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DMDII FINAL PROJECT REPORT

Non-Invasive Computer Vision Toolkit for Legacy Machines using MTConnect	
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I. EXECUTIVE SUMMARY

To recognize achievements in digital manufacturing we must address issues surrounding the difficulties in acquiring information across legacy, proprietary, and non-computerized machinery. Modern computerized machines provide a wealth of data electronically, automatically and in near-real time. This data provides insightful information to operations, maintenance, and management to quickly identify and resolve issues impacting productivity and quality.

Legacy and non-computerized machines provide little or no data electronically. For this equipment, acquiring process information requires manual monitoring or the application of various sensors and data acquisition devices. This approach is oftentimes slow, expensive, invasive, and often provides limited data. The result is the most vital legacy equipment is simply left unmonitored.

Industry 4.0 Digital Manufacturing will reach its full potential only when we can collect, process and utilize the data from all entities of a manufacturing floor. In this process, the ability to collect and analyze data from legacy machines is of prime importance. Process optimization, part quality, on-the-floor productivity, and machine maintenance are some of the many advantages of collecting data and analyzing it.

To understand how to effectively implement the digital factory concept across all machines and process operations, a valuable source of information is the operators that observe, listen, use, and monitor the manufacturing equipment. They collect and process operation data based on the visual cues (dials, displays, part location, etc.), particular job settings, the operations sounds, and more. These cues form a wealth of information for the operators to control and maintain productivity and quality. If the equipment is not digitized, this awareness and knowledge live a finite and sheltered life within the operator's memory. Digitization of these cues can provide automated feedback, work instruction verification, early detection of operation issues, preventive maintenance, and "big" data collection for downstream applications. Therefore, there is a need to acquire digitized data in a simple, deployable and cost-effective manner that can be integrated with known manufacturing data standards such as MTConnect®, to "translate" the digital inputs into data streams that can be read by commercial status tracking and reporting software solutions.

University of Cincinnati, TechSolve, and International TechneGroup Inc. (ITI) along with industry demonstration partners Raytheon, Faurecia, and Matdan Fasteners have developed an innovative, affordable and non-invasive toolkit that combines currently available camera, computing, and networking technology and components with a new software analytics platform. The Non-Invasive Computer Vision Toolkit has been designed to acquire data from various legacy machine components (gauges, readouts, dial positions, and other shop floor artifacts which are then converted into appropriate data. This system does not physically touch the equipment, require new operator procedures, or add physical sensors to existing utilities. Leveraging MTConnect®, the system will provide a flexible capability to acquire information which will be completely compatible with existing MTConnect® applications. Figure 1 shows an overview of the project along with the outcome and benefits.

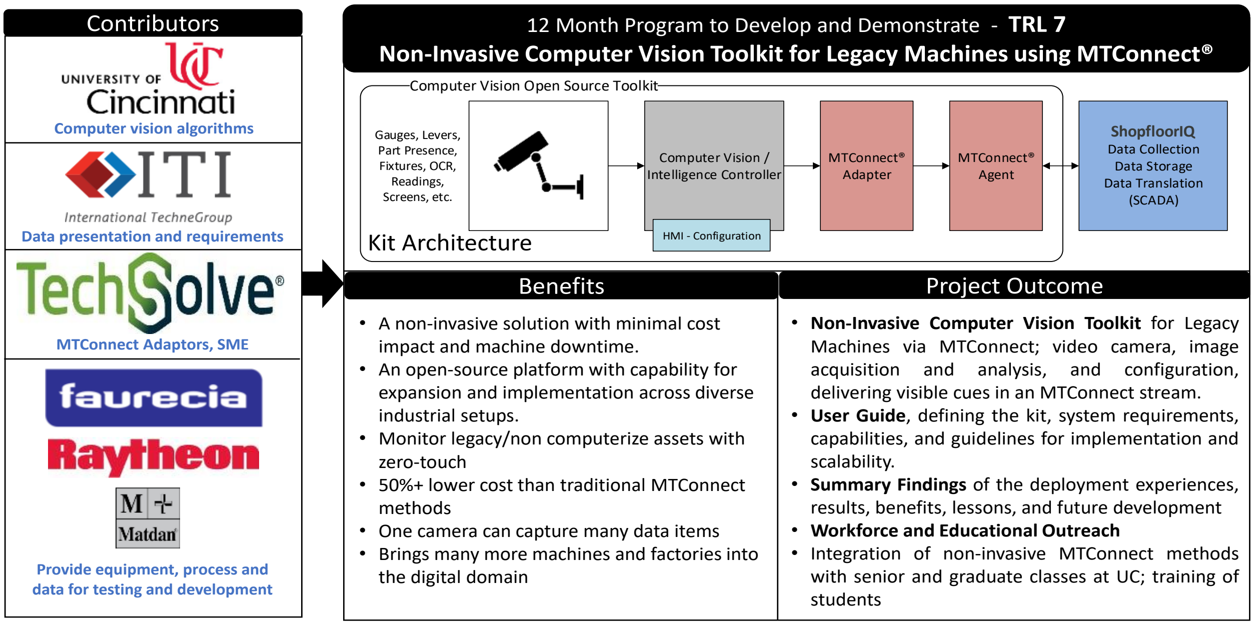

Figure 1: Non-Invasive Computer Vision Toolkit Project Overview

II. PROJECT REVIEW

The project was broken up into the following major tasks: 1) Assessing industry team requirements at the demonstration sites, 2) Development of mock panel testbed environment, 3) Hardware acquisition and configuration for the sites, 4) Software development for image acquisition, processing, machine learning, and integration with MTConnect adapters, 5) Installation and demonstration of mock panel test bed, 6) Installation and testing at the production environment sites, 7) Technology transition and workforce development. Each of these tasks is briefly described in this section.

2.1 Task Description

Task 1: Assessing Industry Team Requirements

The focus of this task was to collect information on the legacy machines and the associated artifacts at each of the demonstration sites so as to identify and plan the purchase of the hardware including, camera, processing computers, and network accessories.

UC team, TechSolve, and ITI visited Matdan Fasteners in Cincinnati on July 20th, 2017. During the visit, the team collected a set of images and videos of the machine tool as a part of the data collection required for software development. The teams further collected sample machined parts to create a data-set of images in the toolkit development specific to Matdan Fasteners.

UC team, TechSolve and ITI visited Faurecia plant in Fraser, MI on August 23rd and 24th, 2017, and visited Raytheon plant in Andover, MA on August 28th and 29th, 2017. During the team's visit to Faurecia, the team collected a set of images and videos of the injection molding machines and the environment surrounding these machine tools as a part of data collection required for software development. At Raytheon, the project team identified the various artifacts including knobs, toggle switches, safety lights, liquid level and fixture orientations at three different machine locations.

The teams also visited Raytheon early September 2017 to finalize the artifacts for the project use case. This concluded the initial collection of detailed requirements for the project use cases.

Task 2: Development / Demonstration Mock Panel Environments for Machines

To successfully develop, implement and test the algorithms for the Computer Vision Toolkit, University of Cincinnati and TechSolve constructed a mock panel test bed that emulates the real time shop floor environment. Based on the initial detailed requirements that were collected from the three production environment partners, these mock panels were populated with the identified artifacts. The mock panel developed at UC was used to demonstrate the working and progress of the project during various review meetings. The comments and feedback from these meetings were used to improve the User Interface and working of the software. This mock panel was also used to demonstrate the working of the toolkit at DMDII Future Factory Technology Showcase event at Chicago in November 2018.

Task 3 Hardware Acquisition and Configuration

Based on evaluating the requirements at each of the production environment sites, the team decided on a low-cost Logitech camera and an Intel Core i5 or i7 processing unit. The hardware and their specifications are listed in detail in 'Accessing the Technology' section of this report. Raytheon, Faurecia, and Matdan Fasteners contributed to the purchase of the various processing machines, cameras, and necessary mounting apparatus as a part of the project cost share.

Task 4 Software Development

University of Cincinnati, TechSolve and ITI were responsible for the software development portion of the project. UC developed the core module for the CV toolkit software and the integration of the software with the camera. In addition, UC developed the User Interface (UI) for training, which is a one-time offline process that is required to set up and train the software for the local machining environment. The UC team also developed various image processing and machine learning methods that identify and detect various parameters of legacy machines. The vision system interfaces with the camera (imaging system) and the extracted data is then transferred to an MTConnect® based Adapter. TechSolve developed the MTConnect® based Adapter that collects and parses the data from the vision system. The parsed data is then transferred to MTConnect® based Agent which was also developed by TechSolve. The Agent holds a historical collection of the data from all the artifacts along with their corresponding MTConnect® categories and acts as a server from which the data can be captured by downstream applications such as ShopFloorIQ. ITI contributed the visualization/analysis software, ShopFloorIQ, that is installed on a remote machine in the production environment. Various machine parameters extracted from the legacy machines by the CV Toolkit software can be visualized and analyzed in the ShopFloorIQ dashboard. ShopFloorIQ is also responsible for sending text or email alerts to the operator on the shop floor, if necessary, based on the output. ITI developed various stencils for the visualization of the machine output and these capabilities of the software were demonstrated at DMDII Future Factory Technology Showcase Event at Chicago and included as part of the deliverables.

Task 5 Demonstration Environment Installation

The developed toolkit was installed on the mock panels that were developed at University of Cincinnati and TechSolve. This was used as an initial benchmark for success and performance testing of the software and the toolkit as a whole. As mentioned previously, the mock panel along with the installed toolkit was used at project review meetings and the DMDII Future Factory Technology Showcase Event at Chicago as demonstrations.

Task 6 Production Environment Installation / Usage

The final installation of the system at the three production environment sites served as the real time validation and performance of the software. UC Team, TechSolve and ITI made two visits to Faurecia first to install the toolkit software along with the cameras (imaging system), mounting apparatus (to secure the cameras in the machining environment), the processing machines (with the installed toolkit software containing vision system, MTConnect® based Adapter and Agents). The output of the toolkit software was visualized and demonstrated on the ShopFloorIQ software dashboard. The teams then visited Matdan Fasteners production environment to successfully install the toolkit and capture the output on ShopFloorIQ. Installation at Raytheon was accomplished as the final step of the production environment installation.

The detailed description of the three installations is presented in the 'Users & Use Cases' section of 'Technology Outcomes'.

Task 7 Technology Transition / Workforce Development

The outcomes of the project were integrated into University of Cincinnati curriculum in 'Manufacturing Processes' and 'Robot Control & Design' coursework.

The mock panels developed at UC and TechSolve were also used for demonstration of capabilities and workforce development. Raytheon is in the process of building the mock panel test bed to demonstrate the working of the toolkit to personnel on their factory floor.

2.2 Project Scope and Technical Approach

The necessity to upgrade digital capabilities on the manufacturing floor is growing stronger across all industries where costs are being cut, quality is of concern, vital equipment ages, and competitive advantages are required. Replacing or retrofitting legacy equipment is expensive, not only in purchasing of the new hardware, but in the maintenance, training, and validation of the results. In some cases, OEM companies no longer exist and/or limit the modifications for a machine. To realize the goals of the digital manufacturing enterprise, DMDII members must have tools available, which provide legacy data in innovative ways that do not disrupt production, alter the function, create failure points, or void warranties. This project developed and demonstrated an open source kit framework in which computer vision enabled cameras were "plugged in" and configured to non-invasively collect data from a multitude of operations, translate the inputs into MTConnect® standard data streams, and interface these data streams with software solutions to produce status information. Future expansion of the toolkit could provide additional sensor technology such as acoustic, vibration, and high-speed controller data developed through the community. The computer vision toolkit is non-invasive to the machine and operators and affordably provides the intelligence that the US industry needs to gain insight and make decisions on the status of legacy and non-computerized equipment.

In order to develop the computer vision algorithms which can reach across a diverse set of equipment environments, the toolkit addressed a variety of shop floor 'artifacts' that were identified at the three production environment partners where the developed toolkit was installed and demonstrated as a part of the project. Based on the initial industry visits to all the production environments, the following artifacts were identified to be supported in the current version of the system:

1. Gauges (Circular and Linear) – To identify the readings of both linear as well as circular analog gauges seen on legacy machine control panels.

2. Knobs – To identify the position of various knobs that control the process of various legacy machines such as CNC machines.
3. Machine Readouts (OCR) – To identify the readouts from various machine interfaces such as LCD screens on workstations and CNC control panels.
4. Seven Segment Displays – To detect the decimal number from a Seven Segment Display on machine control panels and other locations.
5. Fixtures – To detect the orientation of several fixtures that are required in a large machining center environment.
6. Machine Stack Lights – To detect the status of the machining or other workstation from its Stack Lights.
7. Liquid Level – To detect if the level of a liquid in a bath has reached the maximum level in water or chemical baths.
8. Toggle Switches – To detect the position of toggle switches on a control panel.
9. Part Condition Fastener – To detect improper machining of a fastener part for Matdan Corp.

The business outcomes and the planned benefits of the project are outlined in Figure 1 as a part of the executive summary.

The components of the developed toolkit software including OpenCV, Tesseract OCR, python programming environment, Ubuntu operating system, and other supporting libraries are completely open source and does not require the purchase of any licenses for its installation.

