Real-time Path Planning in Remote Robotic Incremental Sheet Forming: A Case of Research Through Design

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ABSTRACT

Industry 4.0 and advanced manufacturing present opportunities to create efficiencies and flexibility in how things are made. Transdisciplinary approaches to research which employ a research through design methodology are well positioned to drive innovation and extend capabilities of integrating processes where humans and robots can work together in collaborative ways to inform manufacturing practices.

Situated within a five year funded research project to develop mass-customisation for advanced robotic manufacturing, this research combines design and architectural research methods with robotic vision expertise. Through remote collaboration across two Australian universities the transdisciplinary research team composed of architectural, interaction design, industrial design, mechatronic engineers, and robotic vision experts were able to overcome COVID-19 related access restrictions to research laboratories and university campuses from March - September 2020. This case study presents a summary of challenges that were overcome using research through design to create real-time path planning and correction for remote robotic incremental sheet forming processes.

CCS CONCEPTS

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KEYWORDS

Robotic Incremental Sheet Forming, Design Robotics, Remote Collaboration, Mass Customisation Manufacturing, Advanced Robotics, Industry 4.0.

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1 Introduction

Incremental Sheet Forming (ISF) has been used for decades to form metal sheets without the use of a die. ISF processes have increasingly become automated through CNC machining and robotic fabrication processes. This paper presents a case study of a research through design approach to address the challenge of creating real-time path planning and correction for ISF. This was overcome by integrating robotic vision technologies into a remote collaborative robotic ISF process where we investigate and created prototypes for architectural facade applications during the COVID-19 pandemic and lockdowns in Australia during 2020.

2 Context

Design Robotics is a program of research part of the QUT Design Lab in Brisbane Australia. This program was initiated through a large project "Design Robotics for Mass-customisation Manufacturing" funded by the Innovative Manufacturing Cooperative Research Centre (2017-2022). It is in collaboration with industry partner UAP (Urban Art Projects) and university partners Queensland University of Technology and RMIT University. This research was embedded within the industry partner's manufacturing operations to address challenges in robotic polishing of "one-of-a kind" and bespoke metal cast artworks and architectural pieces such as facades. Some of these challenges can be named as path planning for every different work piece and the difference between the digital model and the actual metal cast piece. This research requires trans-disciplinary approaches from expertise across interaction design, architecture, industrial design, robotic vision, and mechatronic engineering. Our approach places design and its processes and thinking at the forefront of robotic research to enable design-led manufacturing within the context of Industry 4.0 [2].

The manufacturing industry is undergoing massive transformations due to technological advances in robotics, artificial intelligence, the internet of things, mixed realities, and big data. This transformation, relying on advanced manufacturing technologies, is referred to as 'Industry 4.0,' which is also driving transformation in adjacent industries, such as construction and supply chains. Industry 4.0 presents opportunities to create efficiencies and flexibility in how things are made, create new professions, job prospects and career pathways, increase mass-customisation capabilities, and de-centralise procedures [5].

Through remote collaboration across two Australian universities the transdisciplinary research team were able to overcome COVID-19 related access restrictions to research laboratories and university campuses from March - September 2020. Knowledge sharing was established through the use of multiple platforms including slack, github, and zoom.

3 Methodology

To address the research aims this project employed a Research through Design (RtD) methodology [1] [6] focusing on making objects that inform the transformation of the world from its current state into a preferred or improved state [6]. Our purpose was to develop and implement designed artefacts with the intention to learn about particular facets of human experience [3] [4] with a collaborative robot.

A research through design methodology [6][1] was used to incorporate multiple iterations, experiments, and prototypes to develop the remote robotic ISF process and integrate the real-time path planning. Based on observations, research notes, photographic and video recordings the process has been documented and evaluated. This paper reports a summary of the challenges, opportunities, and benefits of integrating real-time path planning into Incremental Sheet Forming with a collaborative robot.

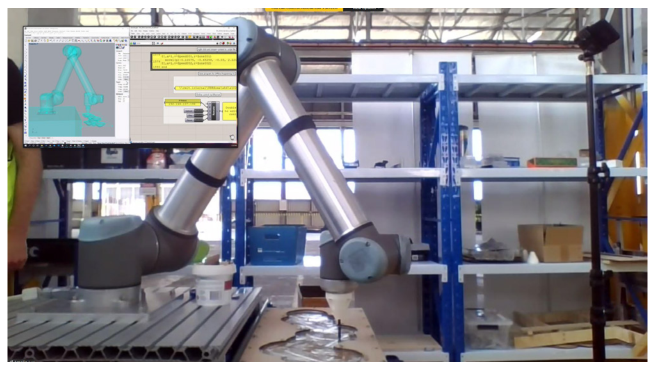

Figure 1: UR10 collaborative robot ISF process in Brisbane and real-time digital twin being operated from several hundred km away in Melbourne.

