Beyond the Final Frontier: Controlling Robotics for Space Use

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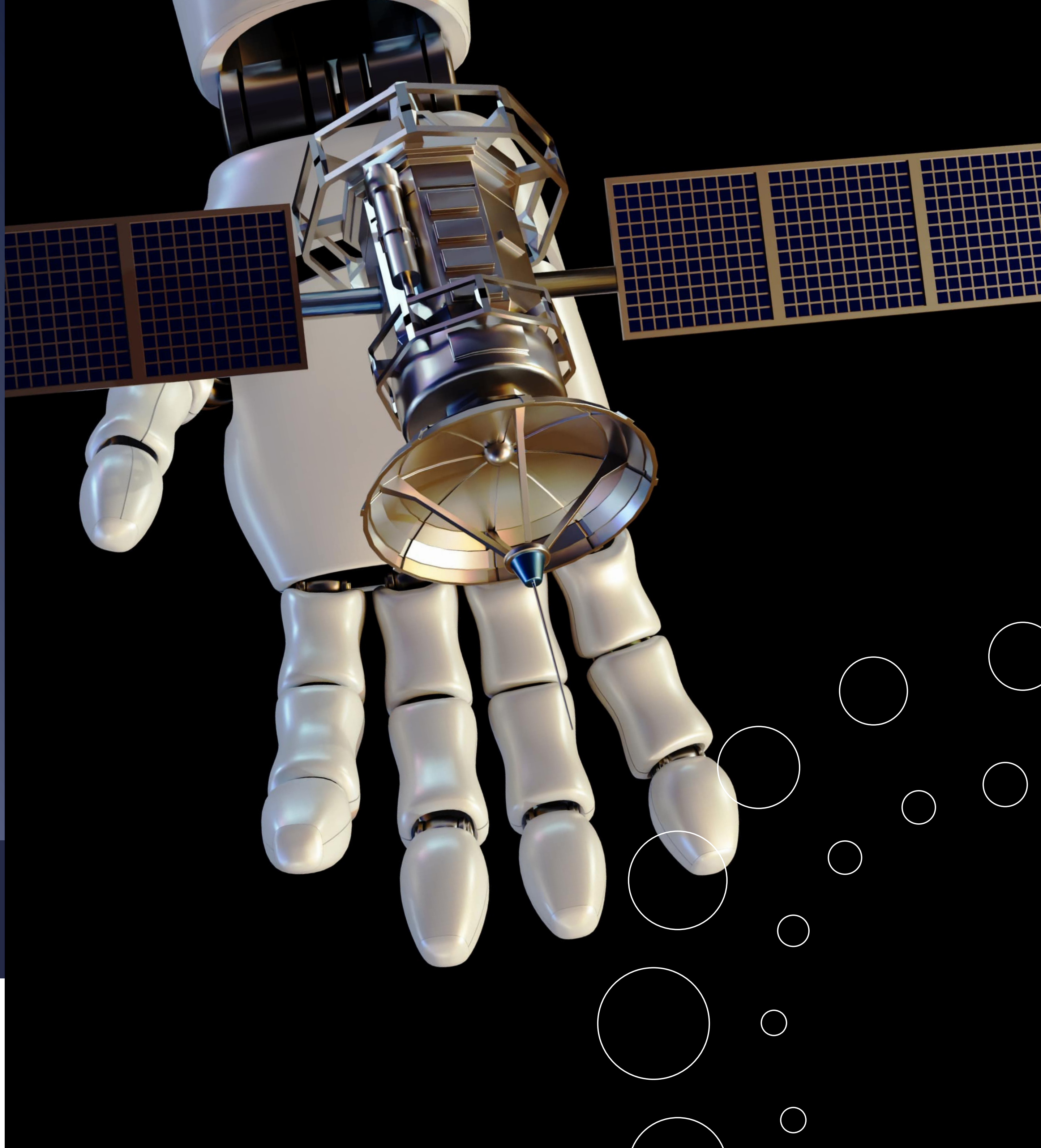

Beyond the Final Frontier: Controlling Robotics for Space Use

As we explore more of the cosmos, there is an increasing interest in using robotic systems in space, such as rovers, to explore and map out territory or robots to assemble and maintain structures. Dr Sean Kalaycioglu from Toronto Metropolitan University (TMU) and Canadian Space Research Inc. in Canada researches how these systems can be deployed and designed to tackle the unique challenges faced by robots in these environments. Working with his colleagues, Dr Kalaycioglu also develops algorithms and models to optimise the control and performance of these systems.

