Extending the Robotic Workspace by Motion Tracking Large Workpieces

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Abstract. The work explores coupling an affordable motion tracking system (HTC Vive Lighthouse and Trackers) with a collaborative robotic arm (Universal Robot UR 5) in order to machine workpieces a few times larger than the robotic workspace itself. The aim of that project is to demonstrate that such coupling would allow a human operator to manually push the workpiece through the robotic workspace without the need of additional numerically controlled motion axes.

In the test scenario, full scale architectural columns are cut with a hot-wire effector out of extruded polystyrene foam (XPS) blocks. The paper lays out the workflow of an integrated design-fabrication process and discusses its use for crafts based robotic practice.

Keywords: Motion Tracking, Collaborative Robot, Digital Crafting.

1 Introduction

1.1 Problem Definition

Every stationary robotic system has a limited workspace, the zone that can be reached by the end effector, which consequently defines the maximum size of the workpiece. The automotive industry traditionally addresses this constraint by having multiple robots working in sync with on overlapping reach to form a larger networked workspace and/or by having the workpiece travel through the workspace on an additional numerically controlled axis. This approach is firstly costly as it relies on additional machinery and secondly time-consuming as it requires system integration and task specific reprogramming. These factors have limited to use of robots in other industries for a long time. It is particular problematic where larger workpieces are the norm i.e. architectural prefabrication and construction.

There are good examples where large workpieces of architectural scale have been robotically fabricated using the traditional industrial robot integration strategies. The Landesgartenschau Pavilion 2014 Schwäbisch Gemünd is a great case of integrating a rotary table in order to robotically mill the flank joints of large hexagonal timber panels [1]. Similarly have linear drives been used in industry and research environments alike. A prominent example of linear axis integration at architectural scale is the research facility at TU Braunschweig Institute for Structural Design that consists of two portals, one for a concrete spaying robot and another one for formwork [2].

Robotic automation is undergoing a paradigm shift from industrial robots where humans and machines are physically separated by safety systems towards collaborative robots where safety systems are integrated into the robotic actuators. Contemporary collaborative robots like the UR Series from Universal Robots or the LBR iiwa Series from KUKA have paved the way for novel ways of human-robot collaboration by providing a safe robotic work environment. While way more agile than industrial robots these collaborative robots still have the same size to workspace ratio and thus the same limitations in handling larger workpieces. A first experiments on full AR/VR and collaborative robot design work environments was initiated with Robo-Stim in 2018 [3]

Fig. 1. Robotically hot-wire cut columns

1.2 Knowledge Gap

There have been several research projects dedicated to integrating motion tracking into a robotic process. From optical systems like OptiTrack such as the Quipt research project by Madeline Gannon to Vive Lighthouse system such as the Master Thesis by Kristian Sletten.

Quipt explores in an artistic as well as technological level novel direct human-robot interaction and ultimately “taming” industrial robots by providing an entirely different safety concept, one where the robot is always sensing, respecting, and prioritizing the human around [4].

Kristian Sletten looks at the technicalities driving a robot remotely via Vive controller movements and provides a software framework for real-time path test and correction [5]. Although both precedent projects make significant advances in direct human robot interaction they are both missing an integration into a full design and fabrication sequence.

1.3 Objective

The work presented here aims to support a wider use of robots in fabrication. It seeks to expand the use of robots to fields where they are hardly present yet due to their workspace constraints. The authors see a specifically suitable niche in areas which are working with collaborative robots such as small businesses in manufacturing but also, creatives like photographers. The available range of collaborative robots comes with an even smaller work area than industrial robots, making it even valuable to find way of working with lager workpieces.

2 Methods

We suggest a solution where a low-cost motion tracking system, HTC Vive Lighthouse, is installed in the robotic work environment trackers and HTC Vive Trackers are attached to the workpiece. The location of the trackers and thus the workpiece position and orientation are used to update the robotic toolpath in real-time. This would allow an operator to manually move large pieces of material through the stationary robotic workspace. The robot would then perform local manipulations in the area of the workpiece which is at that time slice in reach of the robot's end-effector. It requires a precise 3-dimensional representation of the workpiece in a design environment as the motion tracking only updates it location and orientation in space. The human operator is solely responsible for moving the workpiece similar to operating a table saw.

This approach of human-robot interaction is particularly suited for collaborative robots as their safety system relies on measuring torque abnormalities. Such a scenario would widen the application of robots in the realm of fabricating architectural components as well as brining traditional craftsmanship and robots closer together.