III. KPI'S & METRICS

The following KPIs and Metrics were assessed and demonstrated during the project:

Metric	Baseline	Goal	Results	Validation Method
Reading LCD when no Controller API exists	Manual operator observation	Non-contact acquisition of key display text and numbers	Successfully implemented at Faurecia plant	Visual observation on the mock panel test bed
Reading mechanical circular and linear gauges	Manual operator observation	Non-contact acquisition of gauge needle location and value	Successfully demonstrated at DMDII Future Factory Showcase	Visual observation on the mock panel test bed
Reading seven segment digital display on isolated equipment	Manual operator observation	Non-contact acquisition of seven segment digital numerical value	Successfully implemented at Faurecia plant	Visual observation on the mock panel test bed
Detect the position of the Knobs on CNC control panel	Manual operator observation and input	Non-contact acquisition of the position of various knobs on CNC control panel	Successfully implemented at Raytheon plant	Visual observation on the mock panel test bed
Detection of the liquid level in various chemical or water tanks	Manual operator observation	Non-contact detection of threshold liquid level based on prior input	Successfully implemented at Raytheon plant	Visual validation at Raytheon plant

Position of fixture prior to work piece being positioned	Manual, observation, and measurement	Non-contact camera feedback to read fixture position	Successfully tested on a simulated fixture on a machine bed	Validated on a simulated fixture on a machine bed
Machine history to perform analytics and find trends, preventive maintenance, and storage	Does not exist	Store MTConnect® stream for playback and analysis, define trends using tools and send out alerts	Collected data exported to MS Excel for analysis. ShopFloorIQ capable of providing text/email alerts.	Appropriate analysis of MS Excel data output from ShopFloorIQ can be performed
Automated detection of error states in the machining process through machine safety lights	Manual detection by the operator	Operator alerts instantly sent by text/email when error state detected	Successfully implemented at Raytheon plant	Visual observation on the mock panel test bed
Part Condition Monitoring	Manual detection while the station is manned by an operator	Automated detection of defective parts and alerting operators to stop the machine and remedy the situation	The CV Toolkit software was able to successfully recognize good and defective parts at Matdan	Confirmation of the CV Toolkit inference by video validation of the process

Other Metrics	Location	Comments
Installation time for the system	Faurecia	Four days. Because of the displacement of the cameras during regular machining, the team had to make a second visit for installation
	Raytheon	Three days. Raytheon had the most number of artifacts that needed to be handled and it took three days for the team to setup the CVT with ShopFloorIQ integration
	Matdan Fasteners Inc.	One day. Matdan Fasteners is an SME and the team only focused on one machine for the installation
Total cost of the system	All locations	The equipment cost can be found from the recommended hardware section that is mentioned in the system requirements. Other costs include labor cost for installation, and for setting up the camera, mounting apparatus, network, and power supply, etc.

IV. TECHNOLOGY OUTCOMES

4.1 System Overview

The toolkit system has three main components as illustrated in Figure 2.

The first component of the toolkit system is the imaging system which consists of a camera and the mounting apparatus to secure the camera which focusses on the legacy machine artifacts to capture the data of interest.

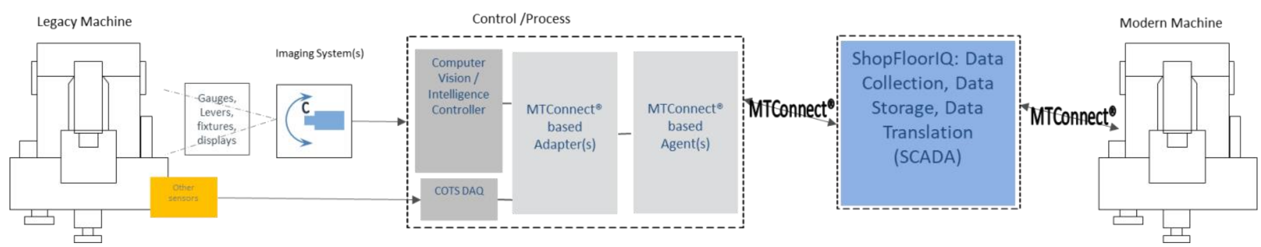

Figure 2: System Process Flow

The second component of the toolkit system is the software system that is divided into three parts:

The Computer Vision Software – The data collected by the imaging system is captured, processed and analyzed in this component. This is the core component of the system which is responsible for the digitization of the legacy machine output. The first step in the computer vision software is the User Interface (UI) for training which enables the user to train the software for a particular artifact of the legacy machine and its corresponding factory/industry environment. Various Image Processing and Machine Learning techniques are applied on the data that is captured by the imaging system and the digital output that is generated by the Computer Vision Software is broadcasted to MTConnect® based Adapter through a TCP/IP network connection.

MTConnect® based Adapter – The digital output of the Computer Vision Software is collected by the MTConnect® based Adapter in JSON format which contains the respective artifact information and its corresponding parameters. The MTConnect® based Adapter is responsible for parsing of this JSON data and creates a stream of MTConnect® standard data which is then collected by an MTConnect® based Agent.

MTConnect® based Agent – This component stores the timestamped legacy machine artifact data in MTConnect® standard format and acts as a server which can broadcast the data on demand through an HTTP connection.

The third component of the toolkit system is the analysis software, ShopFloorIQ, which is responsible for visualization, statistical & data analysis. It serves as a central dashboard for all the legacy machine data that enables the operator to monitor and maintain all the legacy machines on the plant floor from a single remote location. It can also be used as an industrial automation system for preventive maintenance as it can trigger text/email alerts based on the digital output from the Computer Vision software framework.

4.2 System Architecture

Figure 3 presents a brief layout of the system architecture.

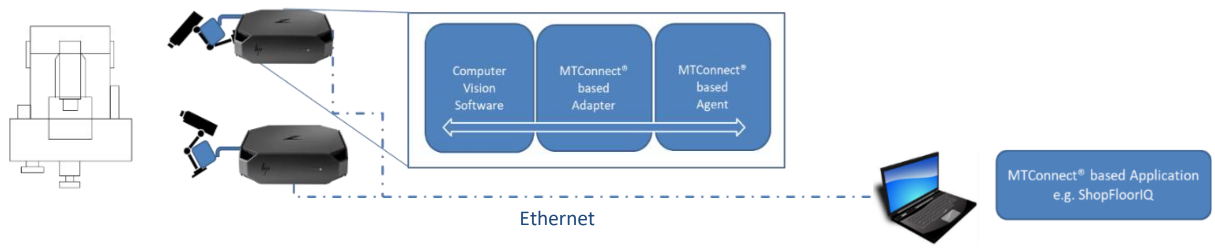

Figure 3: System Architecture

As represented in the figure, the cameras of the system are placed in the machine environment close to the legacy machine so as to focus on the desired artifact. The images are collected at 30 frames per second (fps) by the camera and the camera feed is transmitted to the processing machine through a USB connection which requires that the processing machine and the camera be placed no more than 10 feet apart. The Computer Vision Toolkit software is installed in the processing machine which handles the core processing of the images from the camera feed. MTConnect® based Adapter and Agents are also installed in the processing machine and the data extracted from the images by the toolkit software is transmitted to MTConnect® based Adapter which is in turn transmitted to MTConnect® based Agent through TCP/IP network connection. Due to security requirements at Raytheon, the network connection in the architecture was restricted to cable-based Ethernet connection. The MTConnect® based Agent acts as a server on this network connection and the collected MTConnect® data can be captured by downstream applications such as ShopFloorIQ, that is installed in a remote machine in the same network for visualization, alerts, and statistical and data analysis.

4.3 Features & Attributes

4.3.1 User Interface for Training

The development of the User Interface is the preliminary step required to use the CV toolkit, train, and setup the system for the legacy machine artifacts in their corresponding production environments. It is a one-time offline process performed by the operator to tune the system for the artifact under observation. Figure 4 shows sample screenshots from the User Interface for training. This User Interface for training is used for various purposes:

a) Selecting the Region of Interest (ROI) of the required artifact from the camera image.
b) Zooming in to the focus area in an image (for a smaller/farther-away artifact).
c) Correcting the alignment of the image to ensure that the artifact image is consistently horizontal.
d) Processing the image with the help of various image processing software sliders available in the. User Interface to perform OpenCV routines.

e) User input of various parameters corresponding to the artifact such as types, units, and position values.

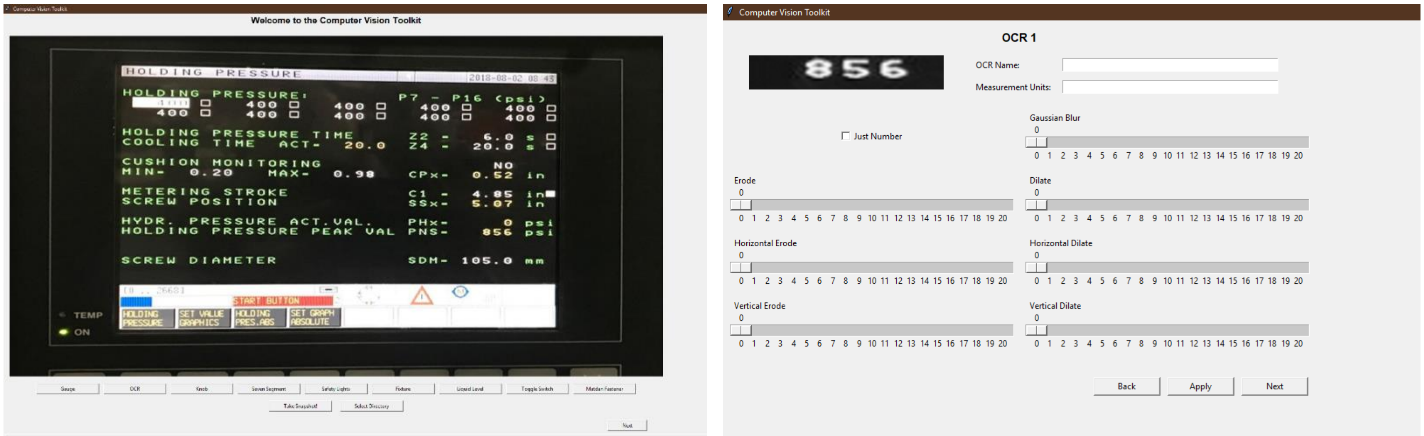

Figure 4: User Interface for Training

Consider the gauge artifacts as shown in Figure 5, there can be many types of gauges that are used in the industry environment, and the type of gauge used depends on the application or the machine parameter under observation. For example, pressure gauges are typically circular whereas gauges used for electric signals such as ammeters are typically rectangular with the needle moving in a circular arc. There can also be linear gauges in the production environment where the readings can be horizontal or vertical. Also, the length of the needle typically varies with the size of the gauge. To identify the needle from the rest of the image, the length of the needle is required for interpretation of the needle position. In addition, to identify the current value of the gauge from the needle position, the range of the gauge values, which varies depending on the gauge type and application, are required. So, to properly identify the gauge value, the system requires all these gauge parameters. Once the camera is positioned to acquire the image of the artifact, the operator interacts with the system and provides the required parameters through the User Interface for Training.

Figure 5: Various Types of Gauges

The user has the option to store the training parameters in the form of a configuration file to be used for re-training of the system if necessary.

4.3.2 MTConnect® based Adapter and Agents

a. MTConnect® based Adapters and Vision System communication

To enable data transfer between the Vision System and the adapter it is necessary to establish both a method to communicate the data and a format to encode the data. Today most intra-device communication is performed via TCP/IP over Ethernet or Wi-Fi. This is the communication protocol that was selected. JSON was selected for the data format since the required information included the data item, the MTConnect® Category of the data item, the dimensional units of the data item and a timestamp to mark the time of the collection cycle. The following description provides a sample of the JSON format:

Figure 6 illustrates the communication between the Adapter and the Vision System that occurs in two steps, as follows:

- The adapter requests the size of the data buffer that the Vision System is going to send.
- After the Vision System sends the size of the data buffer, the adapter sends a request for the data and the Vision System sends the data buffer in the JSON format.

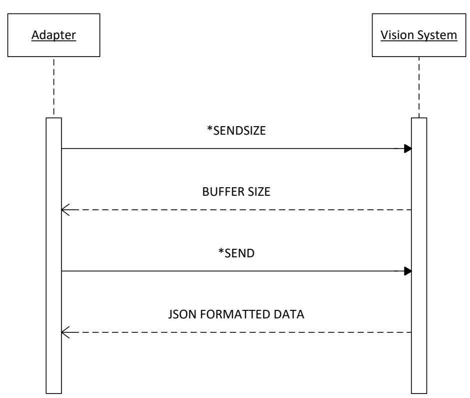

Figure 6: Illustration of Adapter and Vision System Communication

b. MTConnect® Agent and Application communication

The MTConnect® Agent communicates with MTConnect® compatible applications using a RESTful HTTP protocol via an Ethernet connection. Figure 7 illustrates the communication process between the Application and the Agent, as follows:

- The MTConnect® compatible Application sends the request http://agent_url/probe to get the list of available data items from the MTConnect® Agent.

- To get the values of the data items, the MTConnect® Application sends either http://agent_url/current which returns the last value of the data items or http://agent_url/sample which returns the first 100 values of the data items in the MTConnect® Agent's buffer.

