions and the other is On-Orbit Servicing missions. For In-Space Manufacturing missions, the tools are used for joining components (bolting, clinching, riveting), aligning assemblies, and gripping parts for handling, among other tasks. On orbital maintenance missions, the tools are used to cut, grip and patch MLI parts, open and close fill and drain valves (FDVs), cut fuse wires and install refuelling adapters.

PERIOD Project:

The first orbital deployment is planned as part of the EU's PERIOD project [5]. In this in-orbit demonstration (IOD), the tools will be used to build a reflector from individual parts, assemble a satellite from cube-sat modules, and attach the reflector to the cube-sat-based satellite. Finally, this satellite is launched from the ISS and the functionality of the built antenna is validated. The PERIOD system is depicted in Figure 2.

Figure 2 – The PERIOD system installed on the Bartolomeo platform outside the ISS

The system for the period mission will consist of three boxes one for the robotic system called the factory box one that houses the cubes has modules and reflector parts called the assembly kit box and one that houses the refuelling experiment with the assist interface called the refuelling box [6]. The idea of the Multipurpose Tool was developed during the Space Tug project. The reason for the modular approach was the limitation of the belly space and the large number of different tools needed for this servicing mission. This approach was then further developed in the MANTOS funding project and a breadboard was realized. With this breadboard, tests were performed and first tool operations were implemented in the laboratory. The developed tools are currently being adapted to the requirements of the in-orbit demonstration period in the funding project STARLIT.

3 TOOL CONCEPT & ARCHITECTURE

The robotic tools follow a modular approach, starting with the avionics board, which can be reconfigured so that it can also be used to control and monitor the tool magazine and workbenches, and ending with the interchangeable tool mounts/extensions driven by the actuation module. This module is called the Multi Purpose Tool (MPT) and includes the avionics boards, the end effector camera, and an interface with a drive shaft to actuate the tool mounts, as well as an interface to the last joint of the VISPA manipulator. The breadboard of this system is shown in Figure 3 with a cube-sat gripper and a cube-sat mock-up.

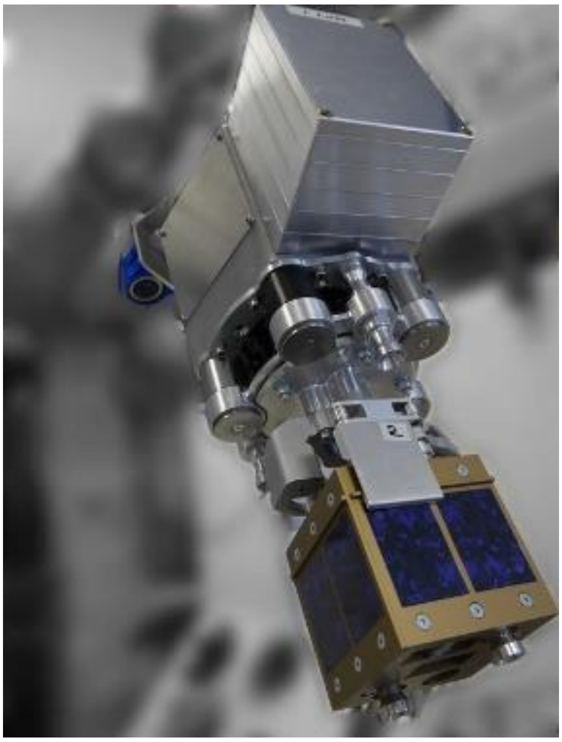

Figure 3 – The Multi-Purpose Tool with Cube Sat gripper socket and a cube sat module

For the PERIOD mission, the factory box will have three MPTs and four sockets. A socket to screw the antenna parts together and adjust the antenna shape, a frame gripper to hold the larger antenna frames and the assembled reflector, a gripper to grab the small bars used to connect the structural frames, and a joint swapping gripper to change the actuators of the VISPA arm. This architecture with the interfaces and the different sockets can be seen in Figure 4.

