ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA143

MOTION CONTROL DEVELOPMENT OF THE MATERIAL HANDLING SYSTEM FOR INDUSTRIAL LINAC PROJECT AT SLRI

R. Rujanakraikarn†, P. Koonpong, S. Tesprasitte
Synchrotron Light Research Institute, Nakhon Ratchasima, Thailand

Abstract

The prototype of industrial linac for food irradiation application using x-ray has been under development at Synchrotron Light Research Institute (SLRI). Several subsystems of the machine are carefully designed for proper operation. Material handling system with its motion control and its relationship with a beam scanning system is explained in this paper. Hardware selection and software development together with a networked control system is described. This system is being developed and tested with the object detection system to monitor and control the position and velocity of materials on a conveyor belt.

INTRODUCTION

Synchrotron Light Research Institute (SLRI) has been developing a prototype of linear accelerator for industrial applications. One of the main purposes of this new project is for food irradiation application. Since agricultural products are Thailand's primary economy, this newly proposed project is aimed to increase the availability of the low-cost machines for domestic uses. This accelerator-based system is one of the platforms that can provide good facility for food irradiation. There are three key elements in this accelerator-based system, an accelerator system to deliver the energetic beam, a scanning system to provide uniform beam coverage of the product, and a material handling system that moves the product through the beam in a precisely controlled manner [1].

In the designed prototype there are several main components for each key element. Firstly, the accelerator system consists of an electron linear accelerating structure of the S-band standing wave type, a 3.1 MW magnetron driven by a solid-state modulator, and a hot-cathode electron gun. Secondly, the scanning system comprises a beam scanning magnet and a scanning horn to provide full coverage for irradiation to products. Lastly, the material handling system is composed of conveyor system, motor drive system, and electronic control system. The diagram of this accelerator-based irradiation facility prototype can be shown in Figure 1.

The primary goal of the irradiation facility is to deliver the specified amount of required radiation to the products without unnecessary, wasteful, and excessive dose. Thus, monitoring and control of the process parameters and the information of objects to be scanned are important in order to effectively spread the beam with appropriate field strength. Once the parameters and object information are known, the motion of the conveyor belts in the material handling system must be precisely controlled.

† roengrut@slri.or.th

This is to ensure that each product moves through irradiation zone to receive desired dose without slippage or gaps. This can effectively improve the efficiency of the irradiation facility.

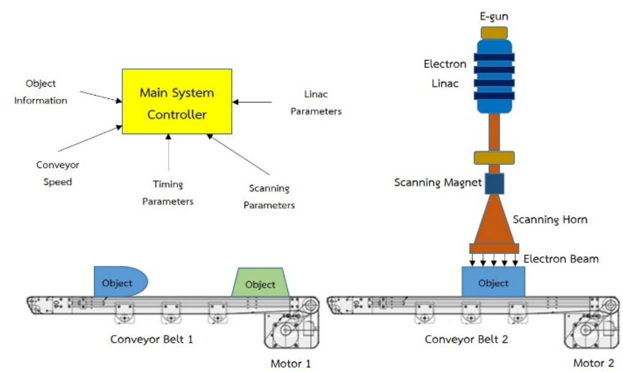

Figure 1: A prototype of accelerator-based irradiation facility.

In this paper, a real-time motion control development of the material handling system together with its relationship to the beam scanning system and object detection system is described. Hardware selection and software development together with a networked control system are explained. Elementary result of the design and tests is briefly explained with some discussion on proper machine operation. Concluding remark is summarized at the end of the paper.

SYSTEM DESIGN

This section explains the brief description of the prototype system design. An overall system diagram showing the beam scanning and the material handling systems is shown in Figure 2. In this diagram, all subsystem controllers are connected in a private network to form a networked control system. These controllers are responsible for motion control of the conveyor belt, camera control for object detection [2], and scanning magnet control for the generation of time-dependent magnetic field deflection of the beam. The main purposes of implementing these subsystem controllers are for process parameter measurement and sensing, and reporting information to and receiving control setpoints from a main system controller which is connected to the same network. The main system controller is designed to implement control algorithms in order to oversee the operation and stability of the whole system. The personal computer in the diagram is connected to the network to receive and display all process parameters and send settings and responses to the main system controller's various requests.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA143

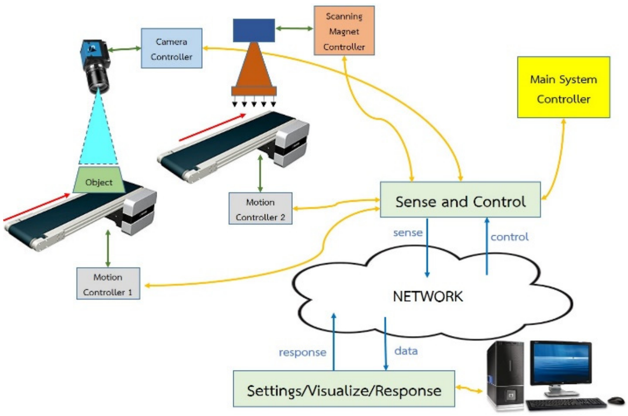

Figure 2: Overall system diagram with networked control system.

