



Maxime Monfort is completing his Master's degree in Mechanical Engineering at Université Laval, which brought him to the Concrete Infrastructure Research Center (CRIB) and specifically to the Université Laval Shotcrete Lab. He is a French student completing his general engineering

studies from Arts & Métiers school in France. His M.Sc. thesis revolves around the challenges of implementing full robotic automation in shotcrete placement. His work focuses on implementing a 3D-depth camera to estimate, in real time, the thickness of the deposited shotcrete layer. He had the privilege to present his work twice with a fellow student, Jongbeom Kim, during the ASA 2024 conference hosted in Austin, Texas. He has been serving as the president of both the ACI and CRIB Local Student Chapters at Université Laval since June 2023.

MONFORT'S RESEARCH PROJECT

SHOTCRETE PROCESS AUTOMATION: SUBSTRATE'S THICKNESS ESTIMATION DURING SPRAYING

For a couple of decades, automation and particularly robotization have had an increasing presence on shotcrete construction sites — in mining and tunneling especially. Currently, it can be used in several stages of a shotcrete project, from spraying of the first layer to placement of the final lining. Everyone working in the shotcrete industry knows that working conditions of shotcreters are not the easiest or cleanest, and some applications require extensive experience and skills. Existing technologies work well to spray a uniform pre-set thickness on walls, but most involve a few minutes' pause in spraying to scan the surfaces to compare a before and after spraying. Further development efforts are required to reach full automation, such as:

1. Scanning the surface to obtain the deposited shotcrete layer's thickness during spraying. This is a crucial point required for the following two.
2. Consistency of an observed thickness (as opposed to an estimated one based on concrete flow and nozzle movement) as the robot's trajectory generation algorithm becomes adaptive in real time. This allows for more precise and reliable spraying thicknesses, especially in changing ground surface conditions.
3. Finally, precise and close-range real-time observations during spraying opens the doors for specific nozzle trajectory generation where placement quality and reinforcement encapsulation (or steel sets, rock bolt plates, lattice girders, etc.) are as important as concrete thickness optimization.

Today, shotcrete automation is focusing on tunneling and mining, but these further improvements in shotcrete

automation can easily expand into other parts of the shotcrete industry.

OBJECTIVES

The Shotcrete Placement Automated by Robot (SPARO) project began in 2019 under the supervision of Marc Jolin at Université Laval. Initially, the research focused on the robot's trajectory for reducing rebound (Germain^{1,2}, 2021; Pastorelli³, 2021; Schaeffer⁴, 2022), but now the main focus of this research work is to explore full shotcrete application automation.

The main purpose of Monfort's project is to find a method to estimate the thickness of the deposited shotcrete layer in real time, i.e. during spraying. After having set the requirements: Observation of a local area about 2 m² (22 ft²) with an accuracy below 10 to 15 mm (0.4 to 0.6 in²), spatial resolution less than 15 mm at a distance between 1 and 2 m (3.3 to 6.6 ft) from the wall, and computing time below 1s to allow real-time analysis. After estimating this local thickness area, the goal is to first display the information to the shotcreter or other crew members (for example the shotcreter assistant or a manager), and in a second phase, transfer the thickness information to the computer controlling the robot. Then the method for presenting the thickness information, especially to humans, need to be reviewed.

RESULTS

A 3D-depth camera was selected after benchmark and lab tests and became the main tool of this research. This camera uses two distinct technologies to estimate depth at 30 frames per second, which allows real-time observation and calculation. Code was developed to start acquisition of the camera to capture and display the thickness of concrete in real time via colormaps with colored gradients (see Fig. 1 below) according to the requirements introduced above.

A current limitation in the study is the requirement for

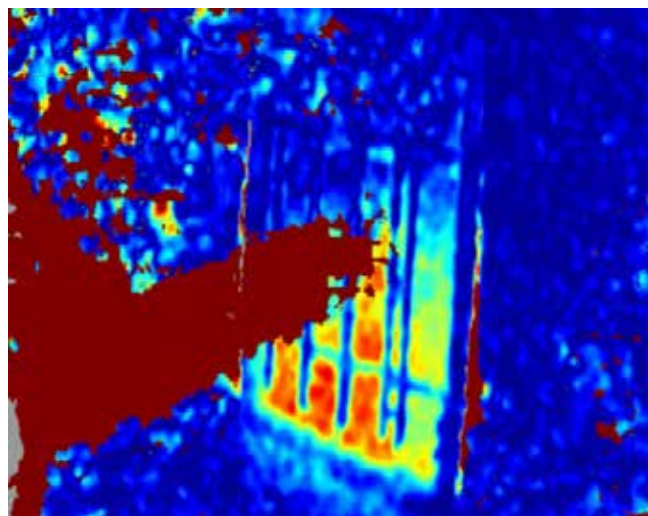


Fig. 1: Thickness observation during placement

the camera to remain fixed during placement; otherwise thickness observation is compromised. Knowing the camera's relative position and including it in the algorithm's inputs are key for the future of the SPARO project. Rest assured, another promising graduate student is already working on this topic (Florian Gayraud).

CONCLUSION & DISCUSSION

The underlying idea of acquiring local information in real time during spraying is fundamental to enabling real advances in automated shotcrete placement. Key functionality is detecting local thicknesses and reinforcing bars quickly and accurately enough to enable trajectory generation and modification based on this observation, rather than using a less precise simulation and theoretical deposition models. This opens the door to real-time spray trajectory optimization that minimizes rebound and maximizes mechanical properties while guaranteeing reinforcement embedment, thanks to AI and manual algorithm drives, for all shotcrete applications. Finally, concrete pumps could also be connected to the spraying robot. The robot could give orders to the pump to adjust its flow rate, its concrete mixture, etc. The camera equips the

robot to adapt its trajectory, responding to spraying hazards.

Better still, the addition of shotcrete layer thickness acquisition to existing lidar technology is very promising. Indeed, information fusion brings confidence, precision, and redundancy, all while expanding the field of possibilities. For example, real-time monitoring and digital twin updating are becoming increasingly feasible. Thus, this research plays a contributing role in the ongoing development of automation of the shotcrete process.

REFERENCES

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