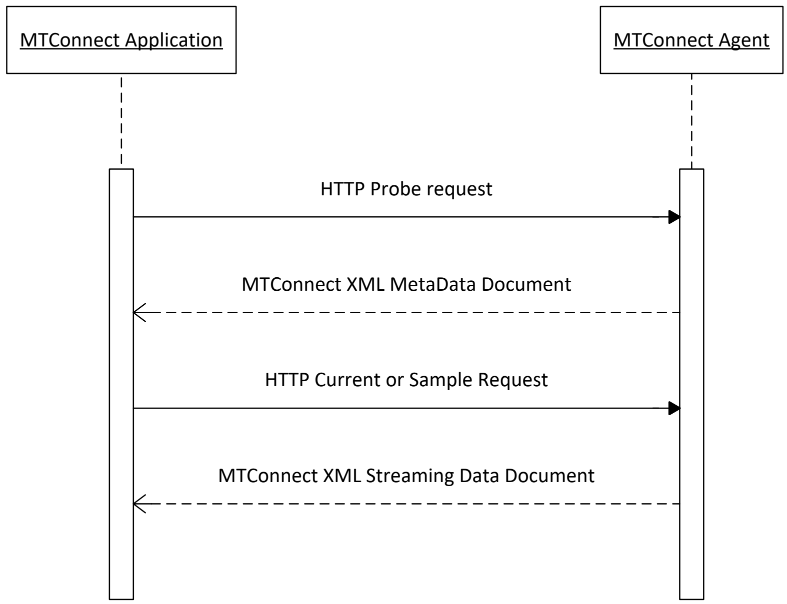

Figure 7: Illustration of MTConnect® compatible Application and MTConnect® Agent Communication

The basic current and sample commands may be modified by extending the commands with a query or "XPATH" filter.

Filter Example: http://agent_url/current?path=//DataItems[@type="EXECUTION"] this command retrieves only the current value of the EXECUTION state of the machine.

Query Example: http://agent_url/sampe?from=1&count=10000 this command retrieves the 10000 data items from the MTConnect® Agent's buffer starting with the data item with a sequence number of 1.

For more information on querying the MTConnect® Agent please refer to Part 1 of the MTConnect® Standard.

c. Configuration of the MTConnect® based Adapter and Agent

The Adapter and MTConnect® Agent require configuration in order to function properly.

- The Camera Adapter requires one configuration file - adapter.ini.
- The adapter.ini file provides the data required to connect to the Vision System application, the port to listen on for MTConnect® Agent connections and the list of data items it will be collecting from the Vision System. Figure 8 provides an example of this file.

```
[adapter]
port = 7878
service = MTC Focus 1

[camera]
port = 6000
host = 10.52.105.11

[data]
#temperature = {"name":"temperature", "mtcCategory":"SAMPLE", "units":"CELSIUS"}
Knob1 = {"name":"Knob1","mtcCategory":"EVENT","units":"PERCENT","id":"fd3"}
Knob2 = {"name":"Knob2","mtcCategory":"EVENT","units":"PERCENT","id":"fd2"}
Knob3 = {"name":"Knob3","mtcCategory":"EVENT","units":"PERCENT","id":"Sovr"}
SafetyLights1 = {"name":"SafetyLights1","mtcCategory":"EVENT", "id":"lites"}
Gauge1 = {"name":"Gauge1","mtcCategory":"SAMPLE","units":"PSI" ,"id":"gauge"}
SevenSegment1 = {"name":"SevenSegment1","mtcCategory":"SAMPLE","units":"CELSIUS" ,"id":"7seg"}
xpos = {"name":"xpos","mtcCategory":"SAMPLE","units":"MM" ,"id":"xpos1"}
ypos = {"name":"ypos","mtcCategory":"SAMPLE","units":"MM" ,"id":"ypos1"}
zpos = {"name":"zpos","mtcCategory":"SAMPLE","units":"MM" ,"id":"zpos1"}
```

Figure 8: Example of an adapter.ini File

- The MTConnect® Reference Agent requires two configuration files, devices.xml and agent.cfg.
- The devices.xml file provides the data structure for the device being monitored. Figure 9 provides an example of this file.

```
<Device uuid="000" name="camera" sampleInterval="1.0" id="d">
  <Description manufacturer="UC" serialNumber="001"/>
  <DataItems>
    <DataItem type="AVAILABILITY" category="EVENT" id="a" name="availability"/>
  </DataItems>
  <Components>
    <Axes id="axis" name="axis">
      <Components>
        <Rotary id="c" name="C">
          <DataItems>
            <DataItem category="SAMPLE" id="s1" name="Spindle_load" nativeUnits="PERCENT" type="LOAD" units="
            <DataItem category="SAMPLE" id="cs" name="spindle_speed" nativeUnits="REVOLUTION/MINUTE" subType=
          </DataItems>
        </Rotary>
      </Components>
    </Axes>
    <Path name="Path" id="Path">
      <DataItems>
        <DataItem type="EXECUTION" category="EVENT" id="execution" name="execution"/>
        <DataItem type="PRESSURE" category="SAMPLE" id="back_pressure" name="back pressure"/>
        <DataItem type="PATH_FEEDRATE" category="SAMPLE" id="feedrate" name="Knob1"/>
        <DataItem type="PATH_FEEDRATE_OVERRIDE" category="SAMPLE" id="path_feedrate_override" name="Knob2"/>
        <DataItem type="ROTARY_VELOCITY_OVERRIDE" category="SAMPLE" id="spindle_override" name="Knob3"/>
      </DataItems>
    </Path>
  </Components>
</Device>
```

Figure 9: Example of MTConnect® Agent devices.xml File

- The agent.cfg file sets the parameters used by the agent to identify the devices.xml file and the adapters that collect the data from the device. Figure 10 provides an example of this file.

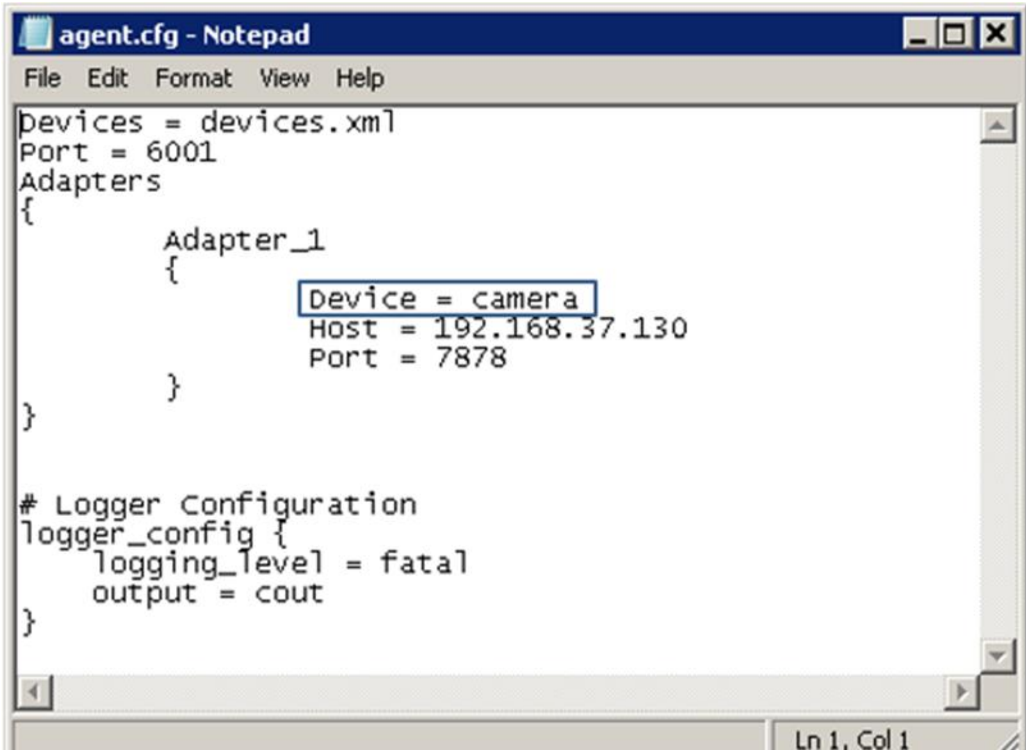

Figure 10: Example of MTConnect® Agent agent.cfg File

Note – Figure 11 demonstrates that the value for Device in the agent.cfg file, see figure 10, matches the name of the Device in the devices.xml file.

Figure 11: Illustration Confirming agent.cfg Device Value Matches devices.xml Device Name.

For more information, refer to the "Linux MTConnect® Agent and Adapter Installation Procedure" in the Non-Invasive Vision System tool kit documentation.

d. <u>Artifacts and their respective MTConnect® Categories</u>

MTConnect® provides a standardized vocabulary or tags to describe data from the manufacturing floor. These data items fall into one of three categories, EVENTS, SAMPLES and CONDITIONS, defined as follows:

EVENTS – Data items which have discrete values, typically enumerated values, fall into this category. These types of data items usually describe some state of the machine or process.

SAMPLES – Data items which can take on any value are defined as SAMPLES. These data items are normally from sensors or scales and the result of a measured quantity.

CONDITIONS – Data items which indicate an alarm or fault of the system are classified as CONDITIONS. CONDITIONS have 4 possible states, NORMAL, WARNING, FAULT or UNAVAILABLE.

The types of data items that are defined by the MTConnect® standard are listed in Part 2 of the standard.

When setting up a camera to collect data from a device using the Non-Invasive Vision System, one needs to match the data being collected with the defined data set in the MTConnect® standard and classify it in its proper category. If the data item is not currently defined in the standard, it is possible to extend the XML to define the data item.

The MTConnect® Category is required for configuring the Vision System, the Adapter and the Agent.

The Data Type is required for configuring the Agent. Examples of the MTConnect® data types are EXECUTION, CONTROLLER_MODE, TEMPERATURE, PRESSURE, POWER, POSITION, LOAD, etc.…

It is helpful to become familiar with the MTConnect® standard and might be helpful to engage an MTConnect® integrator to assist in the installation process.

The MTConnect® standard may be downloaded at https://www.mtconnect.org/standard20181.

4.3.3 ShopFloorIQ

a. Software History

MTConnect4MSVisio was originally conceived and designed by Jim Finn at ITI during the 2013 MTConnect® challenge supported by ManTech. The initial concept was to leverage the Visio platform to create a simple, easy to use, and easy to implement MTConnect® application which could be used by operators and developers to troubleshoot MTConnect® implementations. The idea was simple: create software that could be used on the factory floor with drag and drop, little training, inexpensive, and anyone could use with machine knowledge versus MTConnect® or programming.

Since 2014, MTConnect4MSVisio has evolved into ITI's ShopFloorIQ. The focus is still the same as the principles in 2014: create an easy to use, drag and drop, and inexpensive MTConnect® solution that required no programming and anyone could use it. ITI has received new requirements and has invested to take the software from its initial beta concept into a viable commercial solution. This was targeted in two primary areas: 1) make the software expandable so anyone could add Visio stencils that "plugged" into the application and 2) include additional data elements for import and export for shop floor data (not just MTConnect®).

Figure 12 shows some of the software configurations developed and demonstrated during early workshops:

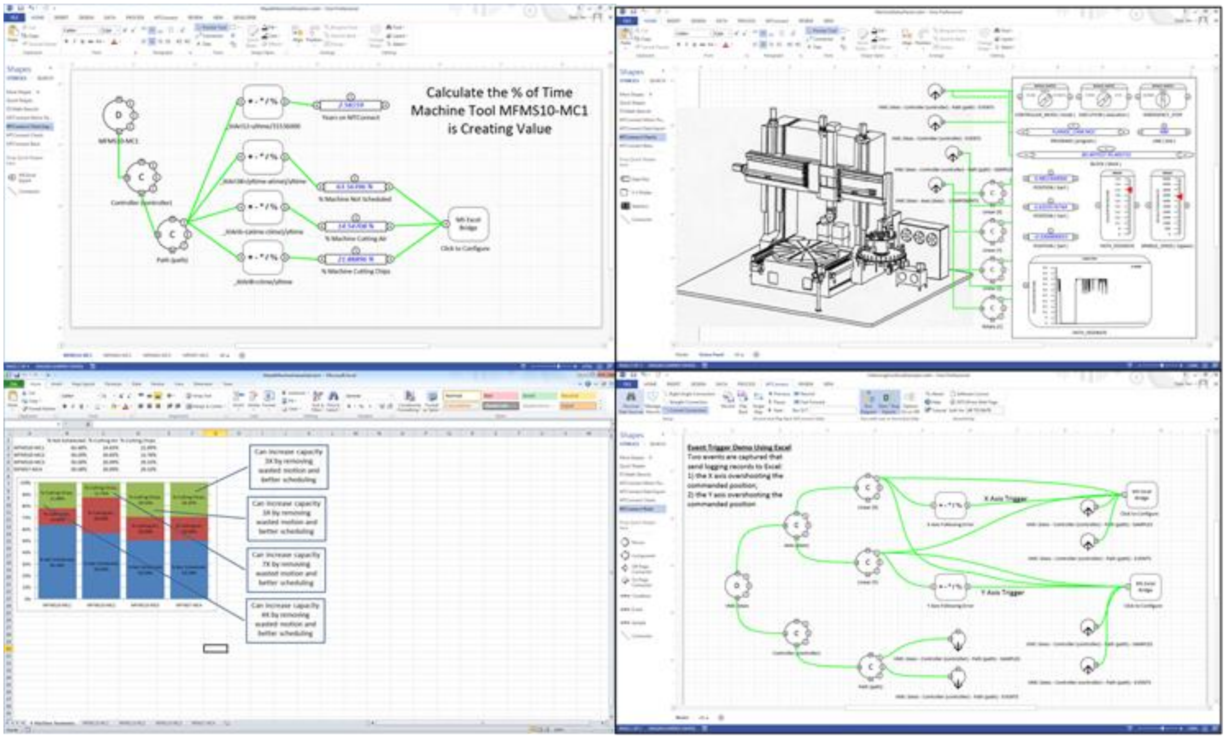

Figure 12: Sample ShopFloorIQ Configurations

b. <u>ShopFloorIQ Software Usage</u>

The software was finally rebranded as ShopFloorIQ in 2018 and is currently available on a trial usage and annual licensing options. The software is built as an application that utilizes Microsoft Visio 2013 or later which is a workflow and diagramming tool. ShopFloorIQ is not an add-in, macro, or plug-in to Visio but a fully developed .NET application that controls and interacts with the Visio application. This allows for people to use Microsoft Visio's easy to use stencils to drag and drop icons to create dynamic data driven intelligent diagrams. With ShopFloorIQ any Visio stencil can display text or change properties (such as color) to show results to a user. The workflow within Visio allows for users to create complex flow diagrams involving one or multiple sources of data which can include MTConnect® data streams, SQL database data, Excel data, other manufacturing systems, etc. These workflows can combine data, compare data, or filter data for downstream export. A good example would be looking at a machine parameter for a part number scanned and comparing it to a calculated value in a database (such as adaptive machining) or storing data based on a part number for digital thread/twin information.

