A CNC ROUTER CONTROL SYSTEM: DEVELOPMENT AND IMPLEMENTATION
(Technical Paper)

MAKER TECHNOLOGIES: CAN THEY IMPROVE EDUCATION INCLUSION?
(STS Paper)

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Bachelor of Science, School of Engineering

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July 26, 2019

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Numeric Control and Computer Numeric Control (CNC) technologies has continued to develop from the early-1950s to current (Kief & Roschiwal, 2012, Chapter 1). In *Manufacturing Engineering Handbook*, Scherer and Geng (2016) defined CNC technologies as "a computer-based controller that can programmatically command servo motors to move machine axes," which is a common technology used in the manufacturing industries (Chapter 10, para. 1). The maker movement is a spectrum of concepts and values. In paraphrasing David Gauntlett, a Canadian research chair, Radford University senior faculty members, Mekolichick and Wirgau (2017), noted the maker movement consists of "values the do-it-yourself mentality, experimentation, exploration, invention, and spirit of collaboration" (p. 23). Similarly, Dale Dougherty (2012), founder of *Make* and the Maker Faire, describes the movement as a way for people to express their "need to engage passionately with objects in ways that make them more than just consumers," (p. 12). Dougherty further notes the integration of the maker movement benefits a variety of societal groups from education to government to businesses (pp. 12-14). Raul Tabarres-Gutierrez (2016) explained that CNC technology and 3D printing technologies are commonly used within the maker movement (pp. 22-23). In his financial analysis, Austin Hatley (2013), associate of Street Authority Network, cited a "35,000% increase" in sales of 3D printers from 2007 to 2011 ("The Next Trillion Dollar Industry").

Dougherty (2012) noted the importance of maker technology, and its associated movement to youth, as the maker movement has aided in the development of summer camps, and after school educational programs (p. 13). The technical project and loosely coupled STS research provide insight on aspects of maker technology in an educational setting. The technical project will focus on the continuation of integrating a non-manufacturer specified spindle driver into a Roland MDX-650A CNC mill, hereinafter referred to as the Roland. For purposes of definition, a mill can be considered a machine which is used to remove material from a stock to leave a desired object. The integration of the spindle driver and other, previously upgraded, motors provide a lens to understand the technical knowledge needed in designing maker technology, and an understanding of the difficulties in using different maker technologies in an education setting. The STS research will pertain to the analyzing the benefits of integrating maker technologies into primary and secondary schooling. The technical project work will be completed throughout August 2019, and the STS research will span August 2019 to early March 2020, allowing enough time to develop the thesis.

A CNC ROUTER CONTROL SYSTEM: DEVELOPMENT AND IMPLEMENTATION

Under the guidance of Gavin Garner, professor of Mechanical and Aerospace Engineering, the technical project will delve into the concepts and intricacies built into CNC mills. This will be conducted through the examination of a halted the Roland conversion, initiated by Mechanical Engineer Jedediah Gallagher. CNC mills operate utilizing a programming code to move multiple aspects of a machine, commonly G-code (Scherer & Geng, 2016, Chapter 10). G-code is a version of machine code interpreted by software to control the various axial motions of a machine. Subagio & Atmaja (2011) noted that manufacturers of CNC mills, and other similar technologies, often implement proprietary control systems causing issues when a machine is discontinued (p. 105). Due to these proprietary constraints, end users must resort to either attempting to develop a new control system, or purchase another machine.

As noted by Mechanical and Mechatronics Engineers Jayachandraiah, Krishna, Abdullah Khan, and Reddy (2014), stepper motors can be an integral device in CNC machines due to their ability to their ability to maintain a fine level of accuracy in movement (pp. 4-5); however, The engineers further recommended to use “DC or AC servomotors and encoder feedback…” in future CNC machine builds “for instructional purposes as well as for more precise operation…” (p. 10). According to Gavin Garner (2019), the precision and feedback from DC servomotors served as the driving force behind the initial upgrade. The upgrade involved replacing the original axes stepper motors to integrated servomotors from the Tecknic ClearPath ®, and replacing the Roland circuitry to an Ethernet smoothstepper (ESS) control board. This not only provides more precise axial control, but also allows for integration of the Mach4 control software.

The technical project objective is to finish redesign of the Roland’s electrical circuitry through integration of the ESS, a 400 Watt brushless DC motor driver, and the pneumatic control to the automatic tool changer (ATC). In addition, the Mach4 motion control software will be configured to control the new upgrades. This project is a summer long continuation of the upgrades originally designed and constructed by Gallagher. The project provides an insight into both the technical aspects of CNC and other computer controlled maker technologies.

