pro2 network+
devices-lab.org
/summerschool

Dexerous End-effector for Space Operations (DEXO)

Yun-Hang Cho
iForge Makerspace
University of Sheffield
Sheffield, UK
y.h.cho@sheffield.ac.uk

Abstract*—Space robotic arms are used for a variety of purposes from assembly to inspection. Historically the objects being picked up by the robotic arm has been co-designed. However, future applications include grabbing other objects such as space junk. Hence, future robotic arm end-effectors need to more adaptable. More objects of different sizes will need to be handled in addition to more complex operations. This paper presents the design of a next generation end-effector with smarter process monitoring and control hardware. This new hardware platform will enable more advanced software data processing, thus unlocking the possibly of new developments in Artificial Intelligence and Internet-of-Things to be implemented.

I. Introduction / Background (Sytle: Heading 1)

Robotics have the potential to protect humans by carrying out tasks which are Dull, Dirty and/or Dangerous[1]. There is perhaps no better example of this than the outer Space environment. With zero gravity, no air, and harmful levels of radiation, it is quite dangerous for astronauts to leave their space station to carry out extra-vehicular activities. Thus, robotic arms such as the CanadaArm and the European Robot Arm on the International Space Station are vital pieces of technology.

Robotic end-effectors, the components at the end of robotic arms designed to interact with the environment are one critical piece of the robotic arm that require particular attention. In the past, these are extremely specialised tools based on expert knowledge of the environment and the target it is supposed to interact with. However, as the industry moves towards modular space construction, the robotic arm end-effector will need to interface with an increasing range of different sized objects and materials. To complicate matters more, These objects may not be fixed and can be rotating or tumbling in space. Hence, the end-effectors should have additional smart sensing instruments attached to permit a more dynamic control system with a rapid response to the changing orientation and position of the target object.

One particular issue is that in microgravity, objects released may often float away. Imagine a robotic arm with an allen key for an end-effector. It attempts to remove a bolted part from a satellite structure. As soon as the part has been detached from the structure, it will begin to float away. If one does not wish to have another second robotic arm to hold the part during this operation, then the existing robotic arm must be able to simultaneously hold the part and undo the bolting mechanism/fixture.

II. Related Work

The European Robic Arm (ERA) is a robotic arm currently in operation on the Russian Segment of the International Space Station (Fig. 1.). One unique aspect of the arm is the ability to “crawl” along the outside of the space station. This is enabled through the use of grappling fixtures on both ends of the robotic arm (Fig. 2.). These can connect to different base points on the space station so that the base and end-effector actually becomes interchangeable.

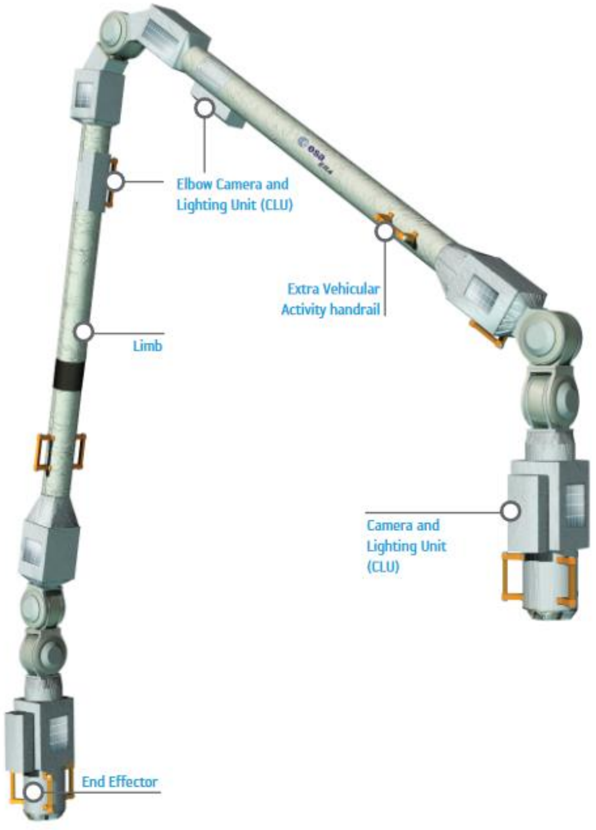

Fig. 1. European Robotic Arm [2]

Due to the variety of tasks that a robotic arm should fulfil, the end-effector should be multi-functional. Examples of this include the robotic arm on the now cancelled NASA OSAM-1 project [3]. Known as Space Infrastructure Dexterous Robot (SPIDER), it was supposed to assemble different parts together to create a 3m long communications Ka-band antenna. In addition to grabbing and releasing objects, other operations might include inspection or other more complex tasks. Thus, a flexible interface is required to enable the future development of a set of End of Arm Tools (EOAT).