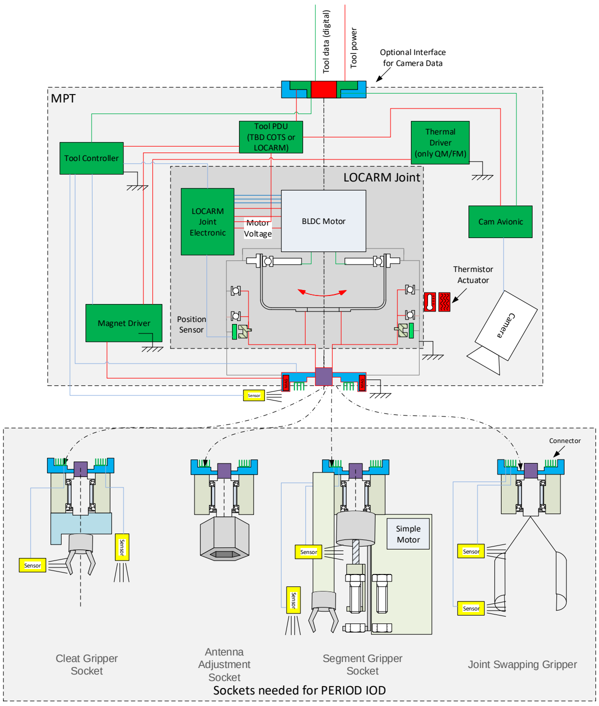

Figure 4 – The System Concept

The avionic architecture is based on a modular PCB (printed circuit board) stack concept. This modular stack concept provides the possibility to adjust the functionality of the avionic to the required needs of the MPT. Therefore, the architecture can be simply reused or expanded for different tool options.

The avionic modules are:

- Tool-Controller (TC)
- E-Magnet, Heater & Simple Motor Driver (EMD)
- Power Conditioning Unit (PCU)
- Socket Interface Board (SIB)
- Main motor controller. (re-use of a VISPA joint including motor, gear and ctrl-avionic)

With these modules, the MPT have the following functionalities:

- Drive one BLDC motor (main drive) for different applications (incl. to screw, to grasp, to hold, etc).
- Drive e-magnets to connect with different tool sockets.
- Thermal management of the MPT
- Drive an additional simple motor (on/off and direction ctrl) for the sockets.
- Measure the absolute position of the main drive shaft.
- Proximity switches on the sockets (e.g. feedback information for grasp activities).

The figure below provides an overview of the MPT avionic architecture.

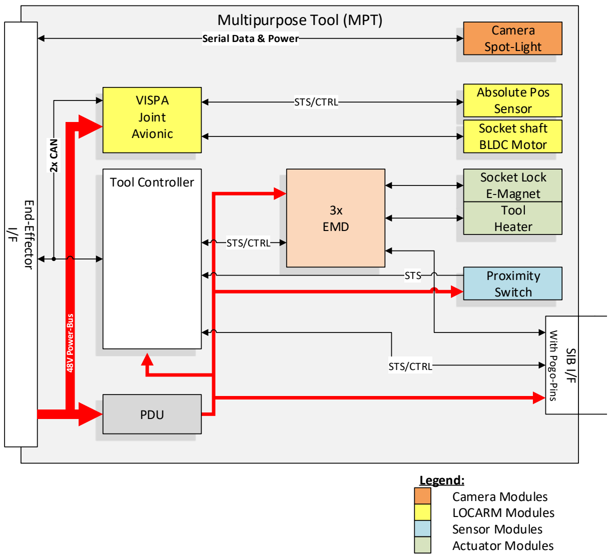

Figure 5 – Avionic Architecture

The physical dimension of the PCBs and the used stack connectors are based on the PC104-Plus standard. The following figure shows the PCB stack with the main modules.

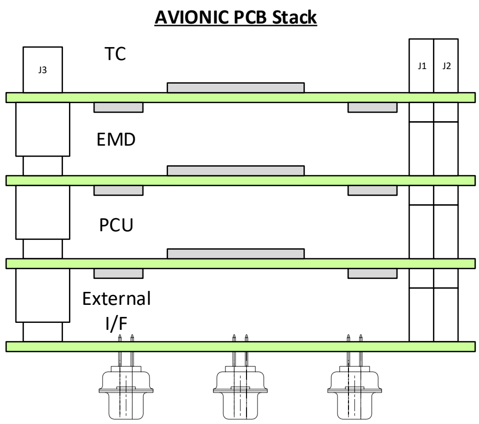

Figure 6 – PCB Stack

The main motor controller (Joint Avionic) is directly located at the BLDC motor.

