Implementation of Vision-Based Control in Large-Scale Manufacturing Systems

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Research conducted under Professor Kira Barton within the Secure Cloud Manufacturing team

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Honor Pledge: “I have neither given nor received aid on this assignment, nor have I concealed any violations of the Honor Code.”

1.0 Abstract

The purpose of the Secure Cloud Manufacturing (SCM) research team is to develop methods to advance large scale manufacturing systems that optimize productivity, efficiency, safety, and security. This allows high quality products to be available to consumers at an economical cost. The research is conducted on a scaled manufacturing system equipped with CNC machines, conveyer belts, robots, and an interactive human machine interface (HMI), all monitored through the use of sensors. The team is divided into four sub-teams: controls, manufacturing, simulation, and cloud and database. This report details the semester contribution of Aleyna Kapur within the controls subteam with the goal of implementing vision-based control. This control can ensure quality is maintained throughout the manufacturing of a product by monitoring its accuracy upon completing a given process. It sustains high production rates by diagnosing processing errors early on to prevent subsequent, large volume errors. In the context of the SCM testing facilities, after a product is machined, its spatial features can be analyzed to ensure the accuracy of the machining process. By utilizing a programmable camera to measure image features, an automated inspection can be implemented to determine if its dimensions fit a desired tolerance. Passing the inspection confirms the accuracy is maintained. Failing may reveal the beginning of machine tooling wear or a major malfunction in the machining process. These results are returned to the main control system for the test bed to react accordingly.

2.0 Introduction

To ensure the quality of production and identify future process failures in the SCM test bed, vision-based control was integrated within the system. To properly implement this control, its core responsibilities and functions were defined to determine the ideal hardware. A National Instruments (NI) Smart Camera met these responsibilities, and was programmed with a defined inspection process. It connected to the test bed in two ways: through standard input/output (I/O) connections and through Ethernet IP. Preliminary testing was conducted as each step of its integration was completed. In this way, functionality was ensured through each additive step, compared to blindly debugging after full setup, where errors may have occurred in many steps.

3.0 Methods

The procedure for implementing vision-based control was broken down into four steps: responsibility identification, hardware and software configuration, test bed connection, and preliminary testing. The following sections outline the methods for each group.

3.1 Purpose of Vision-Based Control

The responsibilities of vision-based control were identified based on its potential to guarantee quality and improve production. With its implementation being in its early phases, it was also necessary for the control to transition fluidly within the entire test bed through its physical installation and through its functionality. Its responsibilities were to add to the productivity and efficiencies already established in the current configuration of the test bed.

3.2 Configuring Hardware and Software
The vision-hardware was determined based on the defined responsibilities and was programmed accordingly.

3.2.1 Hardware
The vision-hardware was chosen with the collaboration of National Instruments. Given their range of machine vision instrumentation and extensive technical support, they were well qualified to assist. A representative came to the test bed to inform which camera was ideal for the SCM application. Its specifications were given to the mechanical sub-team for designing its mount to the test bed. Then the camera was installed after the CNC machining process, above a stopper. The camera can then acquire an image while the part is static.

3.2.2 Software
The camera can be programmed in two ways: through LabVIEW or Vision Builder for Automated Inspection (VBAI). The latter software is specific to programming inspections using a machine vision camera and comes with a pre-programmed function library. The inspection can be translated into LabVIEW, where more sophisticated edits can be made. Because of its ease of use, it was the most time efficient method to begin programming the camera. As vision-based control develops in the future, if desired, the inspection can be migrated and further adjusted in LabVIEW.

3.3 Connecting to Test Bed Logic
The camera was connected to the system logic through two types of connections: multiple I/Os and Ethernet IP. An I/O was created to trigger the camera's function, and a second one was created to feedback the inspection results to the test bed. When first connecting the camera, it was unclear which method would be most efficient and most fluid to integrate the system. Both methods were configured, however the Ethernet IP protocol requires additional configuration due to the difference in system control software and camera software. They cannot directly communicate.

3.4 Preliminary Testing
With the camera installed, the inspection created, and the I/Os connected, the vision-control was tested. The camera is triggered upon receiving a signal from a chosen sensor upon sensing the presence of the part. Once these tests were completed, the results revealed where debugging in the control still reside.

4.0 Results
Following the above methods, the results for implementing vision-based control are explained in the four sections below.

4.1 Identification of Quality Based Responsibilities
The responsibilities of the vision-based control were determined to monitor machining process. The defined responsibility and its purpose are outlined below, (Table 1).