3 Proof of Concept

3.1 Robot, End-Effector, Tracking

To test this concept, we defined a scenario of fabricating a series of 2 m tall architectural columns by means of robotic hot-wire cutting large XPS-foam workpieces using a Universal Robots UR 5 robot (approx. 850 mm sphere diameter workspace). Each column was cut out of a single block of 2000 mm x 400 mm x 400 mm material. The workpiece was equipped with two 2017 Vive Trackers which sense orientation and position at 1kHz and a theoretical tolerance in the millimeter range. The material was manually pushed with a linear guide (see Fig. 2). The speed by which the material was moving had to be manually adjust. It is limited by three physical factors: temperature of the hot-wire, XPS melting point, and wire tension. In our set-up this resulted in a approx. speed of 0.02 m/s. The operation of pushing the column through the robots working area was performed multiple times, each run with a different axial rotation of the column.

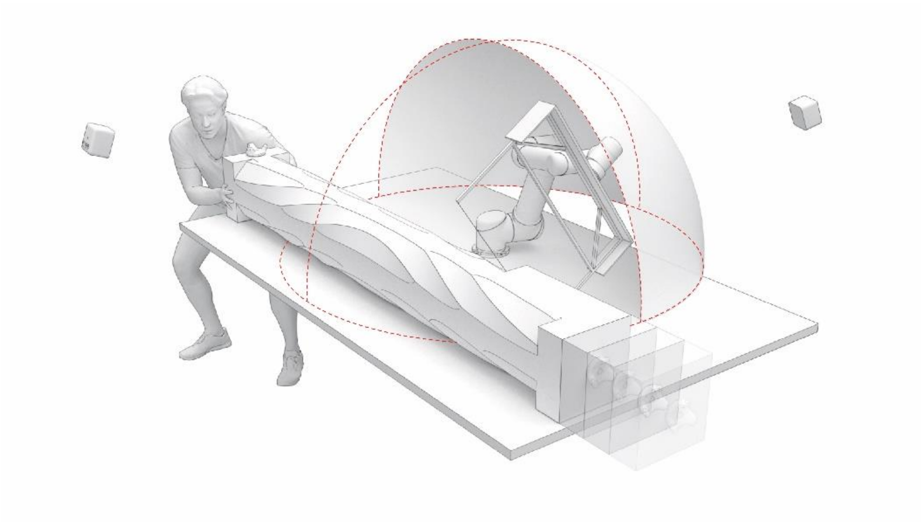

Fig. 2. UR5 robot with hot-wire effector and dashed work area, Vive Lighthouse base stations, XPS foam workpiece with Vive Trackers at either end.

3.2 Integrated Design

The technical set-up for this proof of concept scenario is implemented in the parametric design software Rhino Grasshopper (GH) and the Robots plug-in [6] for generating UR-Script code and sending it to the controller via a socket connection. The design of the columns was developed around the 3 DOF of the hot-wire tool, namely the in-plane rotation, the axial rotation and the cutting depth. (see Fig. 3) The different columns were designed by manipulation the 3 DOF graph directly thus generating a valid tool-path implicitly (see Fig. 4).

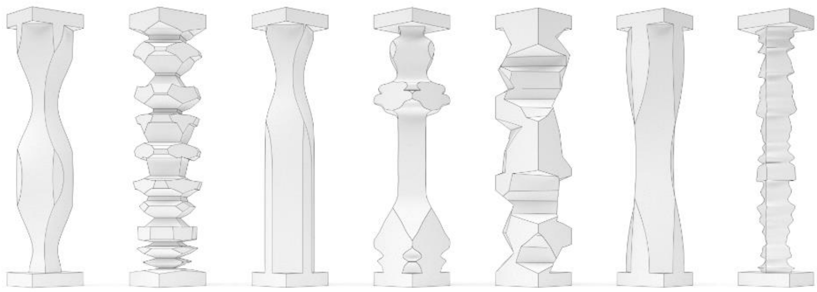

Fig. 3. Variation of column designs, all within the fabrication constraints.

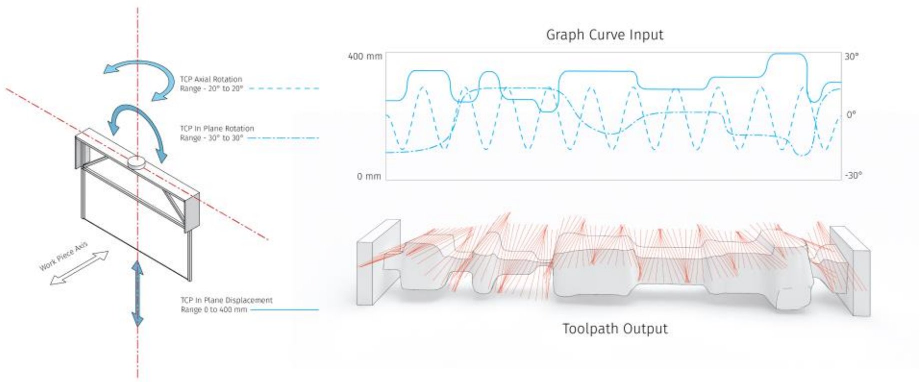

Fig. 4. Three degree of freedom at the hot-wire effector, implicit column fabrication design by direct manipulation of DOF graphs, resulting in rule line toolpath representation.