The stencils available out of the box in ShopFloorIQ are listed in figure 13. Additional stencils have been developed internally for companies which require specific system integrations and can be developed by ITI or through a developer license of ShopFloorIQ. For more information and to watch a video on how to use ITI's ShopFloorIQ, please visit https://www.iti-global.com/shopflooriq.

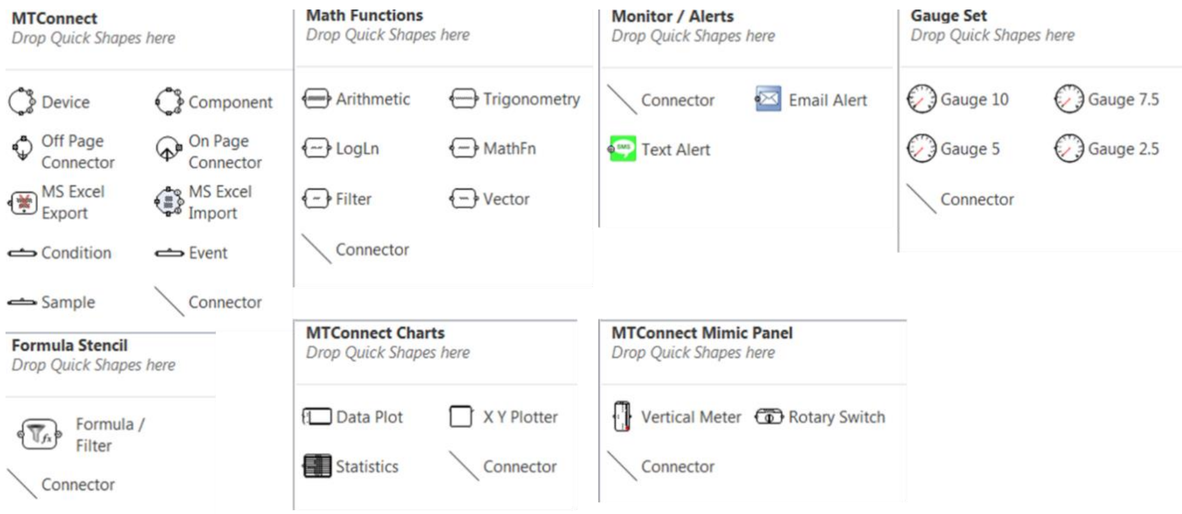

Figure 13: Various Stencils available in ShopFloorIQ

c. <u>Computer Vision Toolkit (CVT) Integration</u>

For ShopFloorIQ to accurately depict artifacts used within the CVT system, additional stencils were developed to provide the ability to view CVT artifacts. These include gauge stencils, improving export capabilities to Excel, and formula stencils which can be used to write Excel-like functions for analyzing information. Additional stencils which were developed during the adaptive manufacturing project included email and text message alerts, database import, and Excel import.

ITI installed ShopFloorIQ at each of the industry sites and University of Cincinnati and provided updates as they became available. Training was also conducted and any feedback was incorporated into the software or documented within our release tracking system. The software installations were used to view, analyze, and test the CVT data as it was in development or deployed at the installation sites.

Figure 14 shows the mock panel layout used to display and test the mock panel during development:

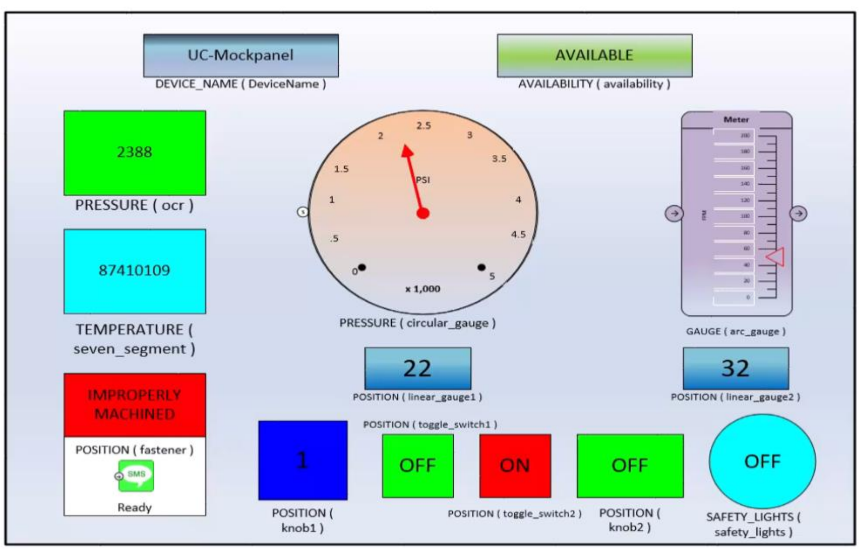

Figure 14: Mock Panel Layout in ShopFloorIQ

ITI’s ShopFloorIQ continues to grow as new interfaces are required for manufacturing data. With the combined strength of the CVT, companies can get more control of digital thread data coming off of the shop floor. ShopFloorIQ is not meant to be just a tool to analyze machine usage or health but a versatile tool to troubleshoot data, collect data, transform data, and combine data with other systems in an easy to use drag and drop interface. For more information or to request a trial, please visit https://www.iti-global.com/shopflooriq.

4.4 Modes of Operation

This section presents the UI training for each artifact and a brief description of the algorithmic methods used for detection of values of each artifact. Details of the algorithms are presented in a separate “Software Design and Documentation” manual.

4.4.1 Gauge Artifact

This is the first artifact available for selection as a part of the User Interface for Training. As mentioned above, the user needs to input various gauge parameters in the process of training this artifact.

Objective: Recognize the value of the gauge at the position of the needle

The algorithm employed in the toolkit is based on detecting the needle in the given frame from the approximate length of the needle that is provided by the user. The user also needs to pre-process the image with the help of the image processing sliders that are provided within the UI. The purpose of these sliders is to help the needle stand-out from the rest of the image when thresholded and converted to Black and White format. The user also needs to input the start and end positions of the needle with their respective values. This is required to estimate the current value of the needle in the given range after the detection of the current position of the needle. In the earlier version of the toolkit, the images corresponding to the start and end position of the needles were stored as the part of the UI for training and the stored images were used to identify the value of the current needle position. Based on the suggestions from the team partners in the Quarterly Review Meeting, this implementation of storing the images was removed and replaced by drawing the needle positions corresponding to the start and end positions of the needle. The user may also need to provide information about the boundary of the circular image in this process. The MTConnect® category for the gauge artifact was identified as ‘SAMPLE’ as the value under observation has continuous range. Figures 15 and 16 show the UI images of a Gauge artifact during the training process. Figure 17 shows the value being detected and displayed on ShopFloorIQ interface.

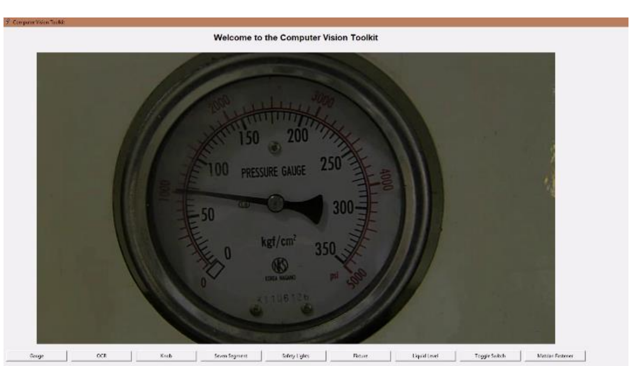

Figure 15: Sample Gauge Artifact

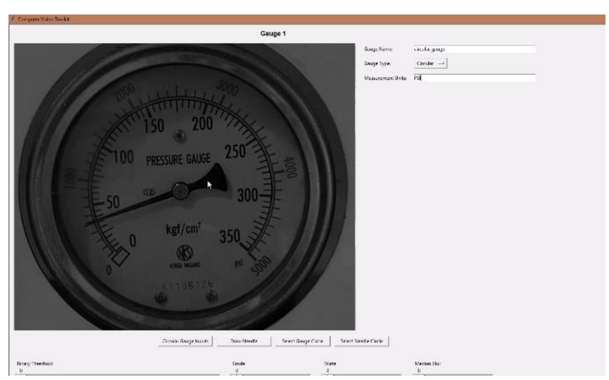

Figure 16: Gauge Artifact in UI

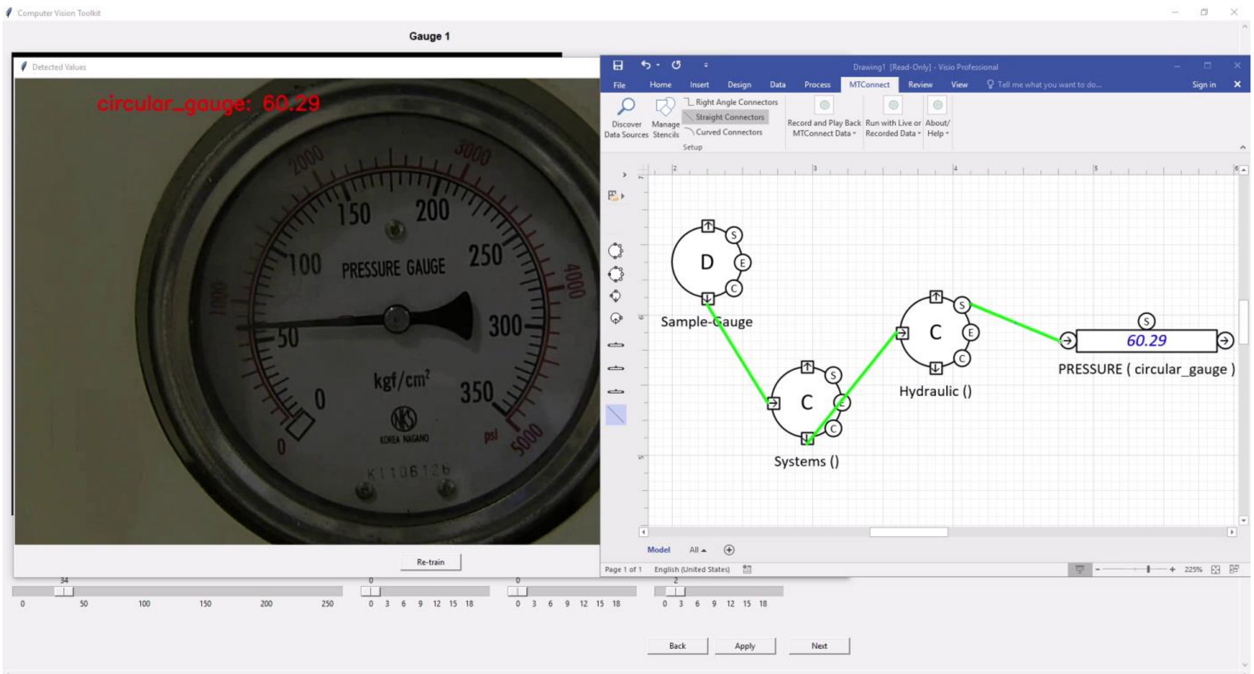

Figure 17: Identified Gauge Value with ShopFloorIQ Output

4.4.2 OCR Artifact

Objective: Recognize the value of the character string displayed on the machining interface (LCD Screen)

This artifact was identified as the production environment requirement at Faurecia. It includes various machine parameters that are displayed as character data on the machine interfaces such as LCD screen or any other machine display output. The algorithm developed requires an image which is preprocessed by the user using the User Interface provided. 'Optical Character Recognition' algorithm from Tesseract is integrated with the toolkit and then applied on the segmented and preprocessed image. The output of the algorithm is collected as character data (string) to be fed to MTConnect®. The MTConnect® category of this artifact was also identified as 'SAMPLE' as most of the machine parameter values from the LCD screen are in continuous range. Figures 18 and 19 show the UI images of OCR artifact during the training process. Figure 20 shows the value being detected and displayed on ShopFloorIQ interface.