Since the main focus of this paper is on the motion control of the material handling system, the detail will be on the design and operation of motion controllers. The relationship to the beam scanning system and object detection system of the prototype is described in the result and discussion section.

Hardware

The motion control system is crucial for real-time control of the machine prototype in order to ensure that the product or object moves through the irradiation zone in a timely manner. For the development phase of the project, a number of hardware have been selected for control system design. The selected ones discussed here are conveyor belts, motor and electronic driver, and controller boards.

Conveyor Belts are chosen from commercially available ones. In the initial phase of this project, with a limited experimental space, only two sets of a two-meter long convey belt with desired specifications to handle product loads and speed range are selected. Custom motor fixtures are also fabricated because brushless DC (BLDC) motor are separately chosen. Figure 3 (from top left to bottom right) shows the selected conveyor belt, BLDC motor and driver, custom motor fixtures, and motor installation, respectively.

Figure 3: (top left) Conveyor belt, (top right) BLDC motor and driver, (bottom left) custom motor fixtures of the prototype, (bottom right) motor installation.

BLDC Motor and Electronic Driver are chosen from the commercially available ones. They are Oriental Motor's BLE2 Series brushless motor [3]. This BLDC motor comes with electronic driver which allows easy settings through its front panel. The motor speed can be arbitrarily set by applying external DC voltage. Its speed can be measured from the driver's pulse output which provides 30 pulses when the motor output shaft makes one rotation.

Controller boards are 32-bit microcontroller boards for the prototype development. Two main microcontrollers are STM32 and ESP32. They are selected to communicate to each other to build a motion controller shown in Figure 2. The STM32 board is chosen to perform general low-level measurement and control tasks such as motor speed detection using timers [4], pulse frequency and duty cycle measurements, DAC control, PWM control, general time-based measurements and interrupt service routines, UART communication, and digital PID controller implementation for motor speed control. The ESP32 board is programmed to report parameters while receiving motor speed setpoint from the main system controller. ESP32 is implemented as a TCP client device to communicate over WiFi with the main system controller or PC as a TCP server. Finally, the two microcontroller boards communicate to each other via UART. Other electronic parts such as amplifier circuits, isolator circuits, and interface circuits are not explained in this paper.

Figure 4 shows some hardware test setup and the result of the board tests. System identification by using a black-box model of the motor and driver system is also performed to obtain mathematical transfer function. The input of this test is based on PRBS generator in order to collect motor speed output over the entire speed range. To help visualize the hardware interconnection of the motion control system, feedback control loop and communication between controller boards are shown in Figure 5.

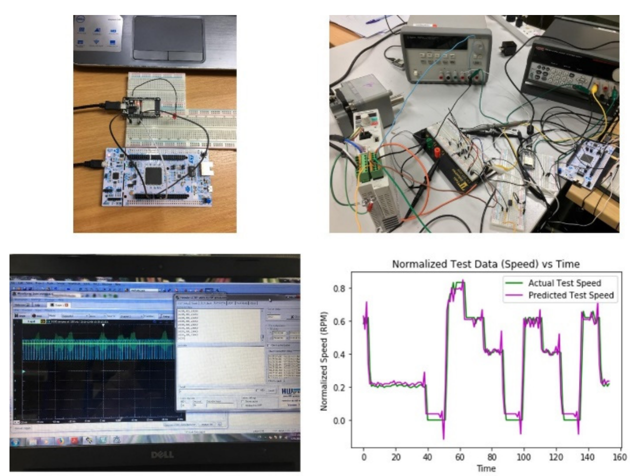

Figure 4: (top left) Microcontroller boards, (top right) lab test with BLDC motor and driver, (bottom left) motor speed detection test, (bottom right) system identification result for the BLDC motor and driver system.