The position and orientation of the 2 Vive Tracker is acquired via a VIVE Lighthouses and then fed via the Steam VR API into a custom GH-component. In GH the current tool position along the columns central axis is calculated as t-value. The t-value in consequence is used to retrieve the current pose for the robot and thus match hot-wire to the respective rule line (see Fig. 5).

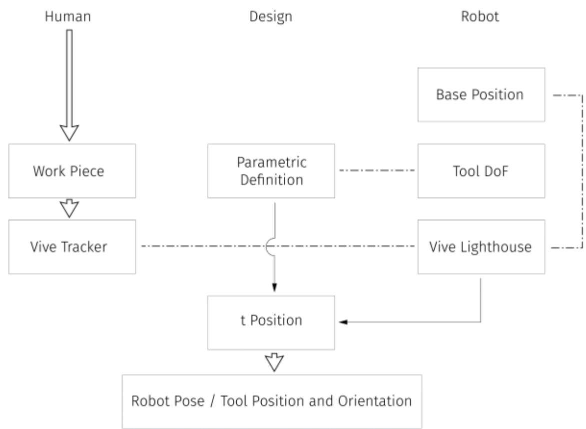

Fig. 5. Flow chart of the TCP position computation framework.

3.3 Fabrication

The process worked well in the test scenario and the speed of production was mainly determined by the hot-wire. The cutting time for one side of a column was between 15 and 30 minutes. The sensual force feedback the operator gets when pushing the XPS foam against the hot-wire is a good indicator for manually controlling the speed. Moving the workpiece too slowly leads to a ticker cut where a fast push of the workpiece ultimately snaps the wire. The job of interacting with the robot by moving the workpiece along its designated axis and rotating it after each pass could be done by a worker with minimum training. In our test scenario students who had no prior experience in robotics nor large scale hot-wire foam cutting. A second limiting factor is the shading of the VIVE Trackers. Our scenario included 2 trackers, one at either end of the column. The signal was "jumpy" at times which was fixed by smoothing but should be eliminated at the source in the next test scenario. The different columns produced were designed to showcase the variability of the process. Further test on repeatability will follow but only make sense when the system is tuned for better accuracy by additional trackers and possibly upgrading to current Vive Pro Lighthouse and Trackers.

Fig. 6. Column fabrication, movement along central axis and rule line indicated.

4 Evaluation

The scenario shows that it is well possible to extend the workspace of a small collaborative robot like the UR 5 easily by factor 4 for the price of a Vive Lighthouse set and two Vive Trackers. This is at least an order of magnitude cheaper than a mechanical solution such as an additional liner or rotary robotic axis. It is also significantly cheaper than an optical tracking solution like an OptiTrack system.

5 Discussion

5.1 Outlook and impact of findings on design

The set-up proposed in our scenario shows “quick and dirty” way of scaling work-area of a collaborative robot significantly. This is particularly interesting for a makers and creatives who already use collaborative robots in their workflows but are limited by the robot reach. It is suited for processes which don’t require CNC accuracy but exhibit great variability within an algorithmic design and production approach. Interestingly, some control over the tolerances is given back to the human operator.

5.2 Further development

Future work would include progressive local 3d-scanning in addition to global localization of the workpiece. This would allow to work with material which does not have a complete 3d-repesentated form at the start. We also see a great potential for designing with robots rather than having them to only execute the fabrication of a given design. Other fast and cheap in-line sensing methods such as 2d shape recognition could also contribute to build an even richer framework for smart collaborative robots.

5.3 Possible products

The process developed for this scenario is to a certain degree independent of the hot-wire effector. More generally it is suitable for subtractive fabrication methods of hard materials and processes which don’t require repeated evaluation of the formfactor by means of 3D-scanning. It could also be used for photography and video studios where a non-linear dependency of object and camera is required and hardcoded path to rigid. Besides these application in the creative sector, traditional craft could also benefit by seeing such an approach of coupling human and robotic action as a suitable digital transformation strategy.

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