The initial research for the technical project focused on either finding a suitable spindle driver for the 400 Watt DC brushless motor, or in the case a suitable driver could not be found, purchasing a 400 Watt DC brush motor. The two main purposes of this research are: 1) incorporating of an integral component, spindle motor, currently not connected to the Roland’s chassis, and 2) minimizing structural redesign due to the z-axis braking system built into the Roland. The block diagram, illustrated in Figure 1 on page 4, shows the design and implemented hardware completed by Gallagher. By maintaining the current spindle motor assembly through a motor driver, the technical project is simplified by halting the need to redesign the z-axis braking system and connections to the ATC. Figure 2, on the bottom of page 4, identifies additional components and process to be implemented in order to establish control of the spindle and axes limit switches.

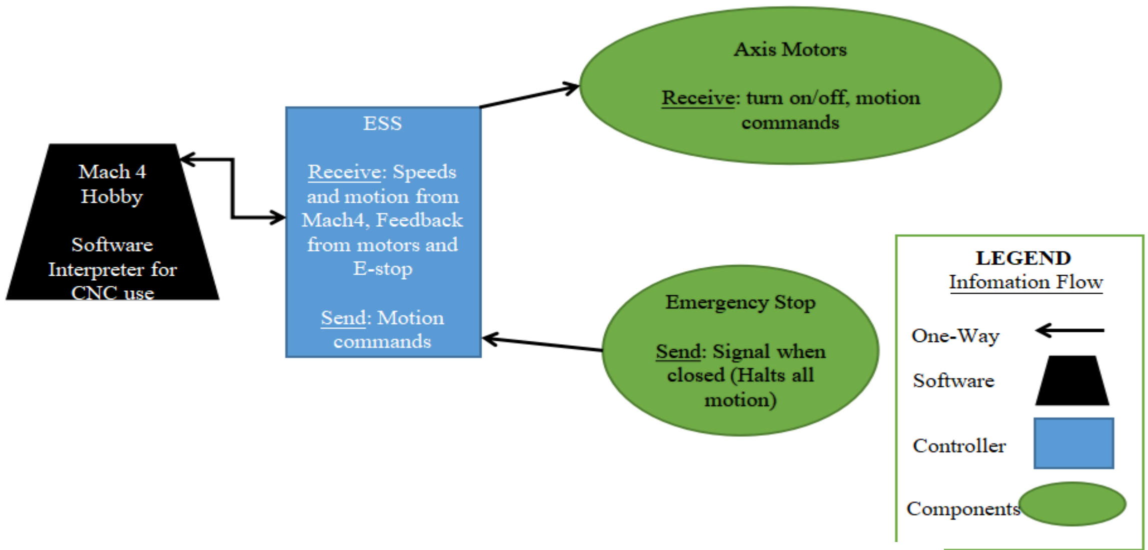

Figure 1: Roland Block Diagram: Identifies current status of Roland capabilities

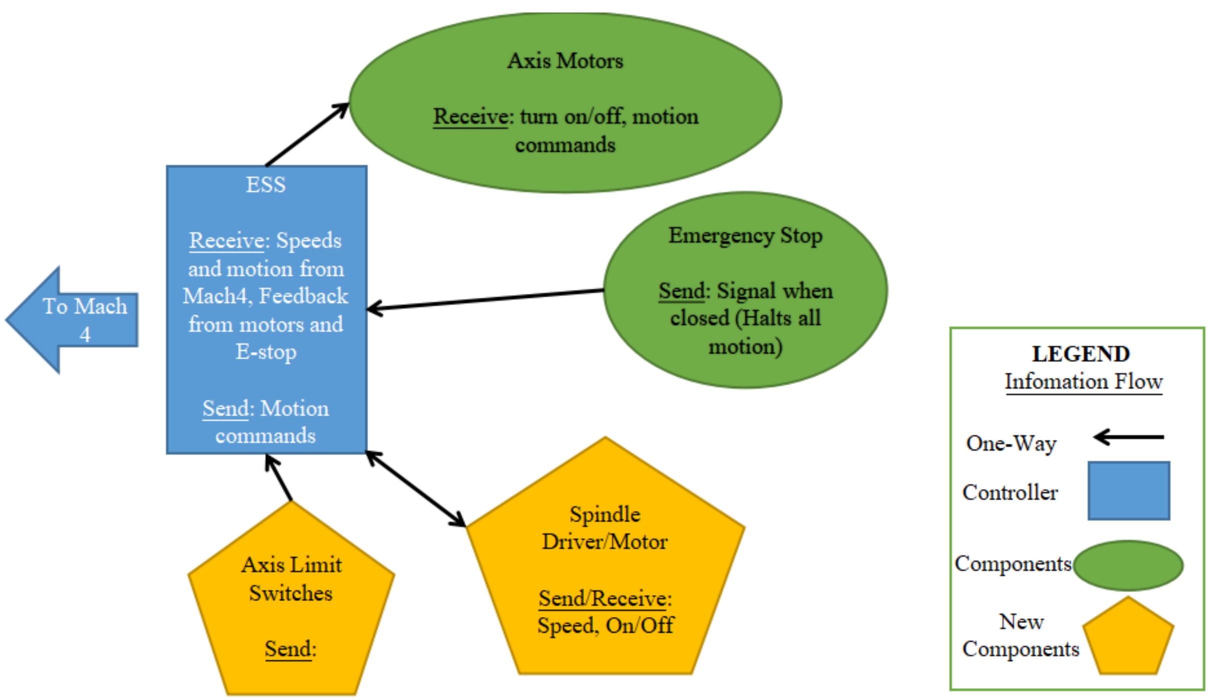

Figure 2: Roland Block Diagram 2: Identifies planned incorporation of new components into Gallagher's design (Hathaway, 2019).

By establishing the connection between the newer spindle motor driver and the ESS, the project, in essence, will bring the Roland up to a mostly working condition. The final aspect to complete the project involves establishing the pneumatic control of the ATC. This is a sub-system under the spindle motor component, as seen above in Figure 2. However, the Roland project will be functional with the integration of the Spindle motor and corresponding driver. A user can manually change tools in lieu of the automatic tool changer. The majority of the technical project's physical work and research will be conducted in the Mechatronics and Innovation Learning Lab found in the Mechanical and Aerospace Engineering building room 005. Funding will be provided through the Mechatronics Lab. The description, process, and findings of the technical project will be written in a scholarly article. By