Table 1: The responsibilities of the vision control and purpose

Responsibility	Purpose
Capture image	- Receive visual of component after machining process - Save image after inspection for future reference
Detect features	- Detect machined features on image - Ensure the desired features are inspected
Measure features	- Quantitatively analyze the feature, measuring desired dimensions
Determine pass/fail	- Qualitatively analyze the feature, determine if specifications are met - Pass if specifications are met, fail if they are not met
Send/receive Signals	- Feedback quantitative and qualitative data to test bed control system

4.2 Utilizing a Smart Camera

The final hardware configuration included the NI 1752 Smart Camera, an 8mm adjustable lens, a red LED ring light, a power adapter, an I/O accessory, and a 15-pin connection cable. This camera was programmed with an inspection using VBAI. All the responsibilities were met by the chosen hardware and software.

4.2.1 Hardware

The NI 1752, monochrome camera was chosen for the SCM test bed. The camera sits atop the inspected component; with adjustments to its vertical height and the 8mm lens, the acquired image has high clarity for accurate inspection. The red LED ring light is mounted to the camera and controlled directly from it through the programmed inspection. With shadows casted all around, and insufficient ambient lighting, the light was necessary for the accurate feature detection on the acquired image.

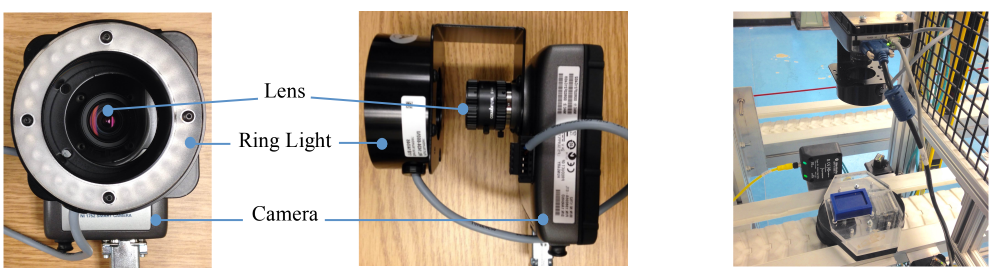

Figure 1: The NI 1752 programmable camera was chosen as the sensor for the vision-based control (left and middle). It was installed atop the pallet stopper to acquire images while the pallet was static (right).

4.2.2 Software

The VBAI inspection was created through a development computer and programmed into the camera. It is in the form of a flow chart (Figure 2), and configured from a pre-made and inspected part. For example, if a dimension shall be measured on future inspected parts, this dimension is defined in the program on this pre-made part. Then the inspection will measure in the defined area, in the same direction and on the same geometry feature in the future. Because the focus of the SCM research is on the processes, the desired features to inspect were expected to change. The inspection states were made for quick adjustments: single functions with in the state will require adjustment as new features shapes and measurement types are needed, but the structure of the inspection will not require major changes. Figure 2 outlines each step of the created inspection. The inspection is completed every time the camera is triggered.

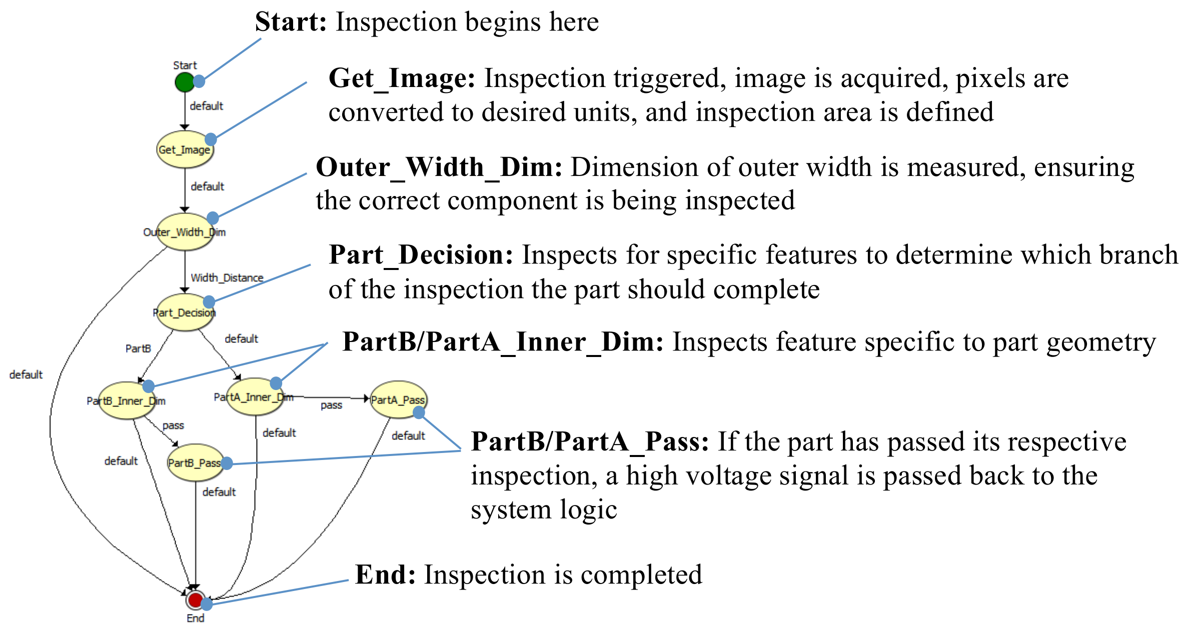

Figure 2: Outline of inspection states. This inspection can inspect two different components, labeled part A and part B. The arrow with "default" aside it identifies the automatic route of the inspection. If secondary routes are available, they are defined by a condition and taken only if it is met.