4 Experimental Setup

The challenges encountered during this process were mainly based on developing appropriate physical and digital tools such as jigs, 3D printed end effectors for the UR10, and grasshopper codes. The material testing involved a selection of thin sheet metals ranging from 0.3 mm to 1 mm. By visually monitoring robot path velocity and fidelity and reading the robots' electric power consumption per rotational joint, it was understood that 0.3mm annealed aluminum sheets were the most appropriate for the scale of the set up and the 10kg force payload of the UR10. The QUT research team in Brisbane had to duplicate the setup that was initially designed and trialed at RMIT in Melbourne which consisted of the robotic arm, a FDM printed tool mount, a spherical die as the tool tip, a rigid frame for mounting the sheets onto and the table onto which the robotic arm was mounted. This occurred across two states with border closures due to COVID-19, meaning that team members could not visit one another in person. All information about the setup and entire code packages were shared and communicated virtually through zoom meetings, slack channels, githubs and videos. The concept was laid out that besides the potential of scalability across materials, the opportunities of this process are the utilization of a new closed-loop system and the product development of this advanced "box" for non-standard production of elements at low costs to be made available for SMEs.

5 Results

Initial tests included various geometries such as cones and polygonal shapes of different sizes. It was understood that the later necessitate the rapid change of direction and speeds of the tool tip which led to lower fidelity in the results. Circular shapes, however, have proven to allow for a more smooth motion. In addition, several tests were conducted to reduce the visual impact of the tool engaging and disengaging with the material and the directionality of the forming process. It was also shown that lubrication between the tool and the material reduces friction, thus overall increasing visual fidelity to the designed specimen. To summarize these early results it can be stated that the experiments showed promising results when it comes to dimensional stability of the weak material when in unformed condition and high fidelity to the digital design.

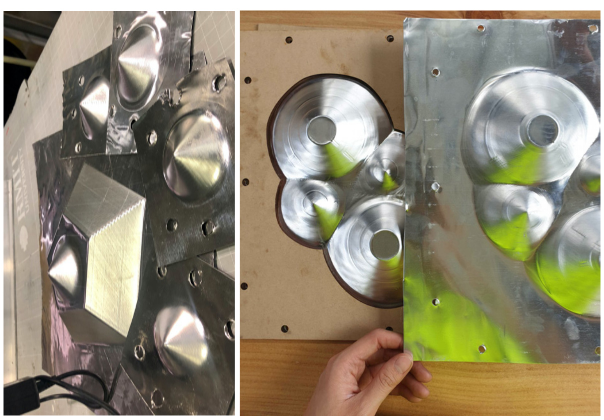

Figure 3: ISF testing pieces at RMIT in Melbourne and ARMHub in Brisbane.

6 Conclusion

Although the research teams were operating in unusual and unprecedented circumstances as a result of the COVID-19 pandemic and lockdowns in Brisbane and Melbourne, we were able to continue the research through virtual means. This involved testing and prototyping of the process through multiple iterations and zoom sessions. The research through design approach allowed for an exploratory and creative process that included input from the different team members across the two universities while testing, failing, and learning by iterating. The ability to see where the robotic ISF process can lead to, where it will inform the digital manufacture of large scaled bespoke pieces that can be used for a range of purposes from high value sculptures, façade elements, to casting and prototyping forms. This process also motivated the team to work together despite the impact of COVID-19 on working environments and practices.

By integrating real-time path planning into remote robotic ISF processes we identified the following benefits to enable mass customisation for the manufacture of architectural applications such as facades and panelling systems. This integration benefits designers and architects, researchers, and manufacturers by increasing collaboration between humans and robots in digital fabrication processes. It allows for changes in the artifact and form to be celebrated and included in design generation, and to be identified and corrected accordingly. Future research will continue to expand the possibilities of robotic ISF and immersive technologies with our industry partner's workers and clients, such as artists and architects to expand the forms possible, the materials used and the scale of the objects to be formed. Additionally, the general public will have access to this process during a public exhibition and demonstration event. One of the aims of our design robotics research is to simplify the collaboration between humans and robots to make work processes safer and more enjoyable for humans, and to better reach the full potential of design ideas and outcomes in efficient manufacturing processes.

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REFERENCES

[1] Bardzell, S., Bardzell, J., Forlizzi, J., Zimmerman, J., & Antanitis, J. (2012, June 11). Critical design and critical theory: the challenge of designing for provocation. *Proceedings of the Designing Interactive Systems Conference*, 288–297. Presented at the Newcastle Upon Tyne, United Kingdom. New York, NY, USA: Association for Computing Machinery

[2] Caldwell, G. A., Donovan, J., Fialho Leandro Alves Teixeira, M., & Brogden, L. (2019). From open innovation to design-led manufacturing: Cases of

Australian art and architecture. *Annual Design Research Conference*. Presented at the Annual Design Research Conference, Melbourne, Australia.
[3] Dalsgaard, P. (2010, November 22). Research in and through design: an interaction design research approach. Proceedings of the 22nd Conference of the Computer-Human Interaction Special Interest Group of Australia on Computer-Human Interaction, 200–203. Presented at the Brisbane, Australia. New York, NY, USA: Association for Computing Machinery.
[4] Dow, S., Ju, W., & Mackay, W. (2013). Projection, Place and Point-of-View in Research through Design. The SAGE Handbook of Digital Technology Research, 266–285.
[5] Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. Business & Information Systems Engineering, 6(4), 239–242.
[6] Zimmerman, J., Forlizzi, J., & Evenson, S. (2007, April). Research through design as a method for interaction design research in HCI. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 493-502).
[7] Zimmerman, J., Stolterman, E., & Forlizzi, J. (2010). An analysis and critique of Research through Design: towards a formalization of a research approach. *Proceedings of the 8th ACM Conference on Designing Interactive Systems*, 310–319. dl.acm.org.