completing this project, the University of Virginia will have a working asset for instructional and course work use, thus enabling students to learn and develop maker skills. This desire to learn and create, according to *Forbes* contributing author Amy Blankson (2018), is a basis for "the heart of the maker movement…" as it is "collaborative, fun and exploratory in nature" (para. 2-5).

MAKER TECHNOLOGIES: CAN THEY IMPROVE EDUCATION INCLUSION?

Traditional education focuses on three main tracks beyond elementary grammar and mathematics: Arts, Science, and Business. In recent decades, education advanced in all these tracks; however, socioeconomic and cultural minority inclusion in the Science, Technology, Engineering and Mathematics (STEM) fields remains a focal point of contention. In their case study, science education professors, Angela Barton and Edna Tan, and doctoral student, Day Greenberg, (2017) noted "large gaps in achievement and interest in science and engineering (STEM) persists for youth growing up in poverty, and in particular for African American and

Latino youth" (p. 4). One manner in which primary and secondary education systems attempt to increase this inclusion is through the adoption of the maker movement activities and values.

FOCUSING ON MAKER TECHNOLOGIES AS A SAVIOR

The concept of solely analyzing maker technologies as the primary focal point for increasing minority inclusion into STEM education is the major complication. Danish communication doctoral student and professor of child-computer interaction, Kasper Christensen and Ole Iversen (2017) defined maker technology as "a technology that is used in maker or hacker spaces" (p. 41). This technology includes machinery like 3D printers, microprocessors, and software for creating designs and art. Dale Dougherty (2012) favored the maker movements incorporation into the aforementioned societal groups through the use of logic and emotions. Dougherty suggests the idea of hand-on learning as a more effective way to teach children, as the hands-on method can prevent children from "[being] disengaged and bored in school" (p. 12).

