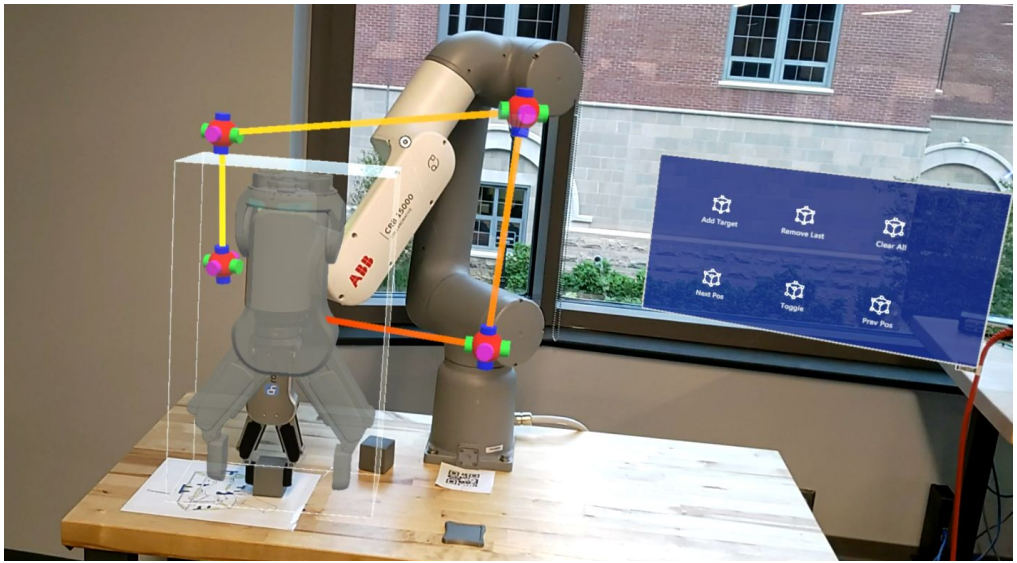
Path Programming for Industrial Robots

Related work, ideas and prototype

What is path programming?

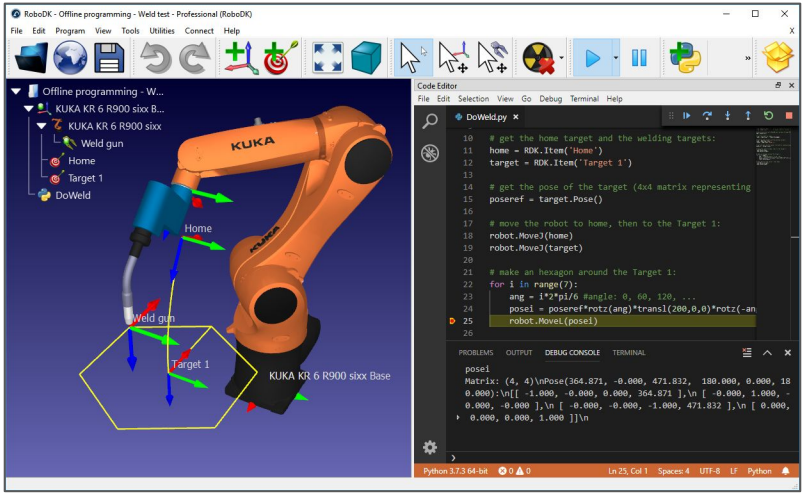
We call path programming the programming method where the user defines instructions for a robot through an interface that is based on a directed graph. Path programming can be an alternative to conventional programming methods found in industrial robots (e.g., lead-through programming, offline programming).