4 TOOL DESIGN

The construction of the MPT follows the same principles that have already been applied for the architecture. The MPT and the avionic are modularly designed to adapt or exchange individual elements during development.

4.1 Mechanical Design

4.1.1 MPT and MPT Interface

The MPT consists of a BLDC drive with a Harmonic Drive gear. The output is routed to the tool sockets via an interface that is an elementary component of the concept. The interface holds the opposite side with the help of permanent electromagnets (see Figure 7). These magnets are active in the de-energized state and can be released via an electromagnetically generated counter field. The transmission of the torque to is realized by means of a splined shaft.

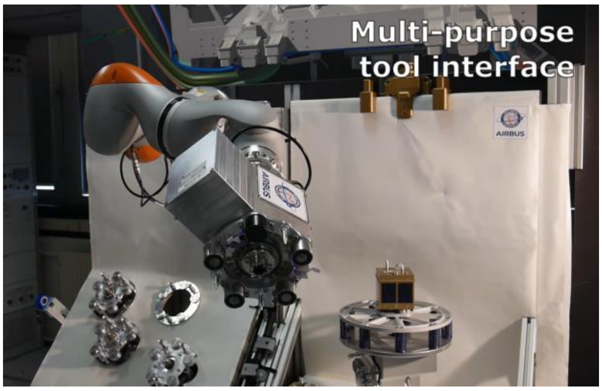

Figure 7 – The MPT Interface

Splined shaft connections are used for the transmission of large and varying torques, such as on manual transmission shafts or on machine tools as well as on agricultural vehicles and shafts of electric motors and hydraulic motors. The spline shaft geometry has been adapted and optimized for a coupling with robots. This connection has been simulated in detail to ensure a smooth coupling.

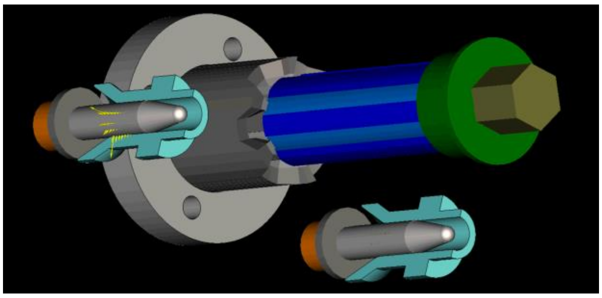

Figure 8 – Simulation of the spline shaft

4.1.2 Wrench Tool

The Wrench Tool (Figure 9) is used for screwing together various components. An important aspect when screwing components in orbit is the local interception of the torque in order not to load the often-fragile structure and the manipulator with the torque. In the field of on-orbit servicing, the opening and closing of FDVs is an application where counter holding at the base of the valve is particularly important in order not to endanger the structure on which they are mounted. For this purpose, the MPT is equipped with a sheet metal part that is pushed onto a hexagonal geometry below the screw or valve to be turned.

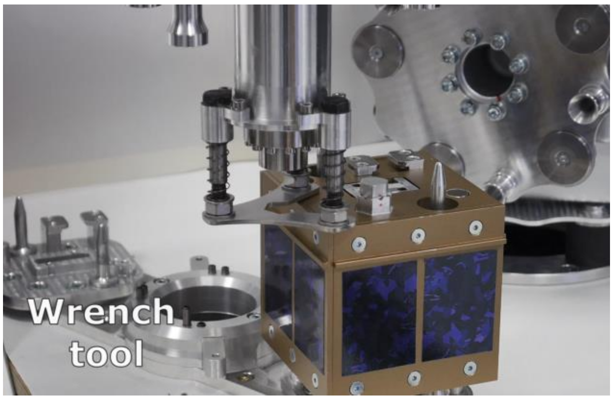

Figure 9 – The Wrench Tool

The sheet metal part is fixed on cylindrical linear guides with springs to compensate the distance during the screwing process.