In applying the definition of technology and technology practice of Arnold Pacey's Triangle (1983) to maker technology, the technical aspect consists of: 3D printers, laser cutters/engravers, CNC mills/lathes, design skills and software (p. 6). The organizational aspect consists of: educational institutions like schools, universities, and libraries; governmental organizations in research and development; business organizations in product development and design; and hobbyist. The "do-it-yourself mentality, experimentation, exploration, invention, and spirit of collaboration" values and "need to engage passionately with objects" make up the cultural aspect of maker technologies (Mekolichick & Wirgau, 2017, p. 23; Dougherty, 2012, p.11). These various aspects constitute the framework of maker technologies and serve as a context in which maker technologies is used. By placing the organizations into groups and applying Social Construction of Technology (SCOT), Figure 3, below, illustrates the socio-technical relationship between the groups and maker technologies. The orange arrows coming from the maker

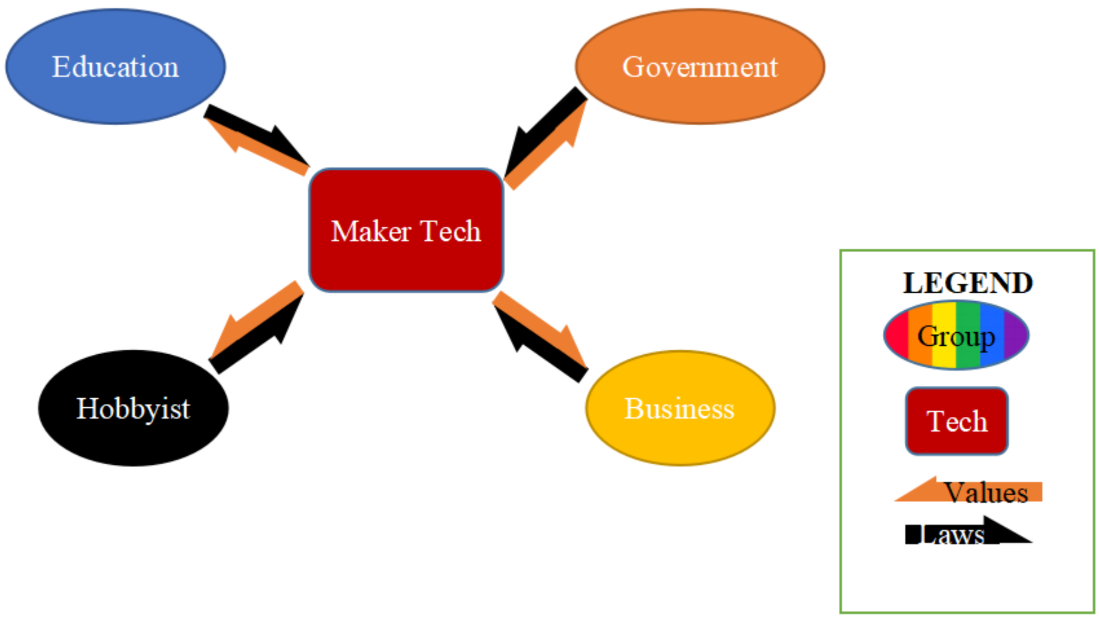

Figure 3: Social and technical relationships of maker technologies: Centered are maker technologies with maker values going to social groups, and social group regulations and laws going to maker technologies (Hathaway, 2019).

technologies block signify the values ingrained in it from the maker movement as they act upon the major user groups. The black arrows denote various laws, regulations, and shaping placed on maker technologies by the user groups.

Richard Bilton (2012), associated writer for VentureBeat, noted an example of the hobbyist who produced weapons parts via a 3D printer, which resulted in attempt to legislate 3D printer use to inhibit such actions. The governmental action and concepts surrounding maker technologies bring forth questions regarding maker technology and education. Do the above models, Pacey's Triangle and the SCOT application in Figure 3, dictate the beneficial effects of maker technologies in education or is it mostly education dictating the use of maker technologies? What legislative measures increase minority inclusion in STEM education? What educational benefits, outside of adding hands-on learning, do maker technologies present? What alternate maker movement paths facilitate underrepresented minority inclusion into STEM education? In recent years, there were efforts to legislate maker technologies into education. As an example, the Congressional Research Service (2014) noted the importance of maker technologies in education as the Obama Administration's 2014 budget incorporated a plan to establish a national network to facilitated manufacturing innovation, which included maker technology inclusion in primary and secondary schools.

ACTOR NETWORK THEORY: RESTRUCTURING EDUCATION AND MAKERS

In the informative article, How 'Makers' Make the Classroom More Inclusive, New York Times writer, Melinda Delkic (2018), provided insight into the notion that schools need to adapt teaching methods to better enable inclusion into STEM classes (para. 2, 11-12, 15-16). For continued success of maker technologies in education, how can the interaction between maker technologies and primary and secondary education centers be changed?