Fig. 2. End-effector on the European Robotic Arm [2]

This is exemplified in the Dextre "robotic man" (officially named the Special Purpose Dexterous Manipulator SPDM) [4]. Launched in 2008 to the International Space Station, Dextre has two arms with interchangeable end effector and tools to enable fine motor control operations. For example, grippers, cameras and cutters. The arm can operated remotely and also autonomously meaning that ground operators can carry out tasks on the International Space Station whilst the astronauts are asleep or occupied. It has serviced as a vital tool for maintenance and demonstration of future technologies such as refuelling of spacecraft.

III. IMAGINGED OR EXISTING PROTOTYPE SKETCHES/DRAWINGS/PHOTOS

A. *Spin-in technologies: Direct inspirations from Earth*

Many Earth based tools are designed to be interchangeable. For example, my KC200f Black and Decker multi-functional drill has a spindle shaft that is used to transfer power to either a drill, a sander or a jigsaw (Fig. 3.).

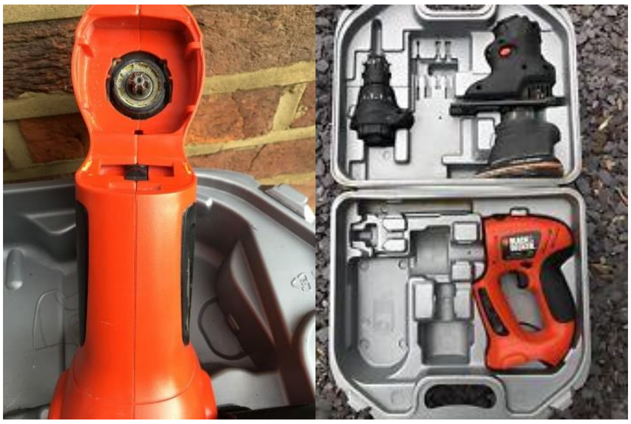

Fig. 3. KC200f Black and Decker multifunctional tool

One of the proposed design features will use the same idea with the "palm" of the robotic arm having a spindle that can be used to provide mechanical power to various tools. I see this as a early precursor to the oscillating power tools that have become popular in the last 10 years. This will be able to unlock fastening mechanisms.

The details of the imagined of existing prototype should be described in body text. Explain what components and materials you have used or intend to use, including part numbers where possible. If the components are hard to source explain where you got them from. Explain how you built or intend to build the prototype.

Include lots of diagrams, sketches, photographs etc. – as many as possible! Paste them inline into the document; don't worry about adding figure numbers and captions if it feels too complicated, but make sure the text directly above or below each image explains what is in each image. Insert a link to an online video if you think that could be useful.

B. *Mechanical Design*

The mechanical design of the end-effector is a tube structure that matches with typical robotic arm lengths. In the middle is the spindle which provides mechanical power to any attached tools. On the outside are four small robotic fingers which extend out to grab objects. If a tool is picked up instead, these fingers guide the tool to mate with the spindle interface so that mechanical power can be transferred (Fig. 4.).

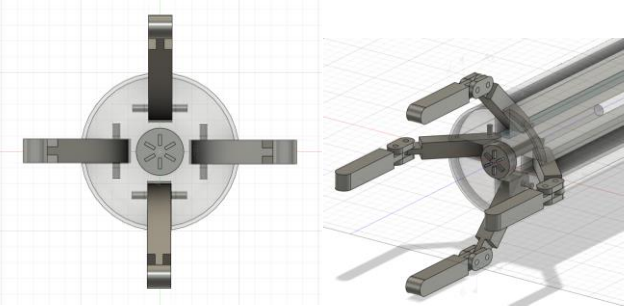

Fig. 4. CAD model of the DEXO design

A video animation of the robotic end-effector design can be viewed here: https://youtu.be/6Xiq90QcWOU

A further set of four longer "fingers" are located behind the small ones (not shown in the video). These enable larger, wider objects to be manipulated. The mechanical action of each finger is achieved using a motor.

C. *Electrical Design*

The electrical design serves two primary functions:

Firstly, to provide power to the 9 motors (4 for the small fingers, 4 for the long fingers and 1 for the spindle).

Secondly, they provide feedback and control. Each of the finger motors use stepper motors with position and force encoders to ensure accurate positioning and torque control. This prevents the fingers from damaging any parts by limiting the maximum force which can be applied.

The spindle is powered using a DC motor. All of these are controlled using an Arduino Mega with motor control modules.

The prototype system is controlled by an Industrial Raspberry Pi (Fig. 5.). This can receive remote uplink/downlink through an RF module. Linked to this are two sensors, the Logitech C920 optical camera provides approximate position awareness whilst the LIDAR sensor (model not yet selected) provides precise range measurement for control.

