Taikichiro Mori Memorial Research Fund

Research Achievement Report

Human-Robot Real-Time Interactive Collaboration in Timber Structure Joinery and Construction

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1. Research Background

Building intelligent machines has been an endeavor for researchers for decades. When we talk about robots, usually an image of a humanoid machine comes to mind that can do tasks and can interact with human. By definition, on the other hand, a robot is a programmable machine that can carry out tasks in an automatic way. With this definition, we can include Computerized Numerical Control (CNC) machines and Industrial Robot arms, which are two of the most commonly used Digital Fabrication machines in Architecture and Computational Design.

The focus of this research is on the Real-Time aspect of using industrial grade fabrication tools for Architectural Design, and Creative Craft. Particularly, it focuses on timber construction techniques and how we can use Digital Fabrication tools for adaptive programming in changing settings.

2. Research Achievements

2.1. CAADRIA 2022 CONFERENCE ACCEPTED PAPERS

i. Smart Hand for Digital Twin Timber Work: The Interactive Procedural Scanning by Industrial Arm Robot

CHIKA SUKEGAWA[1], ARASTOO KHAJEHEE[2], TAKUYA KAWAKAMI[3], SYUNSUKE SOMEYA[4], YUJI HIRANO[5], MASAKO SHIBUYA[6], KOKI ITO[7], YOSHIAKI WATANABE[8], QIANG WANG[9], TOORU INABA[10], ALRIC LEE[11] KENSUKE HOTTA[12], MIKITA MIYAGUCHI[13], YASUSHI IKEDA[14]
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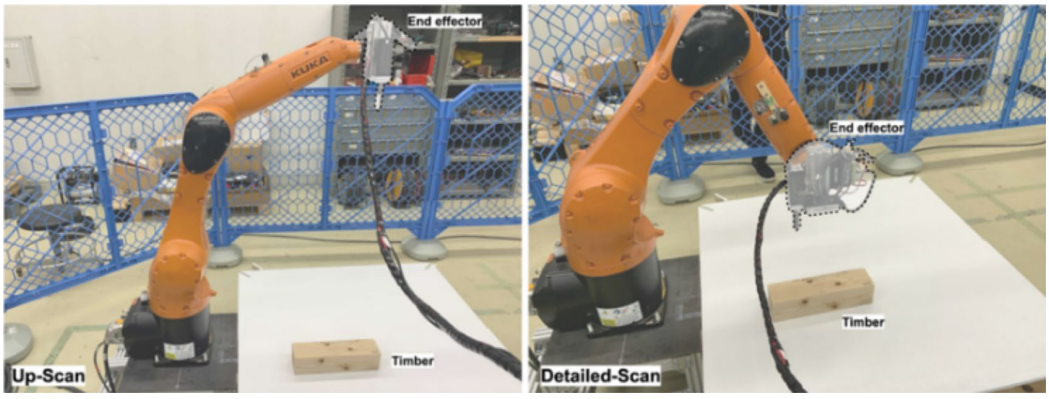
Abstract. This paper describes a 3D automated scanning method for building materials, namely "The Interactive Procedural Scanning", in a collaborative environment composed of a human worker and a CNC robot. This procedure aims to translate the observation skill of an experienced carpenter into an intelligent robotic system. The system frames its function on the first stage of a traditional timber examination process, called 'Kidori', in which observations and findings are marked on the timber surface to provide hints for the subsequent cutting process. This paper aims to recreate the procedures using an industrial robotic arm,

computer vision, and a human worker. A digital twin model of the timber is created with a depth camera serving as a base map to exchange information and receive instruction from the human worker. The margin of a discrepancy between the original processing location and the location of the actual end effector, where the tools are, is minimized in this system.