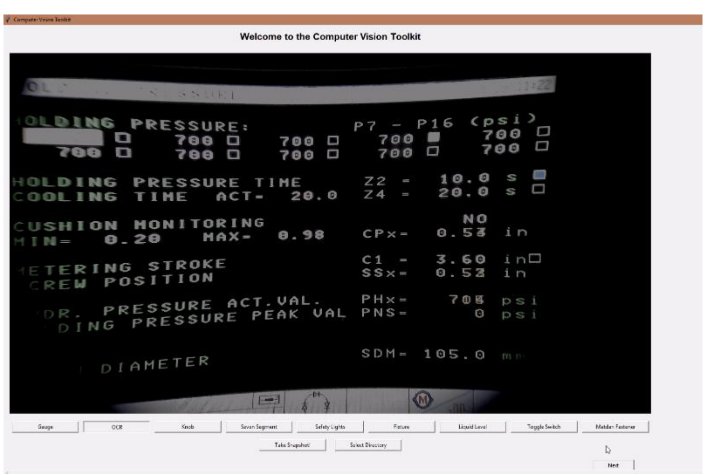

Figure 18: Sample LCD for OCR at Faurecia

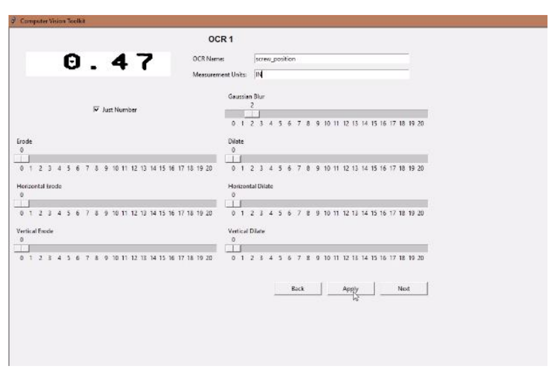

Figure 19: OCR Artifact in UI

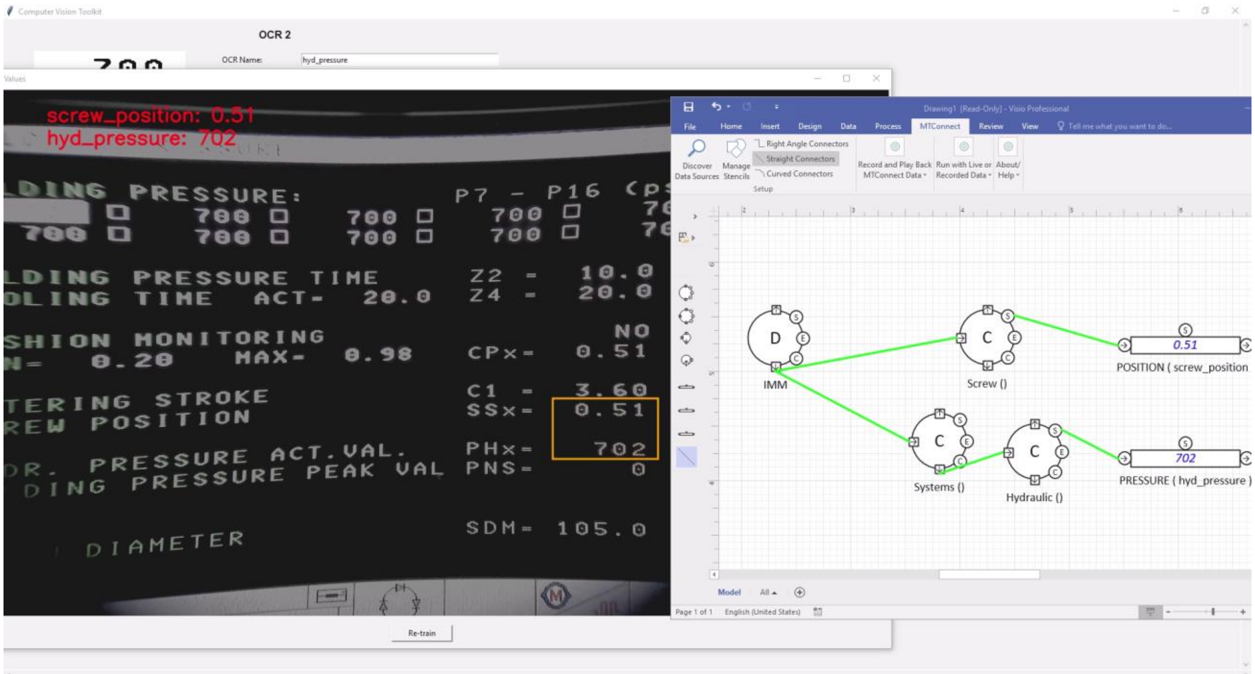

Figure 20: Identified OCR Values with ShopFloorIQ Output

4.4.3 Knob Artifact

Objective: Recognize the value corresponding to the position of the Knob

This artifact was identified as the production environment requirement at Raytheon. It represents various CNC machine control parameters on the panel and the algorithm identifies the correct knob position and its corresponding machine parameter value from the image. As part of the training, the user captures the template images for all the knob positions and the system uses a template matching algorithm on the segmented and pre-processed image. The MTConnect® category of the Knob artifact was identified as 'EVENT' as the observed machine parameter value has discrete possibilities (various positions). Figures 21 and 22 show knobs and associated User Interface on Raytheon CNC control panel during training. Figure 23 shows the three knob values being detected and displayed on ShopFloorIQ interface.

Figure 21: Sample Knob Artifacts at Raytheon

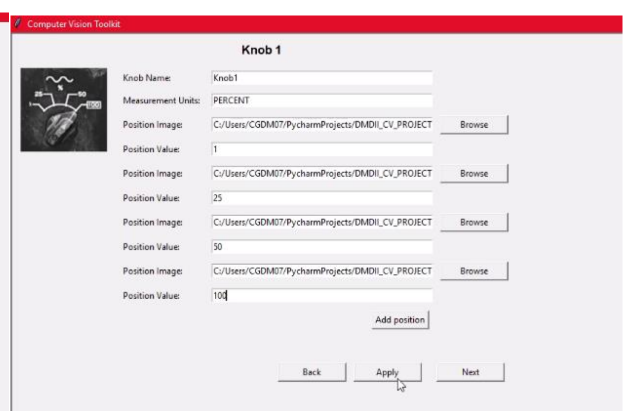

Figure 22: Knob Artifact in UI

Figure 23: Identified Knob Positions with ShopFloorIQ Output

4.4.4 Seven Segment Artifact

Objective: Recognize the value of the Seven Segment being displayed

This artifact represents the numeric output of legacy machines which are displayed on seven segment displays as shown in Figure 24. Similar to the other artifacts, the user can pre-process and filter the image using the User Interface for Training. The user also needs to tune the system for the size of the individual segments of the seven segment numbers in the value under observation. The algorithm detects the integer number on all the individual digits of the value from the presence of the segment. As this artifact can have values in a continuous decimal range, the MTConnect® category was also identified as 'SAMPLE'. Figures 24 and 25 show the UI for a seven segment artifact on the mock panel test bed. Figure 26 shows the value being detected and displayed on ShopFloorIQ interface.

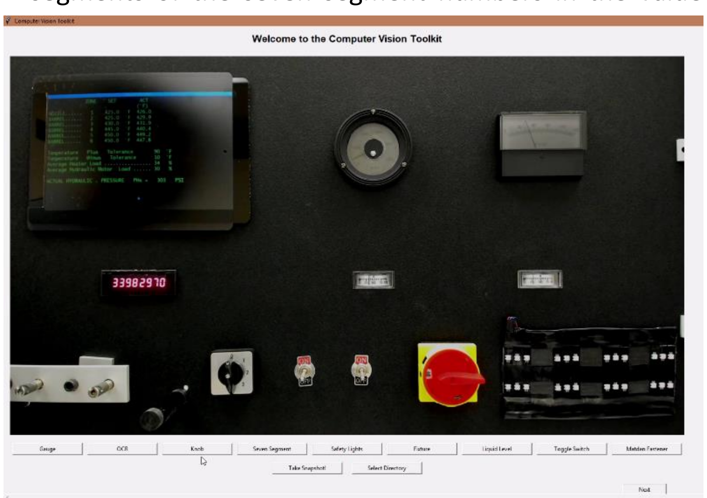

Figure 24: Sample Seven Segment Artifact on Mock Panel

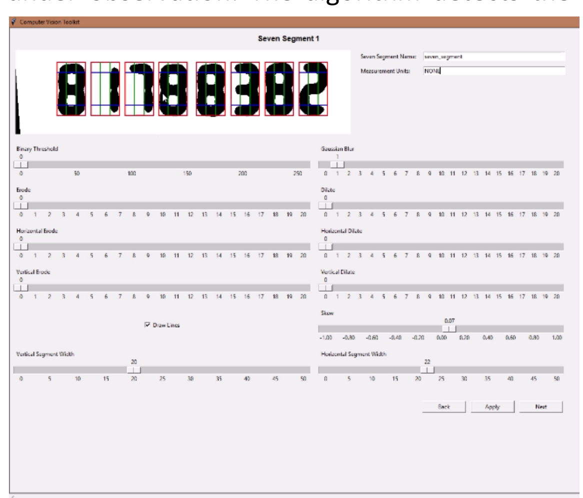

Figure 25: Seven Segment Artifact in UI

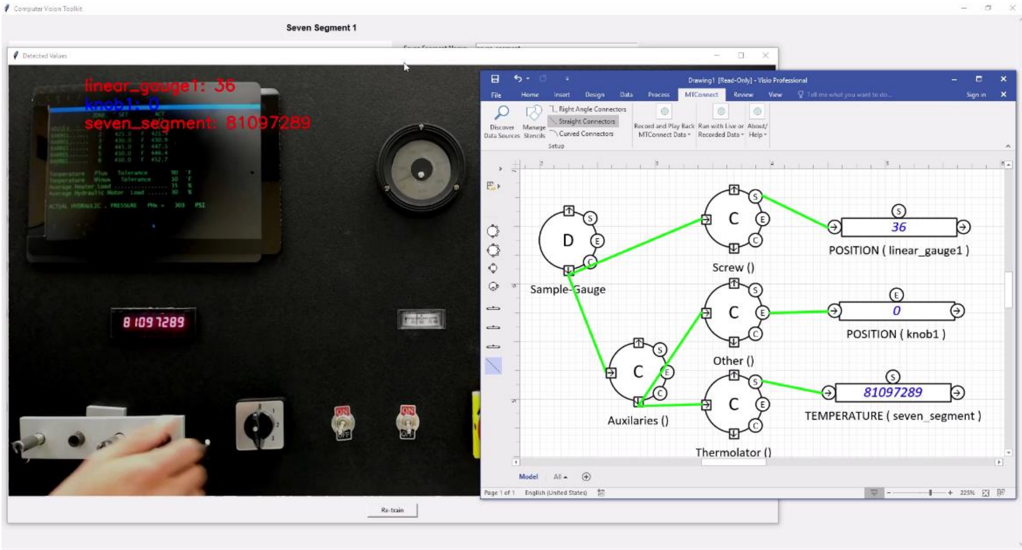

Figure 26: Identified Seven Segment Value with ShopFloorIQ Output

4.4.5 Fixture Artifact

Objective: Identification of misaligned fixtures

This artifact was identified at Raytheon as their production environment requirement. The legacy machine in consideration is a CNC machining center where various tombstone fixtures are mounted on the machine bed. During day-to-day changeover of the machine, the fixtures can sometimes be clamped in a misaligned fashion which may lead to improper machining with associated scrap and machine downtime. With the help of the Computer Vision Toolkit, the operator can quickly identify if any of the fixtures are misaligned and make necessary corrections. The user needs to train the system by capturing template images of the fixtures in the correct orientation. The algorithm then compares individual fixtures in their surrounding area with the properly aligned fixture templates and identifies improperly aligned fixtures, if any. The algorithm also marks the particular fixture(s) that are misaligned. The MTConnect® category of this artifact was also identified as 'EVENT'. Figures 27 and 28 show the UI for Fixture system simulated at UC. Figures 29 and 30 show the detection and ShopFloorIQ output.

