Motion Control

Stepper Motor Motion Control for Scan System

ELECOMP Capstone Design Project 2018-2019

Sponsoring Company:

Cambridge Technology
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Company Overview:

Cambridge Technology designs, develops, and manufactures leading-edge laser beam steering solutions including galvanometer and polygon optical scanning components, 2-axis and 3-axis scan heads, scanning subsystems, high power scanning heads, and controlling hardware and software. Our company partners with OEM customers to deliver scanning solutions that support advanced industrial processes, electronics, and laser-based medical applications.

As the inventor of galvanometer-based optical scanning technology, we make it our mission to drive innovations in photonics by delivering unprecedented technical capabilities through the critical lens of collaboration, quality, and customer service. We dedicate ourselves to excel at:

- Collaboration with our partners to ensure our goals and pathways align
- Innovation to bring tomorrow's beam steering solutions to life today
- Engineering to perfect our products and our processes
- Delivery from the largest engineering solution to the smallest component

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Project Motivation:

Cambridge Technology offers Galvo based laser scanner solutions, which typically consist of a two-axis scan head, servos drivers, a laser steering controller and end user software application. All of our controllers are designed to easily integrate with either an Application Programming Interface (API) or ScanMaster Designer (SMD) software from Cambridge Technology. The ScanMaster Controller (SMC) is designed with two proprietary technologies: GSBus data transfer protocol and our ScanPack control scheme. The GSBus protocol supports 24-bit control signals, the highest command resolution in the industry. ScanPack control is based on comprehensive modeling of the dynamic behavior of our digital galvanometer thus predictively planning the scanning path. The SMC offers a wide range of programmable control signals that provide flexibility in laser control that is synchronized with galvanometer motion and positions

Our plug-and-play interface allows for easy connection to commonly used lasers. Our ScanMaster Designer (SMD) software is simple to use and features a graphic design environment with an intuitive user interface. The software uses standard file formats and features a wide range of editing tools for easy job creation. ScanMaster API provides access to most of the SMD functionality through end customers own user interface. All of our controller and software products are optimized to drive any of our galvanometer XY scanner sets and scan heads.

We are looking to extend the capabilities of the scanner controller and software to drive stepper motors external to the core scanning system.

Figure 1: Scan Master Controller. Galvo Scanner and Laser controller.

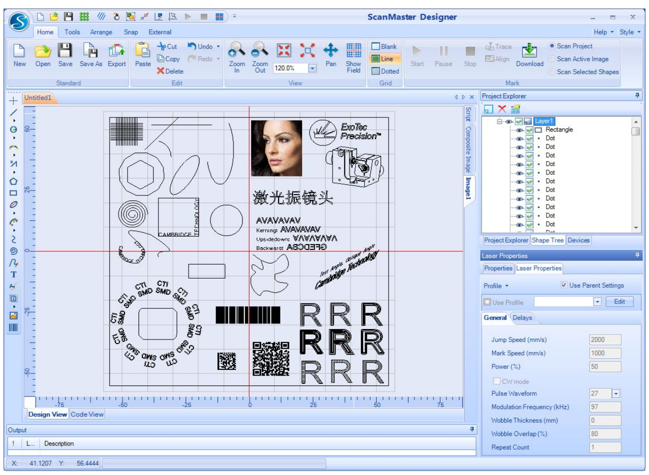

Figure 2: Scan Master Designer software used for a variety of laser processing applications.

Anticipated Best Outcome:

1. Development of FPGA custom logic and associated embedded firmware that synthesizes and delivers precise pulse streams to a step-and-direction motor driver.
2. Demonstration of a trajectory profiler that generates controlled acceleration and velocity profiles using a development board and test actuator utilizing the results of step 1.
3. Integration of the control algorithm into the SMC FPGA and the development of DEMO App on an advanced scanner system.

Project Details:

The project will be developed and tested using a commercially available development module using the Xilinx single-core Zynq FPGA+ARM processor engine. Signal conditioning circuitry and cabling will need to be developed to attach the processing components to a stepper motor driver and stepper motor based linear actuator system. These components can also be obtained commercially.

Research will be required to determine:

- Typical stepper motor drive requirements including micro-stepping techniques
- Appropriate strategies for the step-and-direction signal generation taking into consideration the timing precision, frequency, and sequencing of pulse bursts
- Mathematical determination of step signal sequencing to create controlled acceleration moves with an actual load while using pre-defined acceleration and velocity profiles.

Using the research results, FPGA fabric and embedded C or C++ firmware will be developed and tested. A host-based application to exercise the implementation would be required as well.
As a final stage, the developed technology would be ported to run inside the SMC architecture and demonstrated in an advanced scanning application.