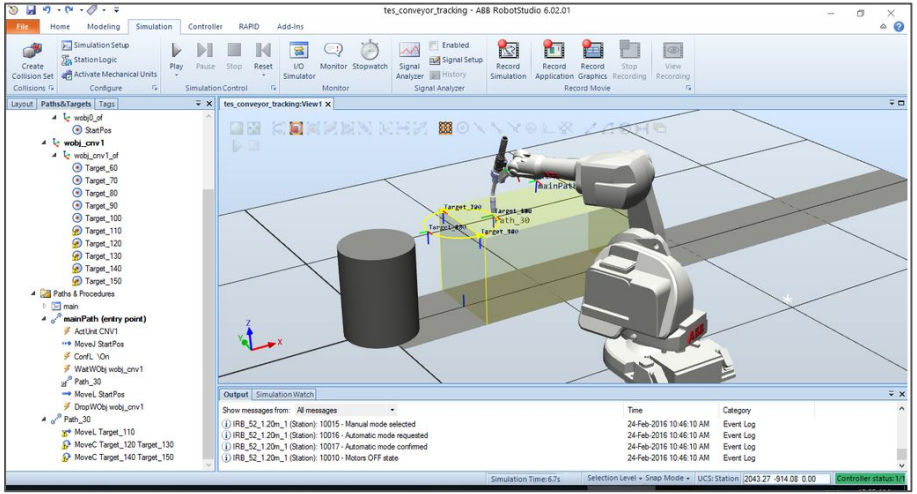
Draft implemented by one of our undergraduate students

Is it something new?

No! The idea of visually representing robot movements through a directed graph is already used by many programming environments such as ABB RobotStudio and RoboDK.



Screenshot from RoboDK



Screenshot from ABB RobotStudio

Image source:
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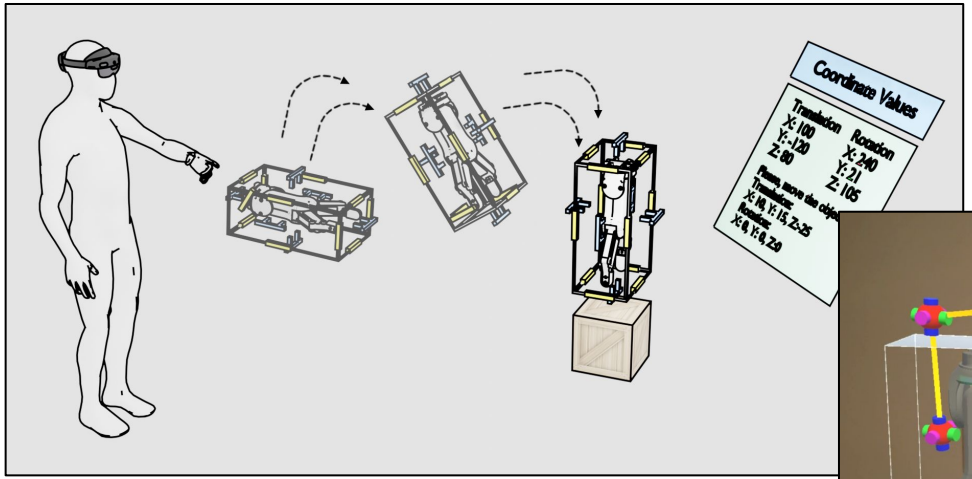
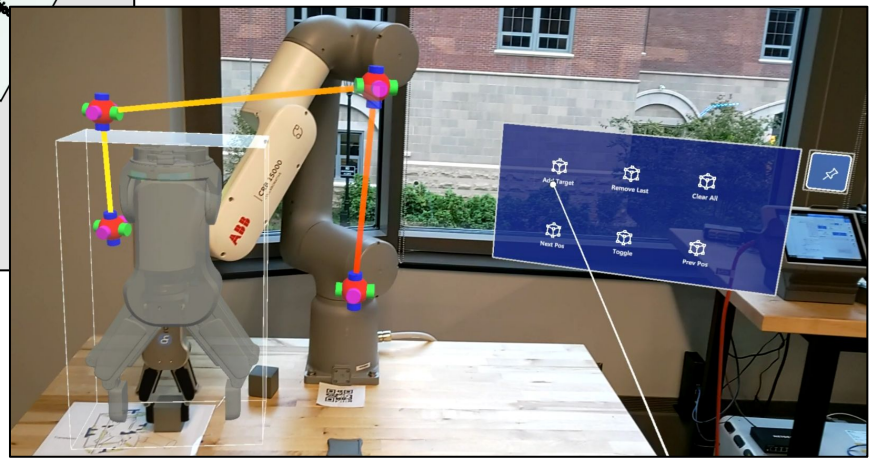
What is our goal then?

