3D-Print-CMM

3D Printing Retrofit Package for a Coordinate Measuring Machine

ELECOMP Capstone Design Project 2017-2018

Sponsoring Company:

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Hexagon is continuing their support of the Program they initiated last year:
http://web.uri.edu/elecomp-capstone/past-projects-2016-2017/hexagon/

Company Overview:

Hexagon Manufacturing Intelligence, formerly known as Hexagon Metrology, is the world leader in quality control solutions for manufacturing. Solutions include hardware, software and services in a broad portfolio of products which include stationary coordinate measuring machines (CMMs) for the automated inspection of manufactured components. Coordinate measuring machines are essentially large precision positioning systems that carry accurate sensors in the x, y, z directions for the dimensional inspection of manufactured components. These machines have specialized controllers and firmware and are programmable through dedicated software. These systems are produced here in Rhode Island at Hexagon's Quonset facility for North America.

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Project Motivation:

Coordinate measuring machines (CMMs) require tool path programming similar to CNC machines but with the addition of measurement analysis according to manufacturing specifications supplied in CAD models and drawings. Often times, only drawings contain the needed specifications and are only available as scanned copies have been in existence for nearly 40 years and have been perfected to the point of becoming commodities over the last 10 years. Most of the technological advancements and value associated with these systems has been with their major accessories, such as software and sensors. For this reason, there has been a push to develop new peripheral products that can extend the capability of these CMMs while creating differentiation among competitors.

One interesting area that has not been pursued by any OEM in the coordinate measuring machine market is the adaptation of these precision positioning frames for purposes other than dimensional inspection. One possible reason for this is that these machines were never designed to carry or apply heavy loads such as those seen by machine tools. However, now with the advent of 3D printing, and particularly fused-deposition modeling (FDM), manufacturing without the high loads imposed by cutting tools is now a reality.

Coordinate measuring machine frames may be ideal dual-use systems for both thermoplastic fabrication and inspection, however there are still several technical obstacles to overcome. Some obstacles include mounting the 3D printing accessories to the existing machine frame and interfacing them with the machine's firmware. The mounting of the 3D printing accessories must facilitate easy setup and the software interface must be able to translate and send instructions to the machine's firmware for executing a 3D printing routine.

Project Details

This is a multidisciplinary research and development project to create a working prototype of a coordinate measuring machine frame retrofitted for 3D printing. The retrofitted machine must be able to fabricate a test object out of thermoplastic material of sufficient size, though it does not need to be as large as the entire working volume of the machine. For simplicity, off-the-shelf products may be used whereby the main mechanical design consideration is mounting brackets or other supports for those components. It is also assumed that the FDM process will be in the form of fused filament fabrication (FFF) for the ease of dispensing material for the build process.

Electrical engineering expertise will be required for the proper wiring of these standard components. Heating effects of those components will need to be considered and the addition of cooling fans where necessary. Electrical engineering expertise may also be necessary to design a specialized heat bed onto which the thermoplastic material will be bonded at the base

during the printing process. This will require the integration of heating elements and temperature sensors to regulate the temperature of the bed.
On the computer engineering aspects, expertise will be required to create an interface able to translate standard 3D printer g-code into a protocol that is recognized by the machine's firmware. This may be straightforward for the normal moving axes of the machine, but some further accommodation may need to be made for other controls not typically recognized by the firmware. For example, other controls for the extrusion rate and nozzle temperature need to be accommodated. For these additional functions, it may be necessary to add cabling or to have the control for those components near the print head itself. However, regardless of where the control of the component takes place, a substantial amount of power still needs to be delivered to the print head for the melting of the thermoplastic.

The diagrams below show the existing machine, Fig. 1, and the retrofitted machine, Fig. 2, with 3D printing components.