Overall System Concept:

Although the project will develop technology using commercially available hardware and software, the resultant work is intended to be integrated into the SMC controller platform. The single-core Zynq FPGA was chosen because it is the same family of devices used on the SMC and the development tools and methods are largely the same. This commonality will facilitate the integration with the SMC platform that uses a dual-core version of the Zynq device. The SMC already has two dedicated step-and-direction interface ports intended for this purpose.

The final integration would involve modifications to several software subsystems implemented in C++ in an embedded Linux environment. This will also include Linux device driver work.

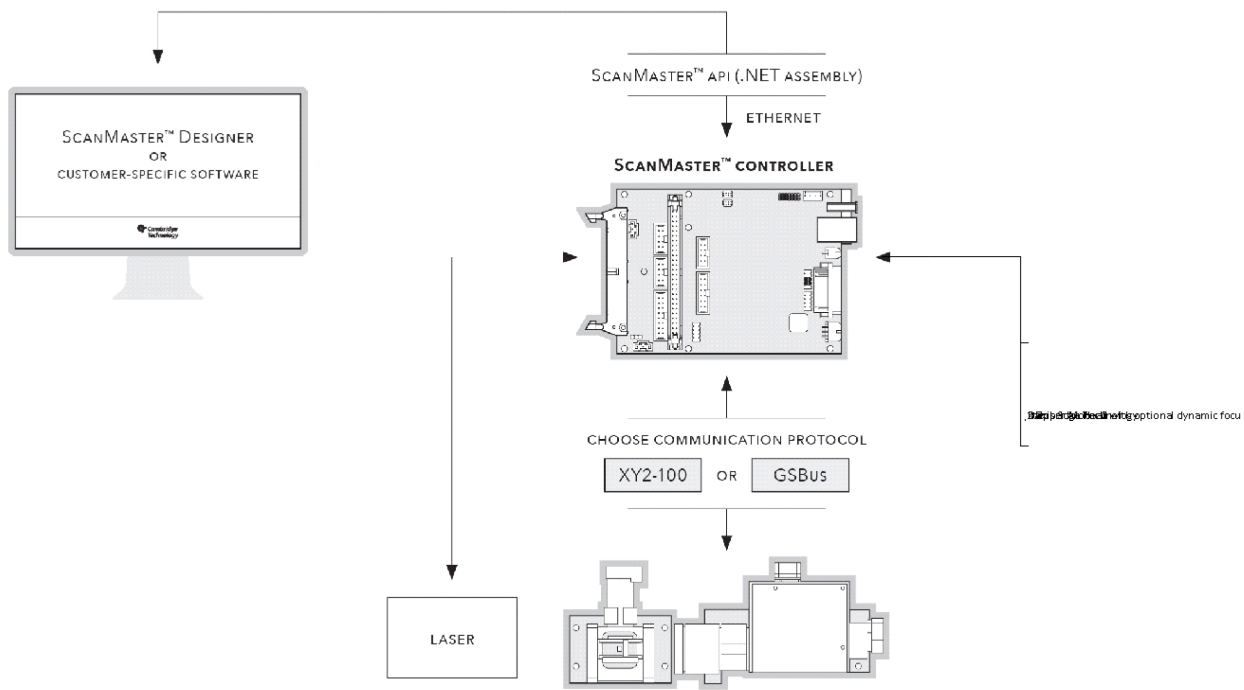

Figure 3: System Block diagram for Cambridge Technology scanning system with support for controlling external stepper motors.

In the final product configuration utilizing the result of the project work, the stepper motor drivers would interface directly to dedicated ports on the SMC hardware platform. These ports interface directly into the FPGA fabric of the SMC processor where the step-and-direction pulse generator logic would reside.