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA143

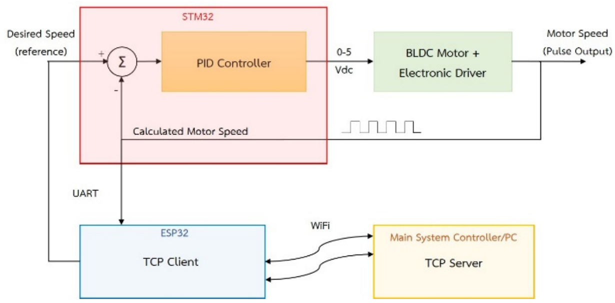

Figure 5: Diagram of the feedback control loop and communication between controller boards for one motion controller.

Software

The main software development in this initial development is for microcontroller boards. The software running on STM32 is coded in C. Standard HAL drivers are used in most of the code. For ESP32, the code is designed in C++ for Arduino IDE. Since there are multiple motion controllers in this prototype, care must be considered for client-server communication in the network. Communication between one TCP server and multiple TCP clients is managed using standard JSON data format.

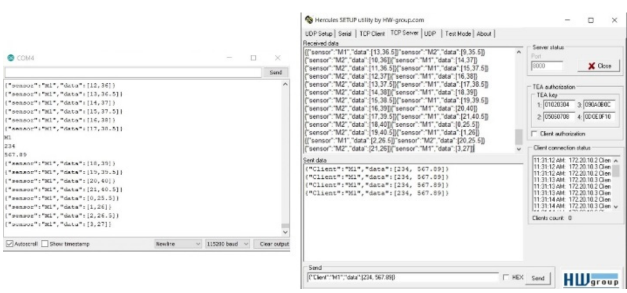
Figure 6: Example test of communication between 2 motion controllers and a PC (as a server).

RESULT AND DISCUSSION

Tests for the proposed motion control system, both hardware and software, of the material handling system are performed. There are series of tests in order to ensure that each part of the system works correctly as desired. In this initial development, PC is chosen to perform as the main system controller for ease of the software test and evaluation.

First, the selected sets of BLDC motor and driver are tested. Resulting smooth operation over the desired speed range is achieved. System identification is performed in order to obtain transfer function of the black-box model. This mathematical model is expected to be used in a controller design with more advanced control algorithms. This is expected to be further designed in the future once the main system controller is developed, and the full interoperation between all systems (motion control system, object detection system, scanning system, and accelerator system) is needed for system commissioning.

Motion of the combined motor and conveyor belt system is tested after installation of the motor with the custom fixtures. The test result ensures that the mechanical design of the fixtures fits perfectly to the conveyor belt parts and BLDC motors without hindering the motion of the system.

Controller boards are carefully tested in order to obtain accurate motor speed information and take complete control of motor speed. These primary tests are motor speed detection using STM32's timer, DAC output test, and interrupt tests. Tests for ESP32 are accomplished by carefully testing its IoT-ready capability. UART communication between STM32 and ESP32 is tested to ensure the correction of information exchange. TCP communication between a PC as a server and multiple ESP32 clients is fully tested and the result is satisfactory. Small transmission delay occurs during the entire test for our wireless network.

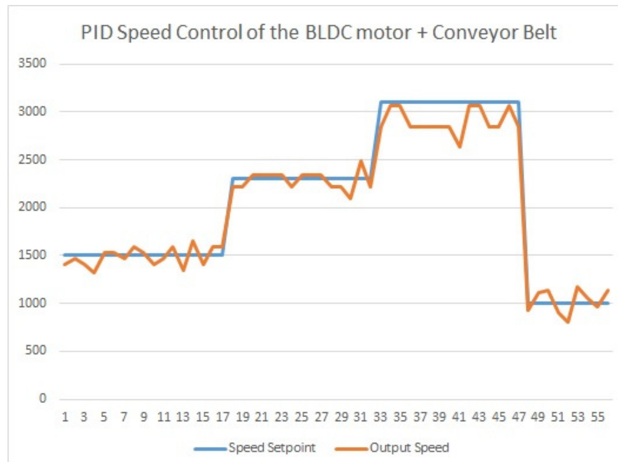

Figure 7: PID speed control test over network.

The BLDC motor and conveyor belt speed control is performed by the implementation using digital PID controller on STM32 board. The test is carried out over network using ESP32 board and PC. The initial performance test result for one motion controller is shown in Figure 7. For low motor speed (less than 2,500 RPM), the performance of the controller is acceptable. Moderate result is obtained for the motor speed of more than 3,000 RPM. Regarding the desired conveyor speed with respect to operational condition of the machine, it is preferred to run conveyor belt with slow speed. This is directly related to the beam output from the linac in the accelerator system. Better control performance, however, is still needed for our motion control system. More improvement in software coding and controller tests will be performed to achieve better speed control. These, for example, are resolution of the controller output signal, motor speed detection vs transmission delay of the network, communication between microcontroller boards, and application of model-based multivariable control algorithms for this system. During this initial development, the motion control system can perform quite well as an IoT-based control system for our machine prototype.