Implement a robot path programming environment in mixed reality that is specifically designed for end-users. It should be simple, intuitive and visually appealing. We can combine other recent studies, such as jogging in mixed reality, and create a really powerful programming environment.





What is the state of the art?

We're not the first researchers exploring path programming in mixed reality.

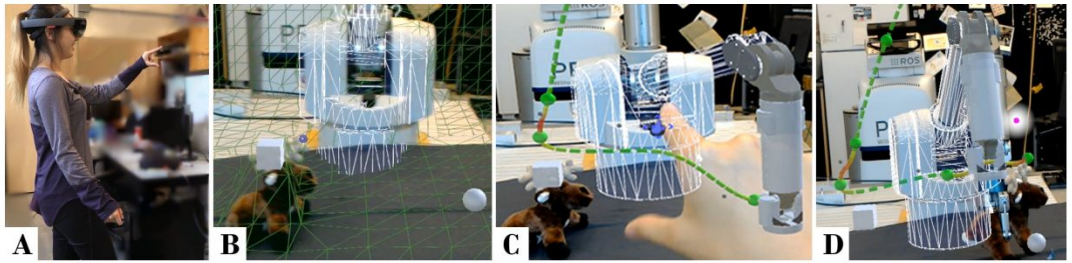


Fig. 3. A pick and place task is completed using our AR Robotics system. (A) An operator wearing the Hololens and gesturing to interact with a 7DOF robot arm. (B) Visualization of, 3D spatial grid, real and virtual robot arm, pick (grey cube) and place (grey sphere) location. (C) Editing visual trajectory by gesturing and then simulate virtual robot through the trajectory. (D) Pick and place execution with virtual and real robot overlapping.

Reference:
Quintero, Camilo Perez, et al. "Robot programming through augmented trajectories in augmented reality." *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 2018.

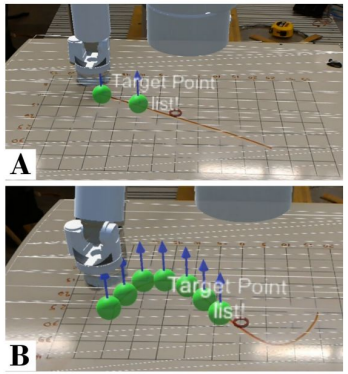


Fig. 6. Participant specifying line (A) and sin (B) shape through the AR-robotic interface.

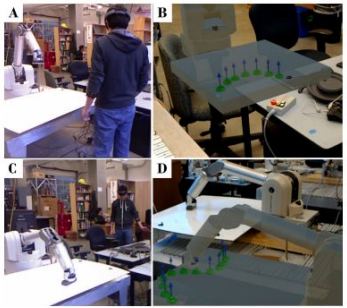


Fig. 4. (A, B) The user set the virtual robot and the CAD model of the dry-erase white board in the side of the real robot and set the path points on the virtual surface. (C, D) The user constrain the end-effector of the robot to the path with an opposite orientation to the surface normals and controls the robot movements inside the path by waving his hand using a MYO device.

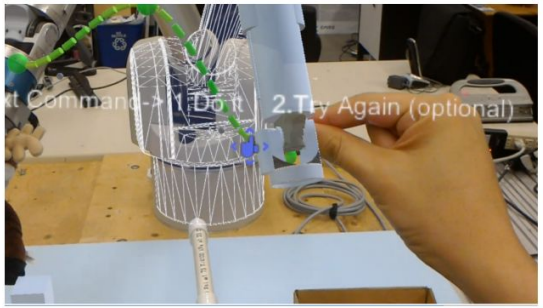


Fig. 7. The participant edits the path to avoid the PVC hurdle and executes a preview to make sure the path is safe.

What is the state of the art?

Most studies are focused on the representation of the direct graph in mixed reality.

Fig. 7. Circle curve. Goal points setting, First arc setting, Simulation.