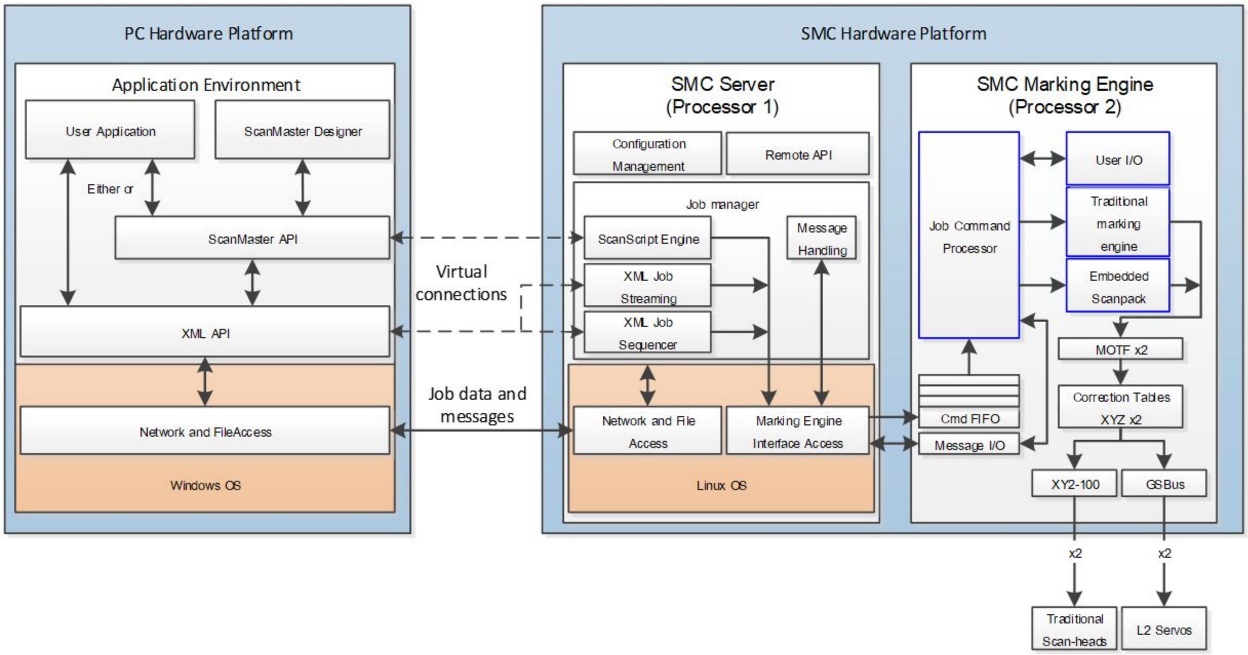

Figure 4: SMC & SMD Architecture overview.

The diagram in Figure 4 shows the distributed multi-processing arrangement of the SMC and associated Windows host base software and APIs. The project work would ultimately be deployed on the Processor 1 element of the SMC that runs a Linux OS with CT custom application software that implements the high-level control and sequencing operations.

Hardware/Electrical Tasks:

1. Procure materials
    a. Zynq development module (suggest the Avnet MiniZed module)
    b. Stepper motor and stepper motor driver
    c. Lead-screw driven linear stage with stepper motor coupling
2. Design and build cabling and other necessary signal conditioning circuitry.
3. Research stepper motor step-and-direction control requirements to implement micro-stepped controlled acceleration and velocity moves.
4. Working with the computer engineering team member, design a register level control interface to the FPGA step-and-direction pulse generator.
5. Define, design and simulate the pulse generator logic in Verilog.
6. Support the software effort to integrate the device driver and trajectory generation algorithms.

Firmware/Software/Computer Tasks:

1. Research stepper motor step-and-direction control requirements to implement micro-stepped controlled acceleration and velocity moves.
2. Set up and configure the software development environment for the Zynq embedded processor including an appropriate source control system (suggest SVN and Tortoise client).
3. Research Linux device driver architecture and implementations.
4. Working with the electrical engineering team member, design a register level control interface to the FPGA step-and-direction pulse generator.
5. Define an API for configuring and activating the step-and-direction hardware.
6. Develop a device driver and corresponding test code to configure and activate the step-and-direction logic.
7. Develop algorithms to map acceleration and velocity parameters to time-domain pulse sequences.
8. Implement the API defined in step 5.
9. Expand the test app to exercise the API.

Composition of Team:

- 1 Electrical/Firmware Engineer
- 1 Computer/Software Engineer

Skills Required:

Electrical Engineering Skills Required:
- Motion Control Theory
- FPGA fabric design and simulation using Verilog
- I/O Mapping
- Cabling and interconnect design
- System Design & Integration

Computer Engineering Skills Required:
- Motion trajectory planning Math
- C/C++ application development in a Linux environment
- Linux system programming including device driver development

Preference will be given to students who have completed or are enrolled in ELE 405: Digital Computer Design. The course covers advanced FPGA design on Cyclone V boards using VHDL - similar to Verilog.

Anticipated Best Outcome's Impact on Company's Business, and Economic Impact

Adding the described capability to our system will make our system more suitable for integration with more complex laser scanning systems. One example of an advanced feature for scanning systems is the ability to vary the size of the laser scanning working field. This is accomplished by changing the position of the objective lens in the optical path as well as changing the physical distance between the scanner and work surface. This position change would be accomplished by using a stepper motors controlled through SMD. Another example is to insert a 1 or 2 dimensional linear motion stage or conveyer into the working field. Having the ability to control the motor(s) for such a stage provides more flexibility to scanning customers, allowing them to scan trays of parts where the tray size exceeds the working field of the scanning system.

A rough estimate for the economic benefit enabled by this feature is \$250k – \$500k generated through additional system sales into more complex application spaces.