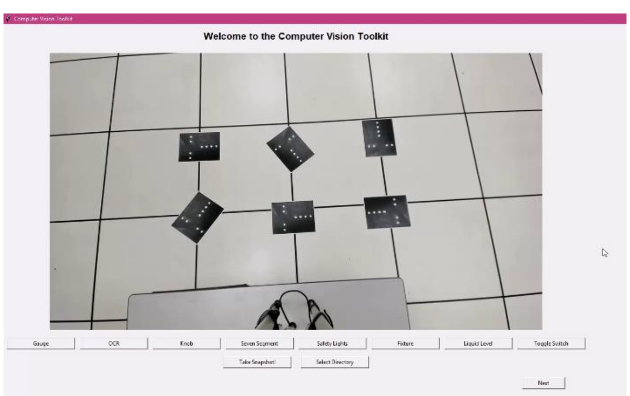

Figure 27: Sample Fixture Simulation

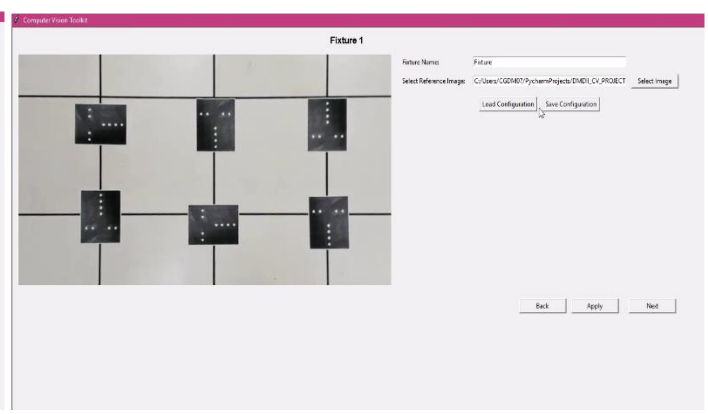

Figure 28: Fixture Simulation in UI

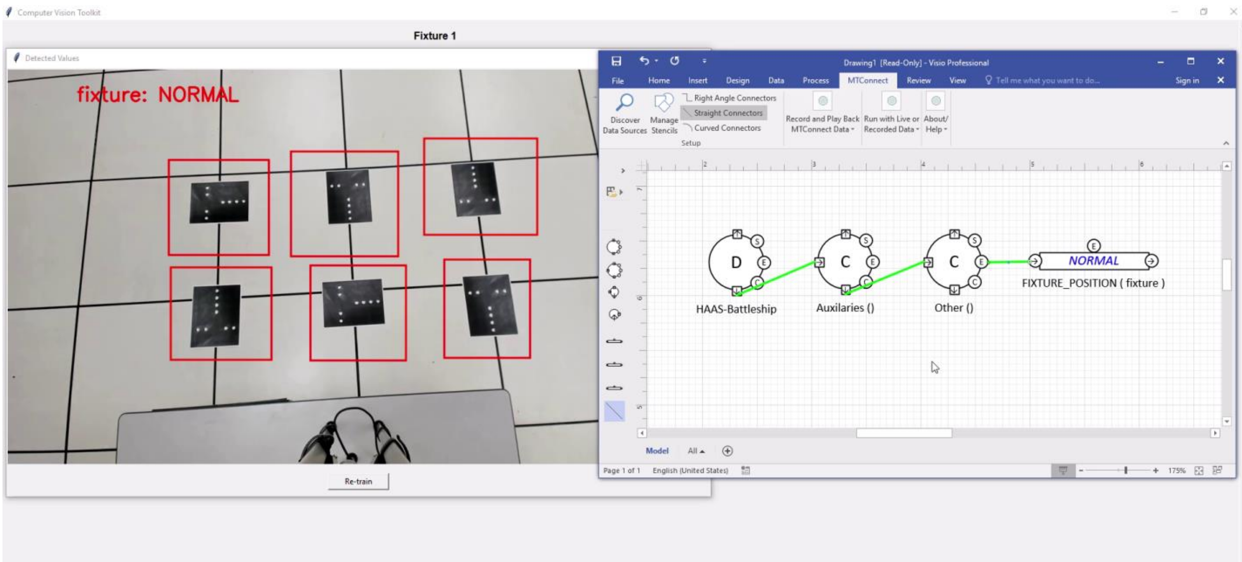

Figure 29: Fixture Simulation in 'Normal' Condition with ShopFloorIQ Output

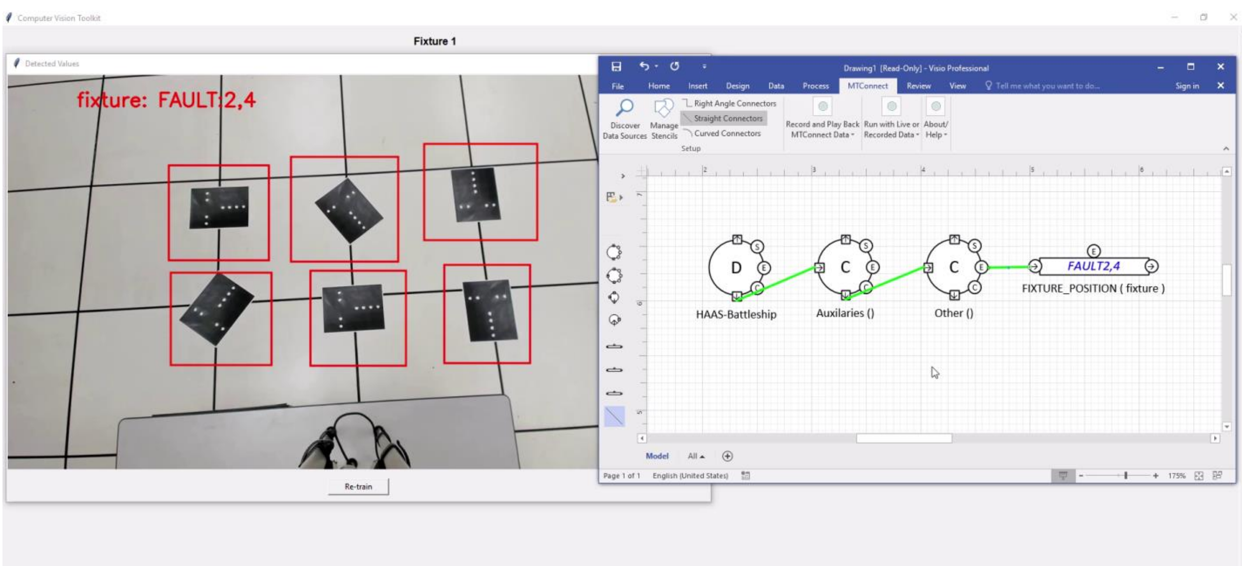

Figure 30: Fixture Simulation in 'Fault' Condition with ShopFloorIQ Output

4.4.6 Liquid Level Artifact

Objective: Alert if the liquid level exceeds the maximum permissible level

This artifact was also identified at Raytheon as their production environment requirement. The main purpose of including this artifact is that various liquid baths that are used in production environment constantly need operator supervision to identify if the level of the liquid in the bath has reached the maximum permissible level or in the worst case, the liquid has started to overflow from the bath. With the help of the Computer Vision Toolkit, the user has the option to receive an email or SMS alert if the water reaches or exceeds the maximum permissible level. The user needs to input the current water level and maximum permissible water level by drawing two horizontal lines on an image captured as a part of the training. The output from the vision system is transmitted to ShopFloorIQ through MTConnect® based Adapters and Agents. The ShopFloorIQ can send SMS or email alerts to the user if necessary. The

MTConnect® category of this artifact was identified as 'EVENT' as the two possible output values from the algorithm were 'Okay' and 'Alert' which represent two discrete events. Figure 31 shows the detected value and ShopFloorIQ output of sample liquid level artifact at Raytheon production environment.

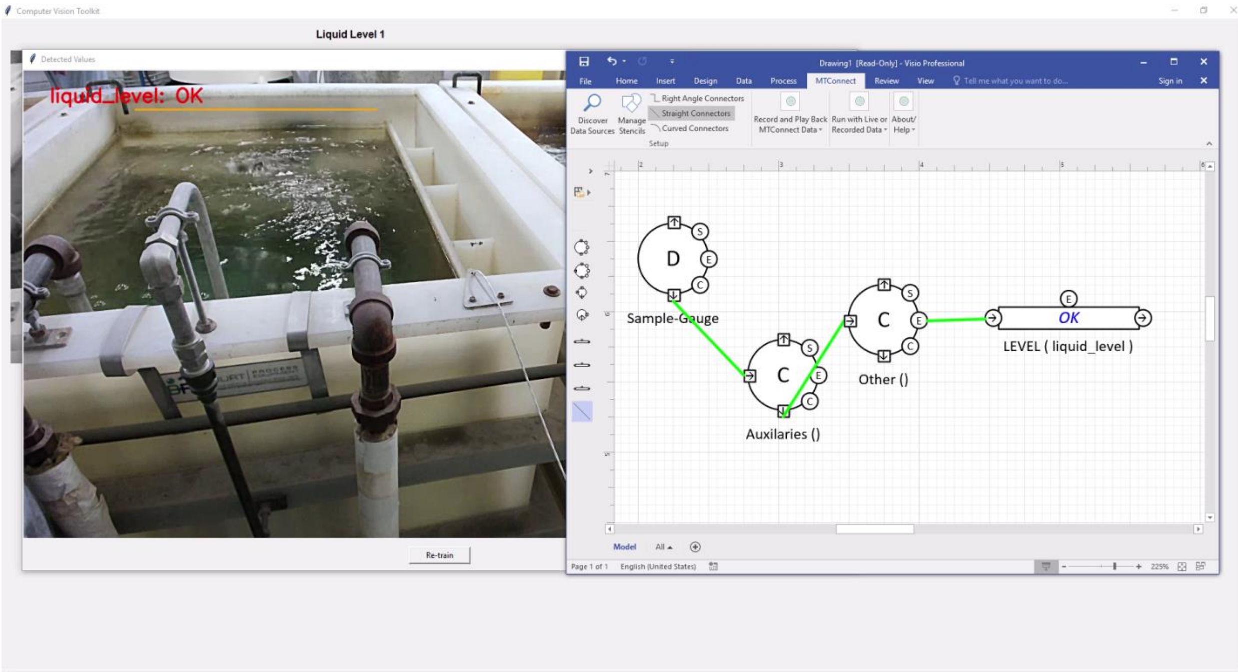

Figure 31: Sample Liquid Level Artifact at Raytheon with ShopFloorIQ Output

4.4.7 Machine Safety Lights Artifact

Objective: Recognize the color of the active machine light

This artifact represents various machine safety lights of a legacy machine which can be used to identify the machine process state. In the training process, the user needs to capture an image through the UI where all the lights were switched off and the algorithms recognize all the lights that are currently 'ON' by matching the pixel brightness values in the segmented image. The output transmitted through MTConnect® based Agents and Adapters is collected by ShopFloorIQ for visualization and also alerts regarding machine process state can be issued to the operator through Email/text if necessary. As various lights represent various discrete machine process states, the MTConnect® category of this artifact was

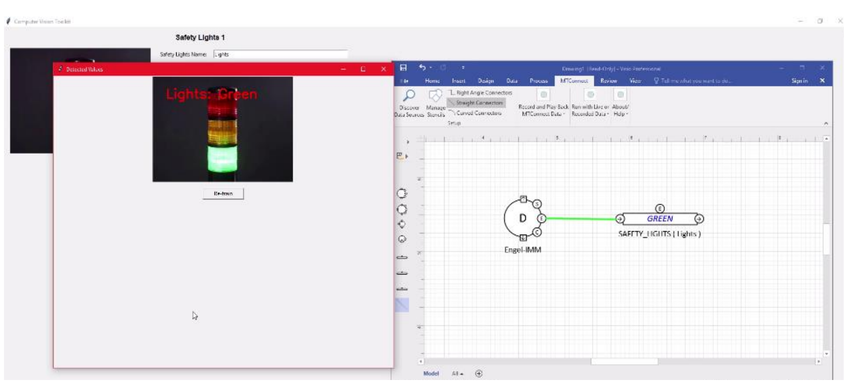

Figure 32: Sample Machine Safety Lights Artifact with ShopFloorIQ Output

identified as ‘EVENT’. Figure 32 shows the detected value and ShopFloorIQ output for a sample Machine Safety Lights artifact and its UI.

4.4.8 Toggle Switch Artifact:

This artifact works similarly to the Knob Artifact in all the aspects of the software. Figure 33 shows examples of toggle or binary switches

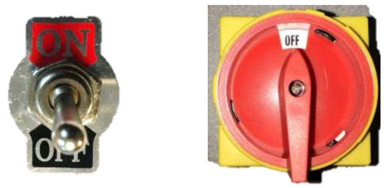

Figure 33: Sample Toggle Switches

4.4.9 Part Condition Artifact:

Objective: To identify whether the part is properly machined

This artifact was specific to the SME partner, Matdan Fasteners production environment. In this legacy machine under consideration, two tools work simultaneously on a fastener part to make two quarter turns. During the regular production cycle, one or both of the tools may break which results in the production of improperly machined parts or un-machined parts. Without constant supervision, the machine may run for hours with a broken tool(s) resulting in time and raw material wastage. Computer Vision Toolkit algorithm developed was used to overcome this issue which also helps the operator focus on other production machines. The user needs to train the system with the template images of properly machined, improperly machined and un-machined parts so the system can recognize the tool breakage, and the output to ShopFloorIQ can trigger SMS/Email alerts to the operator if necessary. The system can also identify the absence of the part in the feed system and alert the operator thereby preventing machine operating without a part. Figures 34, 35 and 36 show the detected value in UI and the ShopFloorIQ output at Matdan Fasteners production environment for ‘Properly Machined’, ‘Improperly Machine’ and ‘Unmachined’ parts.

The CV Toolkit is flexible to accommodate other types of part defect artifacts and can be trained appropriately.