4.1.3 Gripper Tool

The realized gripper for Cube Sat modules uses the rotational movement of the MPT drive and generates a counter-rotating closing movement of the two gripper jaws by means of parallelogram-like kinematics.

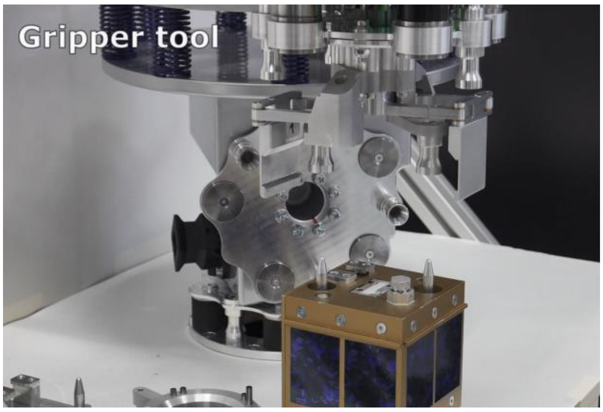

Figure 10 – The Gripper Tool

The advantage of this kinematics is the simple arrangement without complex gears and above all without linear guides. Mechanisms intended for use on the ISS must have a twofold safety against the occurrence of a catastrophic failure. This means that all hazards which could harm astronauts or endanger the ISS and the subsystems must be prevented. For this reason, the grippers are additionally pulled together by a spring to ensure a safe grip even in the de-energized state without the motor.

4.1.4 Clinching Tool

The clinching tool enables the joining of sheet metal strips without additional material. It is similar to riveting but without the rivet. This is made possible by pressing the two sheets with a special die. The materials reach the yield point due to high local pressure and become wedged. The breadboard of this tool is depicted in Figure 11.

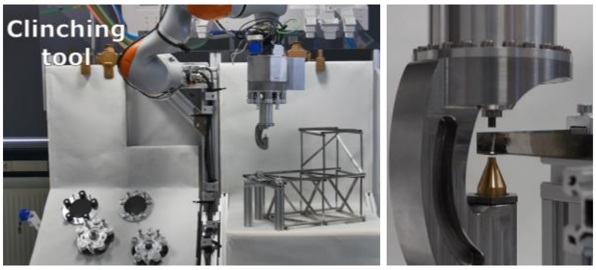

Figure 11 – The Clinching Tool

The rotary motion of the MPT is transmitted via a spindle to a punch, which is pressed against a die on the opposite side.

4.2 Avionic System

The tool avionic consist of several modules:

- Tool-Controller (TC)
- E-Magnet, Heater & Simple Motor Driver (EMD)
- Power Conditioning Unit (PCU)
- Main motor controller. (re-use of a VISPA joint including motor, gear and ctrl-avionic)

Tool-Controller TC:

The core element of the TC is a ARM microcontroller which is available in different quality levels including commercial/Industrial, automotive and as radiation tolerant options. All options are fully compatible to each other regarding functionality and pinout. The radiation-tolerant version is available in the standard plastic package and in a ceramic package. With this different option, the avionic recurring costs can be adjusted to find the best solution between costs and reliability. To be adaptable and flexible for future reuse the TC provides several different interfaces:

Figure 12 – Tool-Controller overview

For the MPT it is foreseen to use the two CAN Bus interfaces as host communication interface.

Power-Conditioning Unit PCU:

The MPT uses the 48Vdc main power bus of the robot arm and generates all required secondary voltages (12V, 5V, 3.3V). Because the highest power demand is on the 5V rail, the 5V is directly generated out of the 48V primary bus using a DCDC converter. Due to lower power consumption on the 3.3V and 12V rail these voltages are generated out of the 5V rail, using a linear regulator (3.3V) and a charge pump (12V).

E-Magnet Driver EMD:

The EMD module is a multipurpose module it can be used to drive e-magnets (solenoids), thermal heaters and simple motors.