Robotics as a Key Tool for Space

Space exploration has developed exponentially since the first space flights of the 1900s. Today, robotic technologies can play a key role in the scientific and engineering challenges that the future of space exploration holds. Autonomous robots, designed to carry out tasks and deal with their surroundings without constant human control or input, can be used as rovers to explore different environments and used to service and assemble equipment. In the not-too-distant future, these robots may even be able to construct large space structures using multiple robotic systems simultaneously.

Whilst there are many potential applications for this technology within space exploration, the design and control of these systems require detailed consideration and study. Dr Sean Kalaycioglu from the Department of Aerospace Engineering at Toronto Metropolitan University (Canada) works with his colleagues to develop these systems through the use of control algorithms, or mathematical steps to solve the problem, which account for the unique materials and structures the robots consist of and take into account the different tasks and situations the robots may face. By developing these systems, Dr Kalaycioglu can innovate these new technologies and expand the potential of these robotic systems.

Using Control Algorithms to Optimise Performance

Control algorithms are used in many areas of engineering and design. These algorithms aim to take a set of inputs – for example, readings from sensors on the robot or information about what stage of a process it currently is in – and feed them into an algorithm which takes these into account whilst trying to progress towards its goal. They also usually aim to minimise delay times and overshooting or going beyond the expected target.

Dr Kalaycioglu and his colleagues have developed a new control algorithm for a system with multiple rover robots, each with a robotic arm, who are sharing the handling of a large portion of a structural assembly that is key to the mission, called the payload. These rovers have mecanum wheels – these are wheels without tyres and, instead, have rubber-like rollers attached around the rim. The angle of these rollers allows for the wheels to last longer and gives more control in narrow spaces and manoeuvrability in many different directions.

In their algorithm, Dr Kalaycioglu and his colleagues consider how to reduce the forces experienced by the joints in the arms of the rovers and the mecanum wheels when turning or twisting. By minimising these forces, the algorithm helps to prevent joint torque saturation when handling the payload – this occurs when the motors causing the turning force are running at maximum capacity, and this can cause damage if used for extended periods of time and cause the motors to degrade more quickly. Minimising these forces can overcome the issue. The team's algorithm also allows for the movement of the rovers and their arms to be calculated during the operation so that how they handle the payload can be adjusted in real time.

To verify this, Dr Kalaycioglu and his colleagues have carried out multiple simulations to show that it minimises these turning forces, and also that the robots still take the payload to where it needs to go – showing how it is both useful and efficient in the challenging conditions of space.

Models for Predictive Control

Alongside control algorithms, other models can be used to help these robotic systems perform optimally in space. Model Predictive Control (MPC) can be used in many complex dynamic systems, and works by feeding in some current measurements of the system, the system's current progress in the process it is aiming to carry out, some targets and limits of the system and a model of how we expect the system to behave. It uses this information to calculate how to alter parts of the process to get a result that is as close to the target outcome as possible without overstepping its limits.

Traditional MPC often uses linear, or lower order, mathematical calculations known as cost functions to work out what changes to make to get as close to the output goal as possible within the constraints of the model. However, Dr Kalaycioglu and his team have found that this linear model is insufficient for our system of multiple rovers handling a shared load, as the dynamics and constraints of the system are too complex. To overcome this, they propose either optimal control allocation (OCA) or non-linear model predictive control (NMPC).

OCA uses a higher order, containing mathematical terms, which are squared and quadratic cost functions, to calculate the best outputs for the system. It takes in information from the current state of the system, and then calculates the output trajectories for the rovers before they make contact with the payload using the cost function. This method uses less computational resources or is more computationally efficient.