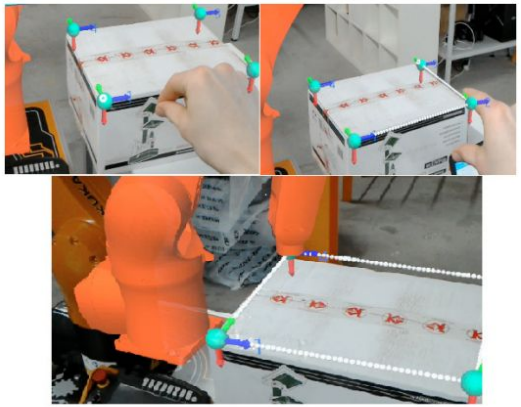


Fig. 8. Rectangle curve. Goal points setting, Lines setting, Path planing.

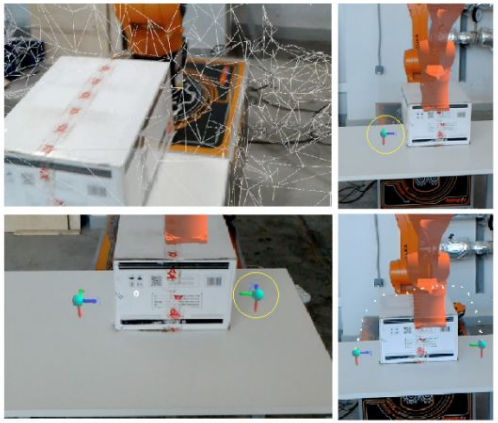


Fig. 6. PTP with collision avoidance. Scanning, Goal points setting, Path planing.

Reference:
Ostanin, Mikhail, and Alexandr Klimchik. "Interactive robot programing using mixed reality." IFAC-PapersOnLine 51.22 (2018): 50-55.

What is the state of the art?

There are also related studies using different technologies for path programming.

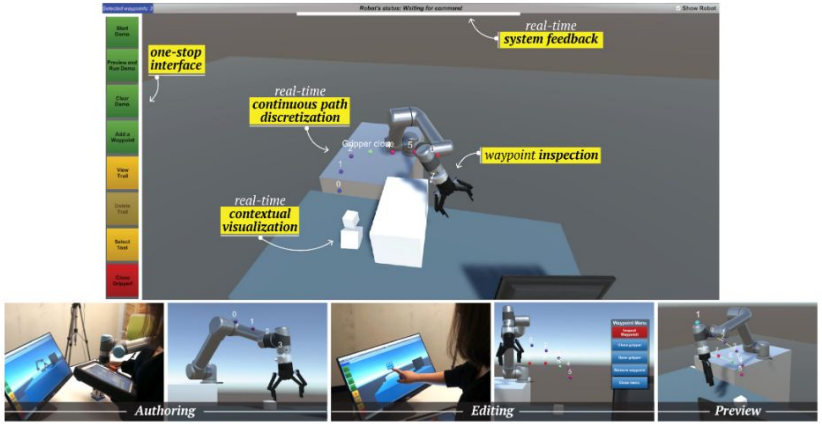


Fig. 3. Demoshop provides users with a one-stop interface through which they can use continuous path discretization to develop and modify programs, mental scaffolds to understand the state of their program, and just-in-time assistance to facilitate their programming process.

Fig. 5. We conducted a between-subjects study in which users were randomly assigned to either a control condition in which they used *Universal Robots*' PolyScope or the experimental condition in which they used Demoshop.

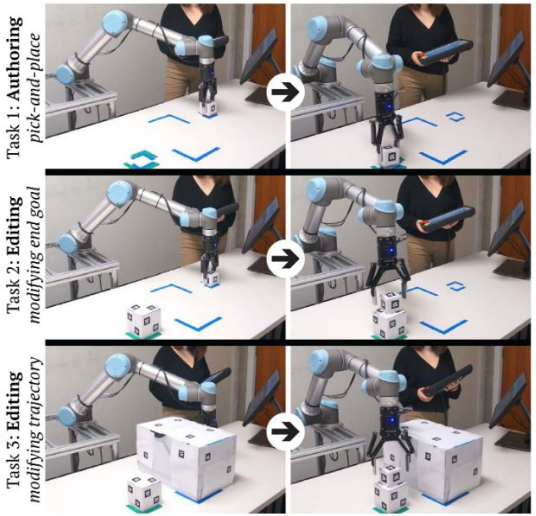


Fig. 4. Our user evaluation consists of three pick-and-place tasks. The first task focused on authoring, while the second and third tasks required the user to edit their existing program to meet new task requirements.

