Six Degrees of Freedom (6DOF) Robotic Additive Manufacturing
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Introduction

- Additive Manufacturing (AM)/3D printing technology is formerly known as rapid prototyping
- In 1992, the first commercialized fused deposition modeling (FDM) became available [1,2]
- The idea of rapid prototyping technology evolved and shifted to the manufacturing
- AM is a method of direct manufacturing from 3D digital models to the physical part
- Produces the 3D part by depositing material layer by layer. This process has the potential of building complex lattice structures for an internal geometry
- AM is considered as advanced automation in manufacturing which is part of the fourth industrial revolution/industry 4.0
- AM technology is classified into seven types based on the material and process. They are Vat Photopolymerization, Material Extrusion, Material Jetting, Powder Bed Fusion, Binder Jetting, Sheet Lamination, and Direct Energy Deposition [1]
- In this project, we have opted for a polymer-based material extrusion process

Robotic Additive Manufacturing (RAM)

- In conventional 3D printing, the mechanism is a gantry system and is limited to only three degrees of freedom
- So, the printing is possible only in one direction, which is along (x-direction)
- Uni-directional 3D printed parts have anisotropic mechanical properties
- Complex 3D models with overhanging features need support structures in uni-directional 3D printing. Which increases the material consumption and overall build time
- By having the capability of multi degrees of freedom mechanism and developing the 3D multi-directional printing process, we can minimize the support structures
- Articulated robots (industrial robotic arms) have multi degrees of freedom mechanism depending on no. of the joints
- In our project, we are using one 6DOF manipulator for the XYZ movements in the 3D space and for the orientation
- The extrusion mechanism for heating the polymer and extruding the material is attached to the end-effector do the manipulator as a tool
- A preliminary 3D printing testing is achieved using one 6DOF manipulator

Printing Process

Figure 1: Conventional 3D Printing Process

Figure 2: Robotic 3D Printing Process

Results

Figure 3: Small Scale Specimens, (I) XYZ Calibration Cube (20x20x20 mm), (II, III, IV) Measured Cube Dimensions, and (V) Curved Surface Print Test

Figure 4: Medium Scale Specimen, (I) Phone Stand, (II) Under Extrusion Problem

Discussion

- AM is a multidisciplinary problem that involves both hardware and software development
- For preliminary testing of the robotic printing, we have been used the same software tools as that of in the conventional 3D printing
- We have observed problems like under and over extrusion in printing medium-scale objects. It is due to the Marlin firmware dependence, which controls the extrusion mechanism
- All manipulators have predefined motion profile for the joints, which is not the same as the motion profile of the Marlin firmware for feeding the material to the hot end
- By developing the synchronous control system for the extrusion stepper motor with respect to the robot speed, the problem of under and over extrusion can be resolved
- Therefore, it is essential to develop a process for multi-directional printing

Future Work

- Using a single manipulator for multi-directional printing can be limited to specific models
- The multi-directional printing for different models can be achieved by using two manipulators. One of the manipulators holds the print base and second one is with the extruder mechanism
- In this approach, we can take advantage of the multiple degrees of freedom to develop complex multi-directional printing.

Figure 5: Dual manipulator setup in Motosim simulation software for the 3D Printing Process

References