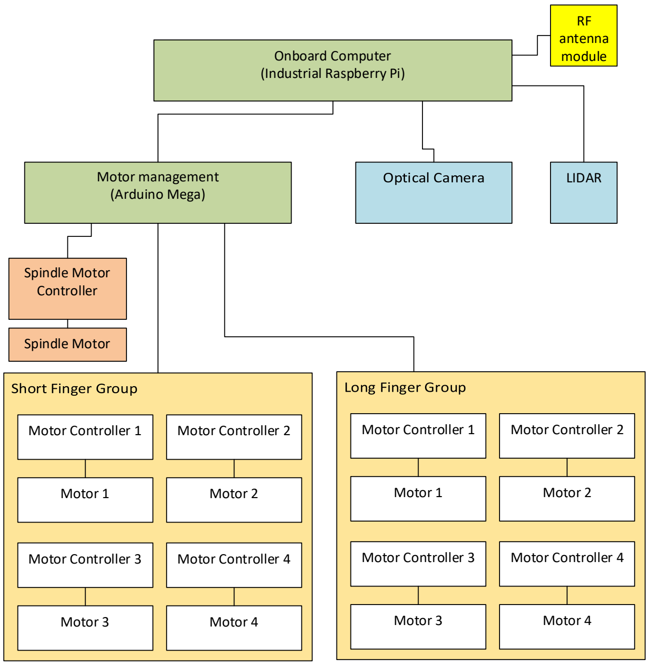

Fig. 5. System Architecutre of the DEXO design

IV. Responsible Innovation and Conclusion

This design is intended to assist with In-orbit servicing of satellites. By extending the life of satellites, there will be less space junk generated. Space debris is currently a very big problem as old satellites are decomposing into smaller pieces creating a huge hazard for all users.

V. Author Bio(s) / Experiences

Dr Yun-Hang Cho is currently a process monitoring and control systems Engineer at the Advanced Manufacturing Research Centre. He has a strong passion for Space and founded the Sheffield Space Initiative in 2017/2018 to enable more students to experience working on real space projects with NASA and ESA. This work includes the design and qualification of two-axis robotic pointing systems for solar observation on high altitude balloon platforms [5], [6], [7]. The Sheffield Space Initiative has now produced over 500 Space Engineers with the Sheffield rocketry team holding the UK national open attitude record [8]. In his spare time, he volunteers at the University of Sheffield's iForge makerspace. Through his prior space project experiences, he has developed a firm belief in rapid physical prototyping to reduce the duration of design cycles for rapidly maturing designs. He also provides support to various space organisations such as the national UK Space Agency as an expert reviewer.

Additionally, through his role leading space sector engagement at the Advanced Manufacturing Research Centre, he also presented the UK trade mission at the Singapore Global Space Technology Convention and at the European Space Agency's Technology Harmonisation Road mapping meetings. Other Space exploration work that he is involved in ranges from planetary science [9] with the California Institute of Technology to in-situ resource utilisation on the Moon and Mars [10].

VI. Acknowledgements

This work was not funded.

VII. Refernces

[1] "Robots Tackling the Three D's of Industry." Accessed: May 24, 2024. [Online]. Available: https://blog.robotiq.com/robots-tackling-the-three-ds-of-industry

[2] H. J. Cruijssen, M. Ellenbroek, M. Henderson, H. Petersen, P. Verzijden, and M. Visser, "The European Robotic Arm: A High-Performance Mechanism Finally on its way to Space CORE View metadata, citation and similar papers at core.ac.uk provided by NASA Technical Reports Server", Accessed: May 24, 2024. [Online]. Available: https://ntrs.nasa.gov/search.jsp?R=20150004070

[3] "On-orbit Servicing, Assembly, and Manufacturing (OSAM) State of Play A document from the OSAM National Initiative to characterize the current state of OSAM capabilities".

[4] E. Coleshill, L. Oshinowo, R. Rembala, B. Bina, D. Rey, and S. Sindelar, "Dextre: Improving maintenance operations on the International Space Station," *Acta Astronaut*, vol. 64, no. 9–10, pp. 869–874, May 2009, doi: 10.1016/J.ACTAASTRO.2008.11.011.

[5] Y.-H. Cho, G. Heung, Y. Bobrov, J. Middleton, G. Verth, and V. Fedun, *SunbYte: A framework for low-cost robotic solar telescopes on high altitude balloons*. 2023. doi: 10.21203/rs.3.rs-2579655/v1.

[6] Y.-H. Cho, Y. Bobrov, G. Heung, S. Shah, and V. Fedun, *Sheffield University Solar Balloon Lifted Telescope (SunbYte - BEXUS 25, HASP 2018, HASP 2019)*. 2019.

[7] Y.-H. Cho, G. Heung, G. Verth, and V. Fedun, *Sheffield University solar balloon lifted telescope (SunbYte - BEXUS 25)*. 2018.

[8] R. Clear, Y.-H. Cho, I. Bobrov, and V. Fedun, "The Sheffield Space Initiative - Introduction motivations and impact assessment," pp. 116–120, Jul. 2020, doi: 10.29311/2020.29.

[9] A. N. Deutsch *et al.*, "The ETNA mission concept: Assessing the habitability of an active ocean world," *Frontiers in Astronomy and Space Sciences*, vol. 9, Dec. 2022, doi: 10.3389/FSPAS.2022.1028357.

[10] F. Tng and Y.-H. Cho, *Exploring Otherworldly Depths: Evaluating Earth's Robotic Cave Exploration Technologies for Subsurface Exploration on the Moon and Mars*. 2023.