Reference:
Ajaykumar, Gopika, Maia Stiber, and Chien-Ming Huang. "Designing user-centric programming aids for kinesthetic teaching of collaborative robots." Robotics and Autonomous Systems 145 (2021): 103845.

What is the state of the art?

CAD-based environments are a great example of how path programming is important in robotics:

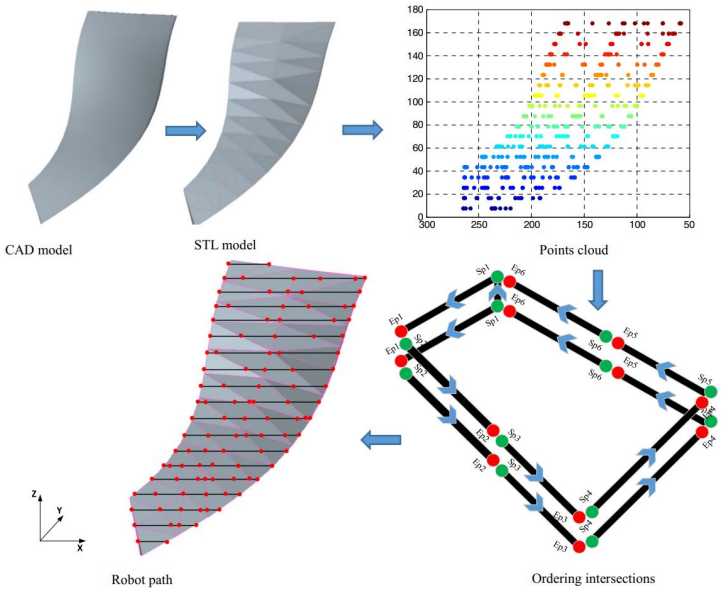


Fig. 10 The process of generating robot programming from CAD

To name a few:

- (Left image) Zheng, Huadong, et al. "CAD-based automatic path generation and optimization for laser cladding robot in additive manufacturing." The International Journal of Advanced Manufacturing Technology 92.9 (2017): 3605-3614.
- Neto, Pedro, J. Norberto Pires, and A. Paulo Moreira. "3D CAD-based robot programming for the SME shop-floor." 20th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM. Vol. 59. 2010.
- Kim, J. Y. "CAD-based automated robot programming in adhesive spray systems for shoe outsoles and uppers." Journal of Robotic Systems 21.11 (2004): 625-634.
- Bedaka, Amit Kumar, and Chyi-Yeu Lin. "CAD-based robot path planning and simulation using OPEN CASCADE." Procedia computer science 133 (2018): 779-785.
- Klein, Alexandr. "CAD-based off-line programming of painting robots." Robotica 5.4 (1987): 267-271.
- Neto, Pedro, et al. "High-level robot programming based on CAD: dealing with unpredictable environments." Industrial Robot: An International Journal (2012).
- Pulkkinen, Topi, et al. "2D CAD based robot programming for processing metal profiles in short series manufacturing." 2008 International Conference on Control, Automation and Systems. IEEE, 2008.

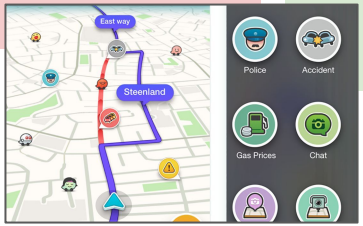
What can we do different?

Limitations identified in past studies:

- Most studies only explore how robots could be moved using directed paths, but do not explore it as an alternative for robot programming, which involves different types of movements, synchronization, gripper manipulation, collision prediction, etc.
- Not all studies clearly specify that their motivations are based on end-users. They don't investigate important aspects such as usability.
- Most studies don’t compare different representations of path programming in mixed reality.

What we could do different:

- Design our prototype as a complete programming environment. Use the knowledge we gained from our questionnaires and apply it to this new experiment to create a beginner-friendly programming alternative.
- Make our study focused on end-users, using as motivation the evolution of collaborative robots and devices such as Hololens. Design an experiment that gets the perspective of end-users on our prototype.
- Create different representations of path programming in mixed reality. Explore what other technologies use to make paths more intuitive and interesting (e.g., Waze).



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