4.3 Multiple I/O connection

The camera is triggered through an I/O connection. It is configured in the *Get_Image* state of the inspection, and is the condition that allows the inspection to run. When the part reaches the stopper, the RFID reader senses its tag and signals the control system to send a high signal to the camera. The results will be sent back to the system through an output I/O, sending a high signal back if the inspection has passed.

The Ethernet IP connection requires additional configuration. Communications with NI and Rockwell Automation are currently underway to determine the right file and or module to finalize this connection.

4.4 Communications with Test Bed

The preliminary test results reveal the installation, inspection, and trigger signal are functioning. However, there remains a glitch with the output signal, as it is not received by the system. Because this signal sending does not require configuration through the system network, the error lies in a misconnection, or voltage magnitude, and will be adjusted the following semester. The multiple I/O connections do have a drawback: with many wires for individual signals, there is more probability for errors, compared to a single connection.

The inspection experienced inaccuracies with the part measurement (Figure 3). The inspection searches for equivalent hue saturations along parallel paths to locate the edges to measure dimensions from (Figure 3, right). Because of this, it detected the cut out lines in the clear pallet that were magnified through the refracted light. It also detected the line of a shadow from the cutout within the part.

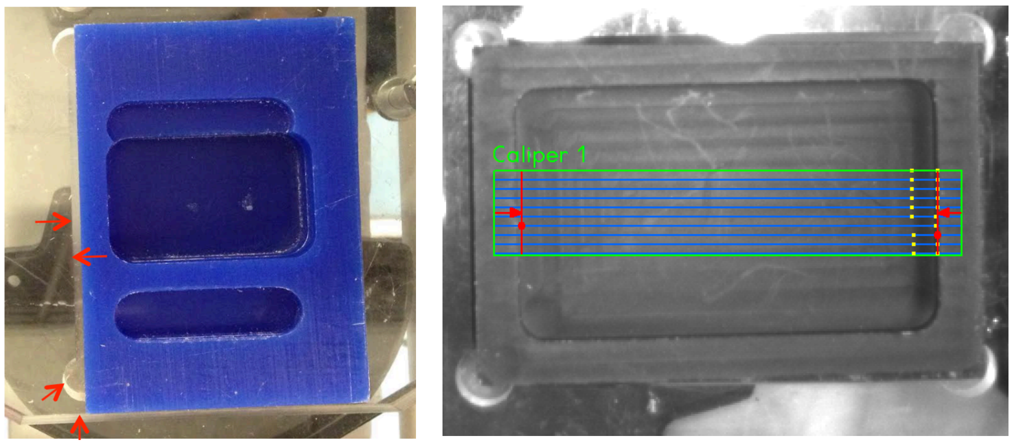

Figure 3: Measurement inaccuracies were experienced due to incorrect edge detection. Defined lines created by refracted light (left) and casted shadows (right) caused the program to perceive them as part edges. The right image shows how the measurement is configured in the inspection. The blue lines across the part find the sharp change in hue saturation. The yellow dots denote where edges are found. In this image, it is finding two sets of edges, one from the shadow and one from the actual inner part edge. The multiple edges detected leads to the inaccuracy.

5.0 Conclusions and Future Work

The foundation has been established for vision-based control within the SCM test bed. Because this type of control is new to the system, all of its components were setup to be modular, as changes are needed. The camera mount was made by the mechanical sub-team to be installable in any part of the extruded aluminum framing. The inspection program can be adjusted as new features are made. Two different connections were setup in order to test the best path of communication. The connections do require debugging, but this is currently underway. The next step to improve the foundation is to use inspection results more constructively. Currently as parts pass or fail, a signal is sent back to the system and is written to the RFID tag, however no changes in processing occur. If parts are failing randomly and infrequently, they could be rerouted and removed from the pallet. If parts are frequently failing, this could be signaled to an operator, and could terminate a particular manufacturing process. These steps would require collaboration with the cloud sub-team, to extract the inspection results from the control and made available through a database. Furthermore, now that this control is in place in the system, collaboration will be needed with the simulation sub-team to incorporate this into the simulation of the test bed. In this way, the test bed can be optimized on all fronts of the team to give way to the impactful designs of the future.