NMPC builds on the inputs of MPC, but it differs from OCA as it also factors in a prediction of the future state of the system to estimate future values of the robot's trajectories. Then, instead of a linear cost function, a quadratic cost function is also used. Through simulating this, Dr Kalayocioglu finds that, whilst NMPC is more demanding on computational systems, it is more effective than OCA and offers exciting potential for cases where the rovers need to carry a heavy load with precise control.

Dr Kalaycioglu and his colleagues also consider how these control algorithms could be used in a situation where a robotics spacecraft could be used to carry out maintenance of satellites in orbit or to carry out assembly of space structures in orbit. They consider a spacecraft with two robots and a payload. They compare the use of OCA here, extending it to include the spacecraft with arms and NMPC, where the NMPC predicts the future behaviour, but the OCA just takes into account the current and past behaviour of the system. Through their simulations, Dr Kalaycioglu shows that both of these algorithms are effective but that the NMPC provided the best results in minimising the forces on the joints.

Optimising Predictive Control Models for Different Applications

In addition to using multiple rovers to manipulate payloads, there is also the possibility of using multiple robots to carry out the upkeep of space structures and even to assemble new ones. Here, Dr Kalaycioglu and his colleagues have devised a passivity based non-linear model predictive control system (PNMPC) to use in these applications. This builds on the ideas from NMPC but adds constraints from passivity – namely, this places conditions on a storage function or the measure of the energy stored in the system at some time.

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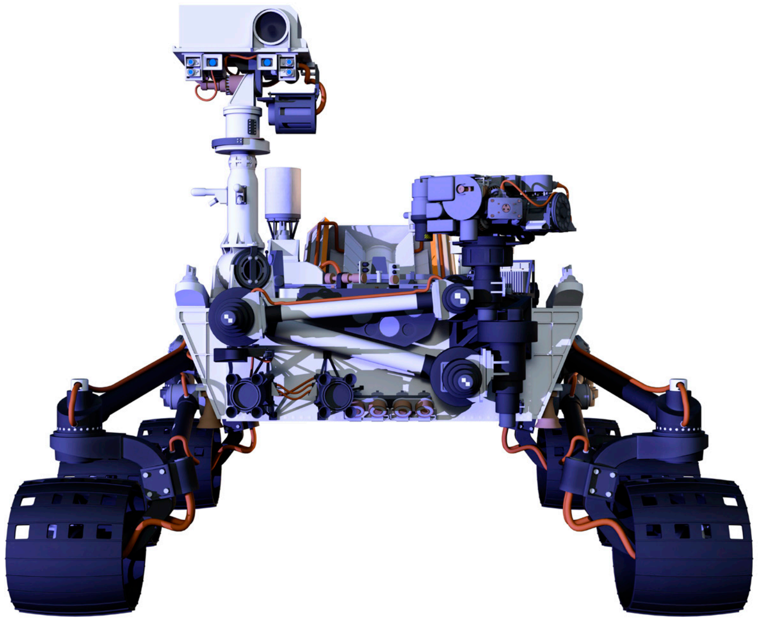

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From control algorithms for rovers handling a shared task and considering optimal model predictive control for different scenarios to considering future systems for lunar exploration, their simulations and optimisation show the importance of effective control in these challenging environments.

By incorporating this passivity constraint into their PNMPC, Dr Kalaycioglu and his colleagues show through simulations how PNMPC is successful in ensuring the stability and optimisation of these applications, but also how it performs better in tracking the performance of the systems. This means it could be useful in these exciting new applications for assembly and maintenance situations using multiple robots.