Regarding operation and interaction between motion control system, beam scanning system, and object detection system, more detailed algorithms and control strategies are further needed. The diagram shown in Figure 8 illustrates that if the object has rectangular shape, the time

ISBN: 978-3-95450-209-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2019-MOPHA143

varying magnetic field strength in the figure is typically desired to give the scanning action that can be used to effectively spread the beam across the object. Since the frequency of the magnetic field strength is fixed, conveyor belt speed must be constant for this object to be successfully scanned. The same control action is necessary for the object shown in Figure 9. Constant conveyor speed is required because the magnetic field has only varying amplitude but constant period. It can be seen that, currently, this motion control system is ready for the entire system tests and further development.

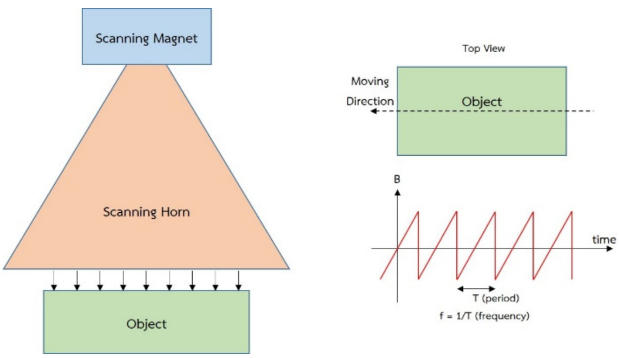

Figure 8: Beam scanning magnet system and time-dependent variation of the magnetic field [2].

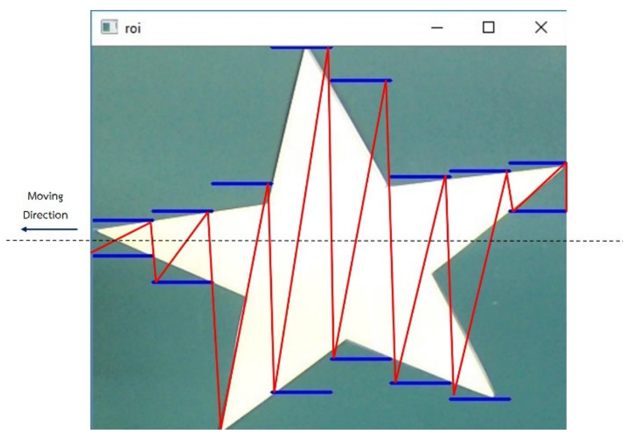

Figure 9: Expected time-dependent magnetic field for the tested object [2].

If, on the other hand, the scanning frequency used to control scanning magnet varies over time, the speed control will be completely different. Velocity profile of the conveyor belt needs more calculation and adjustment in order to match the magnetic field profile at each time instance. At the moment, this is left for further discussion for optimal mode of operation.

CONCLUSION

The proposed motion control for the material handling system is developed for the prototype of linear accelerator for industrial applications, specifically for food irradiation application using x-ray. The primary purpose of the system is to provide automatic control strategies for the motion of the conveyor belts, including motors and electronic drive systems, in order for the product to be scanned to move through irradiation zone in a proper manner with respect to the generated time-dependent magnetic field shape. The system design, both hardware and software, is described in detail with discussion on control system implementation. From the series of tests performed, overall performance of the motion control system is satisfactory. Discussion on control system performance improvement is provided with respect to operational condition of other subsystems of the machine prototype. This motion control system is currently ready for overall real-time system tests and further development of the machine.

REFERENCES

[1] R. Miller, Electronic Irradiation of Foods: An Introduction to the Technology. Springer Science + Business Media, Inc, NY, USA, 2005.

[2] R. Rujanakraikarn, P. Koonpong, S. Tesprasitte "The Development of Object Detection System for Industrial Linac Project at SLRI", presented at ICALEPCS19, NY, USA, October 2019, paper WEPHA132, this conference.

[3] Oriental Motor "Brushless Motor BLE2 Series", `https://www.orientalmotor.com/products/pdfs/2015-2016/D/BLE2_Brushless_Motors_AC_Input.pdf`

[4] STMicroelectronics (2019) "General-Purpose Timer Cookbook for STM32 Microcontrollers", `https://www.st.com/content/ccc/resource/technical/document/application_note/group0/91/01/84/3f/7c/67/41/3f/DM00236305/files/DM00236305.pdf/jcr:content/translations/en.DM00236305.pdf`