Adaptive Real-Time Industrial Robot Programming: The screenshot of each scanning moment and robot attitude; (case-1) Up-scan is the rough scan to find the whereabouts of the timber block; (case-2) Detailed-Scan is a high-resolution 3D scan with high accuracy (see table 3)

ii. Development Of an Affordable On-Site Wood Craft System: Interactive Fabrication Via Digital Tools

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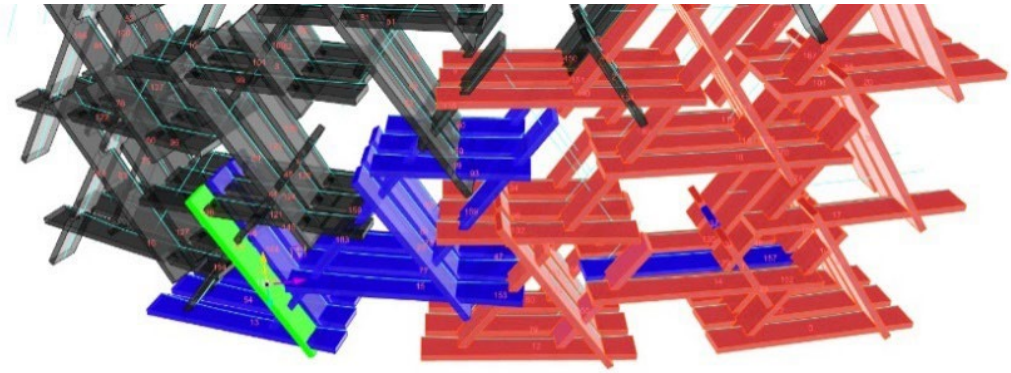
Abstract. This research aims to develop a craft system that simplifies the transition between design and fabrication. One of the main purposes of this system is to allow non-professionals to engage in craft with the aid of affordable digital fabrication tools. By removing the technical hurdles that prevent beginners from engaging in digital fabrication, the system aims to enable those who are interested in making things as a hobby or DIY projects to enjoy digital craft. The developed craft system provides a comprehensive workflow, starting from the initial shape to the final CNC milling machine G-Code generation. It is developed through Object-Oriented Programming, resulting in an interactive system that provides information about the fabricability of the final shelf structure to user/designer. The real-time design-to-fabrication aspect allows for some degree of simultaneous design changes, making the craft experience more enjoyable. In line with the UN Sustainable Development Goals, this research is an attempt to provide more opportunities for individuals to get into digital fabrication, enabling them to acquire skills within the rapidly growing industry. Furthermore, as demonstrated by other digital fabrication tools like 3D printers, DIY builds can potentially be economically beneficial for the users.

Timber Shelf Fabricated with CNC Milling: use of interlocking timber joints to create the self-standing curved structure



Real-Time Visualization of the Fabrication Progress: (Black) Not yet fabricated, (Green) Selected member to be fabricated, (Blue) Fabricated but not yet assembled, (Red) Fabricated and assembled

2.2. SOFTWARE DEVELOPMENT CONTRIBUTIONS

RobotExMachina: Machina Is A .NET Library for Action-Based Real-Time Control of Mechanical Actuators.

RobotExMachina/Machina.NET: A library for real-time robot control. (github.com)

Contributors

- **Jose Luis Garcia del Castillo**
- **Arastoo Khajehee**
- **Nono Martínez Alonso**

In more human terms, Machina allows you to talk to a robot and tell it what to do.

Machina simplifies all the hassle of connecting to a mechanical controller, writing programs in platform-specific languages and managing the asynchronous communication between a machine and a connected application, by providing a human-relatable API of Actions, unified for all the different devices.

Machina is able to control ABB and Universal Robots (UR) offline and in Real-Time. Its functionality to control KUKA robots has been improved in this research. At the moment, KUKA robots' offline programming is fully functional and can be used for fabrications. The Real-Time programming capability is currently being developed via the EKI.Ethernet Real-Time communication software package that was purchased from KUKA with this grant.

Offline Programming: Robot Following a Milling Path Defined by the Computer
https://youtu.be/PyJIDdO1li0

Real-Time Programming: Robot goes to the positions defined by the computer. The moment a location is selected on the computer, the robot reacts by going to that particular position.
https://youtu.be/zLDZ7kv2rI4