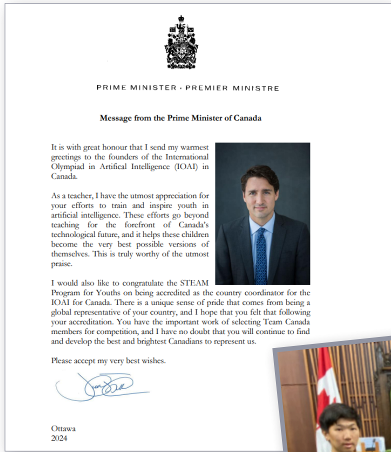
Innovation and the Future of Robotics Evolution

Finally, Dr Kalaycioglu and his colleagues at TMU and Dr. Robot Inc. are looking at how design principles can be used to innovate in developing a Lunar Exploration Rover System (LERS). This system would aim to explore the moon through tasks such as gathering samples of rock and soil or trying to map out the moon's surface in increased detail, for example, and overcome the challenges posed by the complex environment and landscape on the moon.

Dr Kalayocioglu's architecture for LERS consists of two parts: remote subsystems of smaller rover robots to carry out tasks, accompanied by a communication interface to a local subsystem where human operators can oversee the deployment of these rovers. The rovers are equipped with an arm and designed to deal effectively with the moon's terrain. They also feature a command, control and communication system to allow for data transfer with the control station, computer vision and interfacing with the local subsystem.

While LERS is still under development, Dr Kalaycioglu and his team have developed a testbed to evaluate the system and its capabilities. They are also considering how control algorithms can optimise the rover's performance. However, it highlights the continual development and innovation in the field and shows how, in the future, we could have highly sophisticated technologies to take on these tasks.

Overall, Dr Kalaycioglu and his colleagues are working on the development of control systems to optimise our use of robotics in space. From control algorithms for rovers handling a shared task and considering optimal model predictive control for different scenarios to considering future systems for lunar exploration, their simulations and optimisation show the importance of effective control in these challenging environments. By minimising moments and forces that could negatively impact these systems and ensuring the robots can carry out the task at hand, Dr Kalaycioglu's work holds the potential to be key for future space exploration – allowing us to learn more about our own cosmos.



PRIME MINISTER · PREMIER MINISTRE

Message from the Prime Minister of Canada

It is with great honour that I send my warmest greetings to the founders of the International Olympiad in Artifical Intelligence (IOAI) in Canada.

As a teacher, I have the utmost appreciation for your efforts to train and inspire youth in artificial intelligence. These efforts go beyond teaching for the forefront of Canada's technological future, and it helps these children become the very best possible versions of themselves. This is truly worthy of the utmost praise.

I would also like to congratulate the STEAM Program for Youths on being accredited as the country coordinator for the IOAI for Canada. There is a unique sense of pride that comes from being a global representative of your country, and I hope that you felt that following your accreditation. You have the important work of selecting Team Canada members for competition, and I have no doubt that you will continue to find and develop the best and brightest Canadians to represent us.

Please accept my very best wishes.

Ottawa
2024

MEET THE RESEARCHER

Dr Sean Serdar Kalaycioglu, Department of Aerospace Engineering, Toronto Metropolitan University, Ontario, Canada

Dr Sean Kalaycioglu obtained his BSc from the Middle East Technical University in 1984, followed by a PhD from McGill University in Canada in 1988. Dr Kalaycioglu has undertaken several academic roles throughout his career, with an overarching interest in the dynamics and control of robotic systems for use in space. He is now a research fellow at Toronto Metropolitan University and concurrently President at Canadian Space Research Inc. He has held several roles within industry, including working with the Canadian Space Agency and holding the position of Director of Space and Robotics Programmes at Dr. Robot Inc. Alongside his scientific work, he has obtained Master of Laws degrees from the University of London (UK) and Osgoode Hall Law School, York University (Canada) and an MBA from Edinburgh Business School at Heriot-Watt University (UK). Dr Kalaycioglu has published widely and been recognised in his field through numerous accolades and achievement awards. Earlier this year, he was appointed Associate Editor at Frontiers in Robotics and AI. Most recently, Dr Kalaycioglu received a Recognition Award from the Prime Minister of Canada for his contributions to the International Olympiad in Artificial Intelligence Canada, of which he is currently Chair and President. He is also an Editor for the *Advances in Science, Technology and Engineering Systems Journal* (ASTESJ).

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Dr Haipeng Xie, Dr. Robot Inc.

FURTHER READING

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