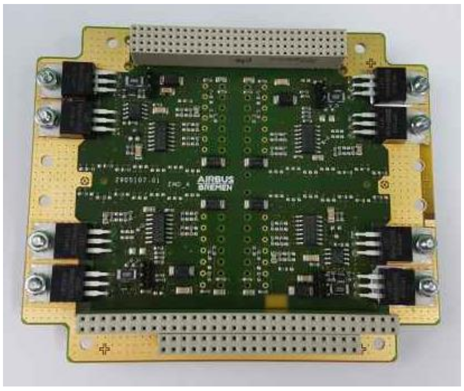

Figure 13 – EMD overview

The EMD PCB incorporates up to four EMD modules. The EMD consists of a LCL, an on/off switch and limit comparators for voltage and current monitoring. The loads are supplied by using the 48V power bus

5 VERIFICATION AND VALIDATION

The development models of the tools have been verified in dedicated component test benches to test the repeatability, the torque control and the functionality of the individual sockets. The validation has been performed in a dedicated testbed in the Airbus Defence and Space robotic lab in Bremen (Figure 14). The testbed consists of two payload slots similar to those of the Bartolomeo platform, a system control desk next to the testbed and a separate ground control station.

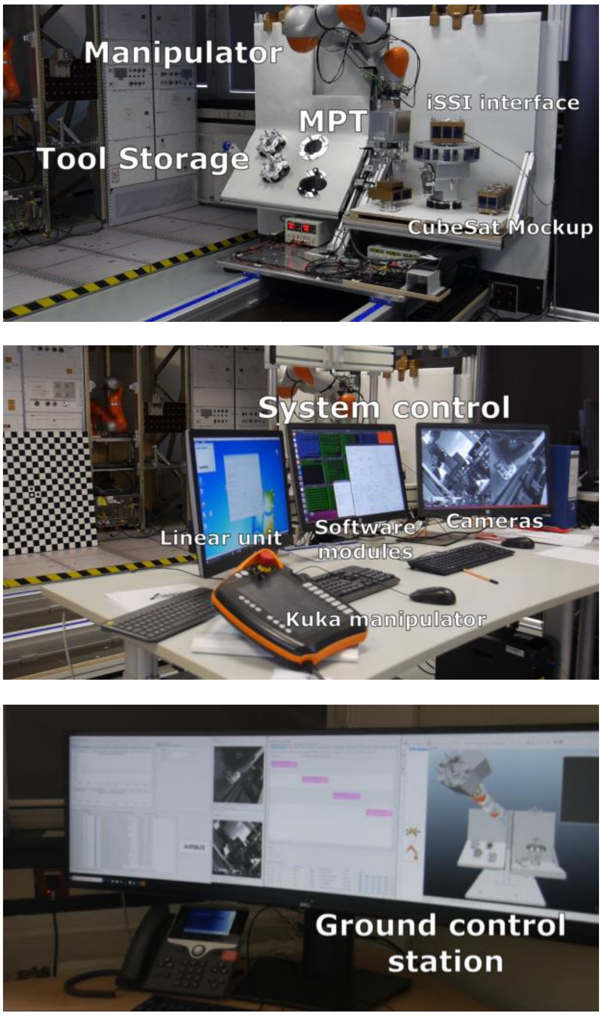

Figure 14 – The RISMAT Testbed with Ground Control Station

The testing with a realistic operational set-up was important to understand the flaws in the design and to check that the situational awareness with the given sensors, the robotic simulator and the camera views is sufficient for an effective and safe execute of the tasks.

6 CONCLUSION

The presented architecture and design of the Multi Purpose Tool (MPT) and the different tool sockets provides solution for mission with the need for multiple tools. The developed tools were successfully validated in a operational scenario which is crucial to ensure that the situational awareness is sufficient and the operations can be realized with the tools. In the project STARLIT[1] the tools and their attachments are further developed and an engineering model is produced and tested. Furthermore, it is foreseen to use those tools in the PERIOD in-orbit demonstration, which is planned as the next development step. This will provide confidence in complex robotic operations to convince investors and customers that the commercial space robotic use is mature and provides a benefit for future mission and orbital services [7].

7 REFERENCES

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