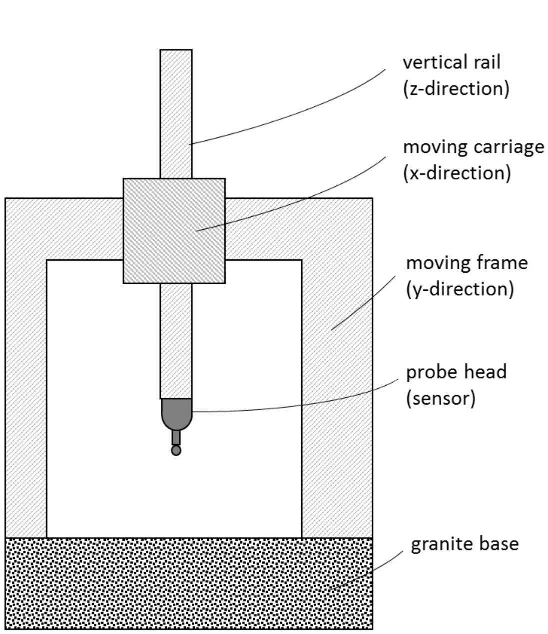

Fig. 1

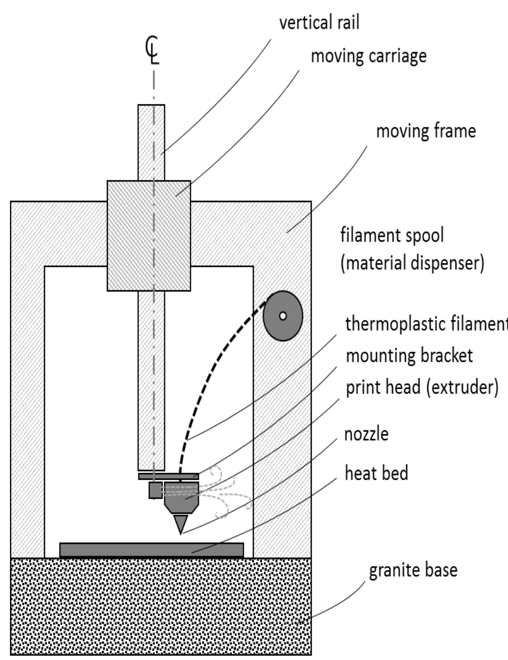

Fig. 2

Student Skills Required & Division of Work

It is envisioned that two students will work on this project, one electrical engineer and one computer engineer. The ideal candidates will have some knowledge of 3D printing, either as a hobbyist or through some other experience. It would be extremely beneficial to understand some of the challenges in printing thermoplastics firsthand since this could help guide the design process. The electrical engineer should be familiar with the integration of heating elements, temperature sensors and servo motors with various control elements. The computer engineer should be familiar with how g-code works and the basic principles behind the design of various firmware protocols. It would also be useful to be knowledgeable in C++ for the adaptation of Slic3r, an open source library for generating a wide range of g-code dialects. Alternatively, Cura is another open source project for generating g-code for 3D printing applications and is written in Phython and C++.

The tasks and scope of work can be summarized in development phases as follows:

Computer Engineer: 3D Printer Firmware Interface	**Electrical Engineer: Component Integration**
Phase I Translator for g-code to Hexagon firmware protocol. ● Knowledge of CNC path programming and machine interfaces is helpful. ● Reading and writing of binary files ● Socket communication via TCP/IP ● Basic command line user interface **Phase II** Integrated CNC print path generator and machine interface. ● Knowledge of CAD and STL model format. ● Integration of 3rd party packages, i.e. open source slicers for g-code generation from STLs. ● GUI for loading STL file, generating print time estimates and testing machine and printer components.	**Phase I** Print head selection and mounting ● Able to estimate heat dissipation of head and calculate heat transfer to vertical rail ● Design for heat mitigation if necessary ● Choose microcontroller for extruder if necessary ● Offline testing of setup ● Wiring diagram for print head to CMM Heat bed selection and configuration ● Choose heating elements ● Size of bed for max power/heat allowed on granite base ● Temperature measurement and control **Phase II** Integration of print head and heat bed with machine controller ● Testing through software interface ● Optimization of printing parameters ● Final wiring diagram for all retrofitted components

Anticipated Best Outcome and Deliverables

The Best Outcome is a 3D printing CMM prototype and retrofit package design for the same. The prototype is intended to be an operational proof-of-concept able to fabricate objects out of thermoplastic. For this project's purpose, the fabricated objects must be of useful quality, i.e. able to be used as support fixtures or other basic temporary tools commonly needed in manufacturing environments. However, the resolution and accuracy of the printed objects do not need to exceed the quality standards of the already developed 3D printer industry because we are presently not attempting to compete with that industry. Our goal is to provide alternative use for the measuring machine asset and value in the form of real tools that our customers can produce themselves. The main deliverable is a retrofit package design that includes a part list or bill of materials for the firmware interface software, standard 3D printing components, cables, hardware, and wiring diagrams needed to retrofit a CMM.

Deliverables Summarized

- Operational prototype capable of printed useful objects out of thermoplastic
- Firmware interface software for sending 3D printing instruction to a CMM
- Retrofit kit including hardware and cables needed to integrate the 3D print head and other accessories with the CMM
- Wiring diagram for the configuration
- Bill of materials (BOM) for all components in the retrofit package
- Summary of 3D printing performance tests and results

Anticipated Best Outcome's Impact on Company Business

Demonstration of the present patented capabilities as a realistic solution for customized fixture fabrication.

Broader Implications of the Best Outcome on the Company's Industry

Productization of an onboard CMM 3D printing solution which can be sold as a retrofit option on existing CMM machines. Such a solution would also form a niche market in the FDM 3D printing industry since CMM frames have much larger work volumes and higher precision than most FDM 3D printers currently available.