To ensure continued adoption of maker technologies and foster an inclusive educational environment, the current SCOT model, as seen on page 7 in Figure 3, should be changed to one which incorporates concepts of Actor-Network Theory adapted to focus on the specific interactions between maker technologies and educational facilities. Specifically, a Handoff Model (Carlson, 2013), as depicted below in Figure 4, provides focus on these interactions.

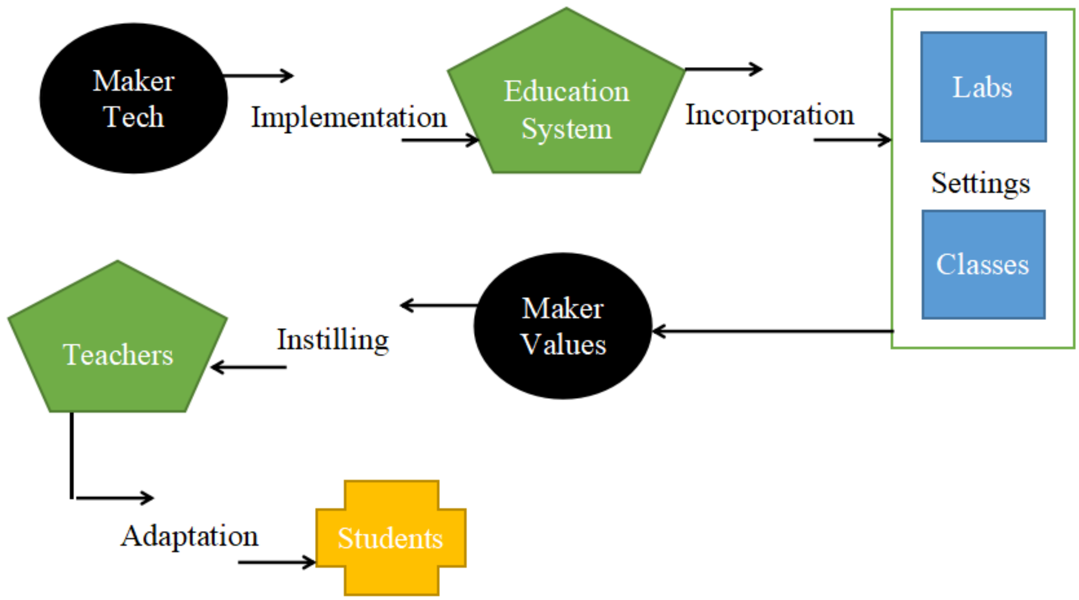

Figure 4: Handoff from maker technology to student: Beginning at maker technology in the top right, the handoff movement flows from top-right to bottom center, the student, incorporating various education levels maker aspects and settings. (Hathaway, 2019).

With maker technology initiating the handoff model, each handoff transition, identified by the arrows in Figure 4 above, generalizes the relationships in moving from one section to the next. The implementation handoff from maker technology to the education system incorporates government legislation, acceptance by educational systems, non-profit organization support, and media coverage. The education system is a crucial part of the handoff model as it involves the hierarchy of schools, public opinion, and funding to accept maker technologies. After which, the incorporation handoff defines how the education system plans to establish settings for maker technologies. This involves design and development of spaces and classes, as depicted by the blue squares, labs and classes in Figure 4. Both during and after these settings are established, the next handoff is to maker values. This block serves as a transition point from major concepts and restructuring to individuals. Following maker values, the instilling handoff challenges the status quo of teaching faculty. Delkic (2018) specifically notes, in two interviews, that some teachers do not understand the concepts of being a maker and need a period of adjustment (para. 8-9, 12, 14). In acknowledging and understanding the values and concepts of the maker movement, faculty members can adapt and incorporate them into lesson plans and projects, as noted by the adaptation handoff. The final section in this model consists of the student. While trivial, the model does not necessarily end with the student because he or she can transfer the skills taught to higher levels of education, work, or facilities outside of the traditional class room. Nicole Lou (2015), contributing writer at *Popular Science*, notes five organization which set out to aid in providing a setting to allow underrepresented youths access to maker technologies. The organizations Lou identified were: National Action Council for Minorities in Engineering (NAMCE), TechHive, We Teach Science, Maker Ed, and Girlstart (para. 3-6).

In order to continue to increase minority inclusion into STEM education, education systems need to focus on incorporating maker technologies and adapting maker values into their schools. By changing how educational systems incorporate maker technologies, teachers can create a more inclusive environment for underrepresented children. The STS research project will be finalized as a scholarly article during the spring of 2020, detailing the connection between the maker movement and increasing underrepresented youth inclusion in STEM education.

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