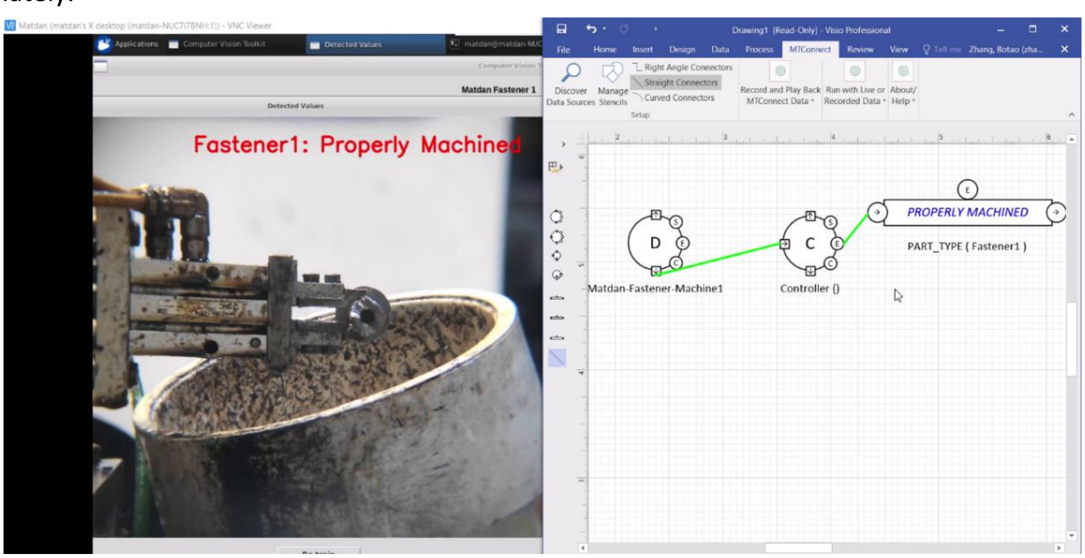

Figure 34: ‘Properly Machined’ Fastener at Matdan Fasteners with ShopFloorIQ Output

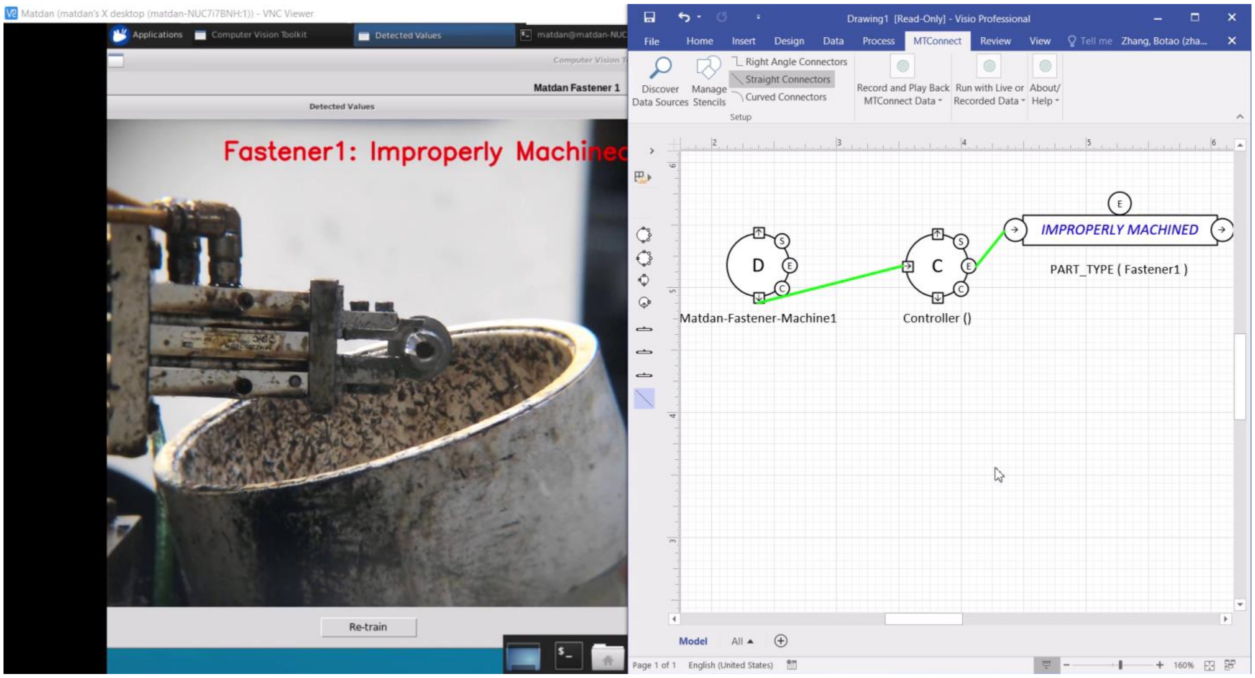

Figure 35: 'Improperly Machined' Fastener at Matdan Fasteners with ShopFloorIQ Output

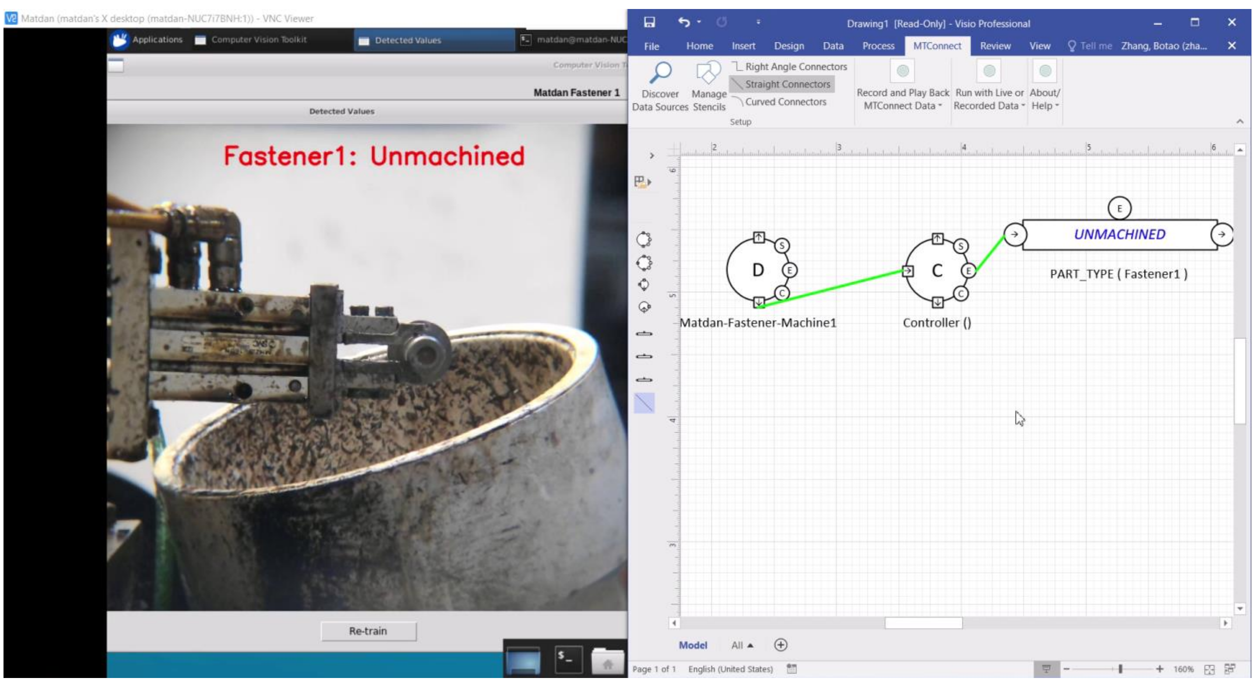

Figure 36: 'Unmachined' Fastener at Matdan Fasteners with ShopFloorIQ Output

4.5 Users and Use Cases

The Computer Vision Toolkit can be installed at any manufacturing environment where there is a need to capture, analyze and digitize the legacy machine data and other environments where the artifacts listed in the Project Scope are used.

Use cases for the project were provided by the three production environment sites at Raytheon (Defense – Aerospace), Faurecia (Automotive) and Matdan Fasteners (SME job shop). Apart from the mock panel test bed that was set up to develop, test and demonstrate the working of the toolkit, these three production environment sites are used to demonstrate the working of the toolkit in the actual shop floor environment. Since various factors such as lighting conditions, operator disturbance, machining vibrations can impact the working of the toolkit, the User Interface allowed the personnel to adapt the software to the local production environment.

4.5.1 Faurecia Installation

UC Team along with TechSolve traveled to Faurecia plant in Fraser, MI on 25th of June 2018, to install the cameras, mounting apparatus and the CV toolkit software. Prior to this, Faurecia purchased HP Z2 machines for the installation of the Toolkit software, prerequisite environment, and the MTConnect® Adapter. In addition, Logitech cameras were purchased as part of the toolkit system.

During the visit, UC Team identified the camera positions for the four artifacts that were identified at Faurecia and together with Faurecia personnel installed the cameras on the mounting arms that were previously acquired. The team then set up the processing machines (HP Z2 machines) on the production floor and trained the toolkit software for detecting the artifacts, collecting the data and transmitting the data through MTConnect® based Adapter and Agents. Faurecia team members were also trained on the User Interface and the configuration of MTConnect® based Adapter and Agents.

Due to operator disruption of the cameras, UC Team had to make a follow-up visit to Faurecia in the first week of August 2018 to recalibrate the cameras and train the toolkit software again. ITI personnel subsequently visited Faurecia to install and setup the ShopFloorIQ on a laptop at Faurecia and demonstrated the visual output of the artifact's data. Figure 37 shows the LCD screen on Engel IMM machine and the camera that was installed as a part of the toolkit. Figure 38 shows Thermolator with seven segment artifact and the installed toolkit camera.

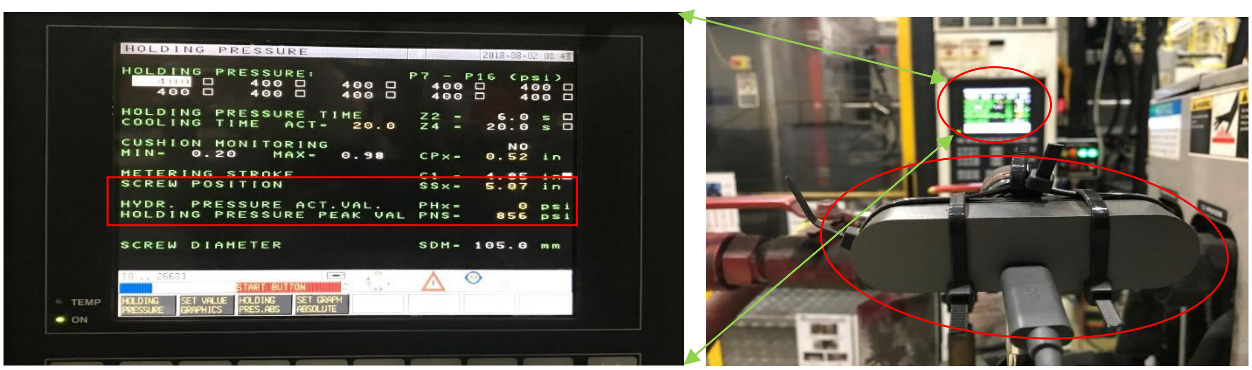

Figure 37: LCD at Faurecia with the Installed Camera

Figure 38: Thermolator Artifact at Faurecia with the Installed Camera

4.5.2 Matdan Fasteners Installation

UC Team visited Matdan Fasteners on 19th of July 2018 to identify the camera locations and also to test the algorithms that were developed at UC. After this visit, Matdan personnel setup the camera and the mounting apparatus at the identified location. They also acquired the Intel NUC machine for the installation of the prerequisite environment and the toolkit software along with MTConnect® based Adapter and Agent files. After the installation of the cameras and the mounting apparatus, UC Team made a follow-up visit to demonstrate the working of the toolkit software algorithms in the production environment. The CV toolkit successfully identified the defective parts during regular production operation, and the output was displayed on ShopFloorIQ interface. Figure 39 represents the view of the camera installed at Matdan Fasteners. The three pictures show unmachined, improperly machined and properly machined parts respectively that are identified by the toolkit software system.

Figure 39: Part Condition Artifacts at Matdan Fasteners Inc.

4.5.3 Raytheon Installation

Raytheon was the most challenging of the three production environment sites for the toolkit installation. There was considerable delay in installing the prerequisite environment and performing vulnerability testing studies due to their security and proxy issues.

Due to security requirements at Raytheon, only US citizens were allowed on to the production environment. Two US citizen graduate students, who were trained on CV Toolkit software, visited Raytheon production environment at Andover, MA in the first week of November 2018 for the final installation and the demonstration of the toolkit. Prior to the visit, Raytheon setup the cameras and mounting apparatus at appropriate locations. During the visit, the team installed and trained the toolkit system on the artifacts that were previously identified. ITI team personnel visited Raytheon to set up the ShopFloorIQ software on a Raytheon machine for visualization of the output. The toolkit successfully identified the values and parameters of various artifacts on the production environment. Figure 40 shows the final installation at Raytheon and all the artifacts under observation

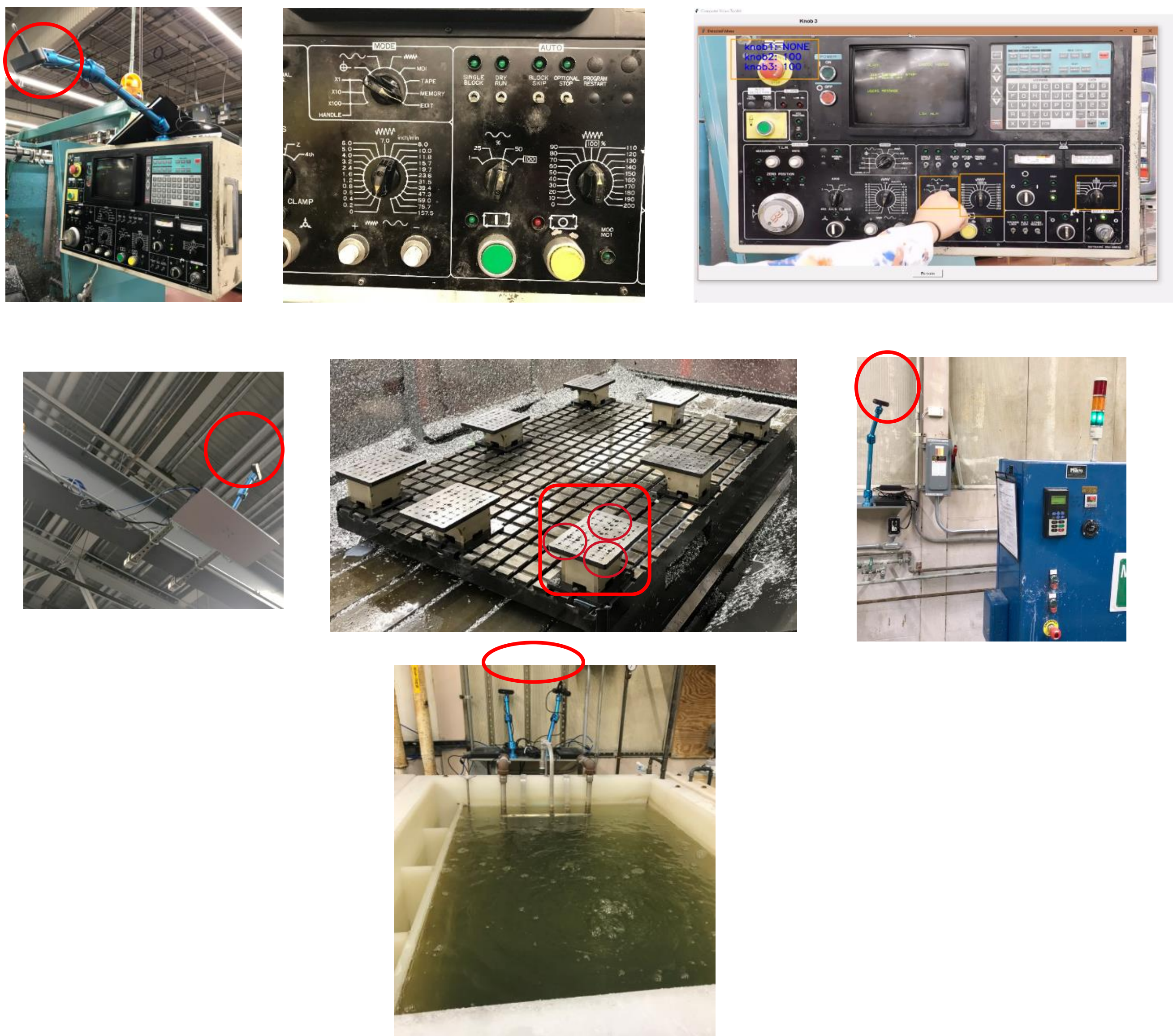

Figure 40: Various Artifacts at Raytheon and the Installed Camera Locations

4.5.4 Installation Summary:

The following are the list of items that are considered to be best practices that can be followed to successfully install the toolkit on any production environment:

a) Careful identification of the legacy machine equipment and the artifacts on the shop floor.
b) Identification of the best location for the camera so that it is vibration free and it does not disrupt the day-to-day operation of factory personnel. The camera that is recommended as a part of the toolkit needs to installed within 6-7 ft. of the artifact without the assistance of any additional lenses.
c) Acquisition of the necessary mounting apparatus to secure the camera in the machining environment and the processing machine.
d) Installation of the toolkit software on to the processing machine and testing the software. The installation file and the manual are provided as a part of the toolkit software package.
e) Identification of the location of the processing machine near the camera. Since the camera and the processing machine would be connected via a USB cable, they should be located in close proximity. Proper ventilation near the processing machine is also necessary.
f) Installation of network and power adapters near the processing machine. The machine needs to be connected to a local area network to communicate with ShopFloorIQ software over the network.
g) Setting up a static IP address for the processing machine so that ShopFloorIQ can communicate with the MTConnect® based Agent (that is installed in the processing machine) seamlessly.
h) The configuration of MTConnect® based Adapters and Agents with the artifacts of interest. The user manual for this step is provided with the toolkit software package
i) Training of the vision system under factory lighting conditions. The CV Toolkit user manual that is also provided with the toolkit software package can be used for training the system.
j) Installation and configuration of the ShopFloorIQ software on a separate system (laptop) using the provided manuals.

V. ACCESSING THE TECHNOLOGY

5.1. Background Intellectual Property

The BIP for this project includes ShopFloorIQ software from ITI and MTConnect® based Adapter from TechSolve.

Apart from these, the following open source tools were used to develop the Computer Vision Toolkit:

a) Python programming environment
b) OpenCV, TkInter, imutils, PIL – Python libraries
c) Tesseract – Open source application for OCR
d) Ubuntu OS
e) MTConnect® based Agent

5.2. Technical and Systems Requirements

Basic knowledge about Ubuntu operating system graphical user interface is required for installing the software. A software instruction manual and a user manual to install and run the software user interface have been provided. All the necessary technical details and steps that are required for training and using the software are included in the user manual.

System requirements include Ubuntu 16.04 LTS operating system with Python 3 interpreter installed. Various libraries such as OpenCV, Tesseract, PIL, imutils, TkInter, Numpy need to be installed in the Python environment to support UI development, image processing, and computer vision. The toolkit system also requires an MTConnect® Agent with its configuration files available from the MTConnect® GitHub site, and an MTConnect® based Adapter with its configuration file that was developed by TechSolve. A convenient ISO image file has been provided to install the specified Ubuntu operating system with the prerequisite environment (containing the aforementioned libraries) along with MTConnect® based Adapter with source code and MTConnect® Agent configuration and executable files.

Keeping in mind the low-cost requirement of the toolkit and the viability to purchase off-the-shelf equipment along with easy installation, the team recommends the following hardware specifications for the toolkit system:

<u>Camera: Logitech BRIO 4K Pro Webcam</u>

- Resolution: 4K Ultra HD, 1080p Full HD, 720p HD
- Plug-and-Play USB connectivity
- Extended field of view
- 5x digital zoom in Full HD
- Cost ~ $200

Figure 41: Logitech Camera

<u>Processing machine: Intel NUC7i7BNH</u>

- Intel Core i7-7567U - 3.5 GHz (4.0 GHz)
- 16 GB DDR4-2133 RAM (8x2)
- 256 GB SSD
- Ubuntu 16.04 OS (provided with the toolkit)
- Cost ~ $750

Figure 42: Intel NUC

For high performance computing, University of Cincinnati recommends the following comparatively better workstation in place of the above processing machine:

<u>Processing machine: HP Z2 Mini G3 Workstation</u>

- Intel Core i7-8700 - 3.2 GHz (4.6 GHz w/ Turbo, 12 MB Cache, 6 core, 65 W) + Intel UHD Graphics 630
- 16 GB (2x8) DDR4-2666 SODIMM memory
- 256 GB 2.5" SSD
- Cost ~ $1,550

Figure 43: HP Z2 Workstation

Necessary mounting apparatus is also required to secure the camera and the processing machine in the production environment.

VI. INDUSTRY IMPACT & POTENTIAL

6.1. Industry Impact:

Specific market addressed: Various legacy machines are typically installed in any manufacturing environment including machine tool, aerospace, automotive, defense, biomedical, plastics, and various other consumer industries. Several of the artifacts on such legacy machines that do not provide the ability for direct communication to extract appropriate data. The developed CVT system specifically addresses this market and the associated legacy machines. The toolkit allows for seamless integration of data streams from legacy machines along with sensor based data from modern machines on the shop floor.

Impact: This system provides a low cost tailorable non-invasive approach for acquiring any kind of data from legacy machines that can be captured by a camera. This provides 24x7 access to the data streams coming from legacy machines and provides options for performing historical data analysis and statistical analytics. The kit software includes interpretation of a set of common artifacts that can be extended to other artifacts.

Size of the market: We estimate that this system can be adapted to a wide variety of industries with possible initial demand between 1,000-10,000 systems. We project that in 5 years this demand may exceed 50,000 systems.

6.2. Use of the technology in other industries:

The system is reconfigurable for various other kinds of artifacts depending on the application.

University of Cincinnati is willing to assist in reconfiguring and tailoring the system for specific industry applications on a contractual basis.

6.3. Next step based on other use potential:

The next step is to develop artifact specific data analysis and trends so as to make real-time inferences to provide runtime process control feedback to alter process/machine parameters. The team is investigating the integration of other sensors with the system such as vibration, acoustic and thermal sensors.

VII. TECH TRANSITION PLAN & COMMERCIALIZATION

The project team purposely selected a diverse set of data to collect as part of the Computer Vision Toolkit that is specifically challenging to acquire through traditional methods. The team chose industry members with diverse data requirements and machinery including the size of parts, security, IT, operating environments, and legacy machinery. The data represents a diverse set of information that pertains to most legacy machines as well as processes and other functions that are outside of many control windows and will have direct applicability to other industries that may have a need to acquire data from a screen, dial, switch, gauge, or digital display.

Upon successful completion of the project, the Computer Vision Toolkit project deliverables will be made available through DMDII. The open source project will contain all source code and examples used to acquire the machine information at all industry partner and demonstrations sites. This will allow manufacturers or technology providers to access the materials, purchase the correct equipment, utilize the resulting computer vision algorithms, and potentially develop new capabilities. The software is provided under the *GNU General Public License version 3* open-source license allowing users to modify the toolkit based on their local conditions. This will allow the community to offer additional computer vision, sensor, and/or integrations as well as preserve the new capabilities available to the larger group. DMDII members had early access to work with the software in the mock panel environments and within the DMDII equipment onsite.

In addition to the open source project development, the team's proposed workforce development and education outreach efforts will address a larger audience potentially through workshops, seminars, papers, and onsite demonstrations and training.

University of Cincinnati is willing to assist in the installation of the system and fine tuning of the CV Toolkit software on a contractual basis.

7.1 Identified Future Plans:

a) University of Cincinnati along with TechSolve and ITI are in the process of obtaining appropriate IP for the CV Toolkit system.
b) UC is also in the process of patenting the CV Toolkit system and the associated algorithms.
c) UC is investigating possible partners who would be willing to work to commercialize this system.

7.2 Identified Barriers to Adoption:

The CV Toolkit software requires training under different lighting conditions to successfully interpret the data. Users also require some basic knowledge of machine learning and image processing algorithms and methods to train the CV Toolkit system for local environment and ensure that the system can learn over a period of time. University of Cincinnati is willing to help in this regard on a contractual basis.

The following key items were identified as potential issues in scaling to a commercial capability:

a) <u>Operators</u>

Operators need to continue to have the freedom to move and operate the machinery without the camera or SVT toolkit to get in the way. During implementation, one operator was tall enough that his head would bump the camera system as planned. Due to the obstruction, this operator would move the camera system out of the way. Placement of camera is key, however, using advanced camera systems that can monitor machine controls from a larger distance (possibly mounted from the ceiling or nearby wall) would be optimal.

Operators are also accustomed to operating machinery at their leisure and settings based on their schedules and decisions. Trust in the data being collected and reasoning behind the data being collected needs to be identified and verified prior to implementation. Regardless of planning and communication, operators can still have concerns that data and camera systems are monitoring their machine settings for disciplinary reasons versus purely machine maintenance, digital thread, or other purposes. This can be more complicated in environments where union workers have trust issues with upper management or existing pressures exist. Being able to feed data back to the operators to improve their job, make their job easier, or provide reduced workloads would be beneficial to gaining operator support.

b) <u>CVT Software</u>

The CVT software that interprets the video into the key-value pair artifacts is sufficient for certain setups. For example, at Matdan where the computer vision system is monitoring a space which does not move regularly, or in other cases where operators are not actively engaging near the system. The following enhancements would take the CVT software to the next level of usability and would help in making the CVT toolkit viable for other environments:

1) Minimize user image enhancement settings: The user selects certain characteristics of the image processing through a slider function in the UI to help enhance the output. If the image processing functions could be automated such that a series of settings that are attempted and tried could be learned, the software could reset these settings on the fly to determine the ongoing best case settings that result in reading results. University of Cincinnati is currently working on enhancing the software to include intelligent automated image processing/enhancement for each type of artifacts.
2) Save user settings: Currently, the user must configure and train the software each time the machine is powered on. Ideally, if the machine is configured, the software would automatically start and load the previous save. During power on other essential activities such as starting MTConnect services could also be configured to happen automatically. This feature has been incorporated in the fixture artifact of the current version of the toolkit. University of Cincinnati is working on incorporating features for saving image configurations for various artifacts.
3) Minimize Images Required: The user must capture multiple images and saved them in order to configure knobs and certain artifacts. During live display, if the user could turn the knob to certain values and then configure that setting it would reduce the requirement to save, remember, and reload multiple images. University of Cincinnati is currently working on supporting live display mode for configuring knobs/toggle switches.
4) Movement / Alignment: Currently, if the CVT system is moved or alignment is modified the user must retrain the system. The CVT software could record key markers of the video and offset the algorithms such that existing areas of interest are readily identified. UC is working on identifying fixed fiducials in the artifact environment that could be used as invariant markers to re-focus the camera.

c) <u>Hardware</u>

The CVT toolkit utilizes less expensive computer cameras for image processing operations. This was a requirement of the program to keep costs for the CVT low. This constrains the specific resolution and the viewable areas which the camera can see. One of the original concepts was to leverage cameras that could move and zoom to read data during intervals. Testing these environments with the ability to read multiple systems within the same CVT system would be valuable in understanding how to scale to larger manufacturing environments where many machines and artifacts are within a specific area and similar systems are configured. Depending on the scale required, the higher end toolkit could allow for more artifacts thus lowering the overall cost for deployment in larger manufacturing environments.

VIII. WORKFORCE DEVELOPMENT

The results of this work will be disseminated through the university and industry community by way of presentations and papers at conferences, integration into classwork, and presentations at DMDII and other channels within the manufacturing and defense-related industries. University of Cincinnati has integrated the content from this project into some of its courses by the UC faculty members involved in this project. These courses include “Manufacturing Processes” offered to undergraduate Mechanical Engineering students, “Robot Control and Design” and “CAD for Manufacturing” offered to both undergraduate and graduate students. All these courses are taught by the PI or Co-PI at University of Cincinnati. The mock panel equipment used in this project has been made available to students for coursework and research projects. These courses as well as various project activities such as algorithm development, data gathering, implementation and integration, train students at both graduate and undergraduate levels with industry-relevant skills in smart manufacturing and IIoT for manufacturing, making them ready to join work-force upon graduation. All course and training materials are available to DMDII members.

UC is planning on publishing and presenting the following two conference papers as a result of this project. These conference papers will be extended to a journal paper later.

- Non-Invasive Computer Vision Toolkit for Legacy Machines – System Architecture, algorithms and computer vision methods
- Non-Invasive Computer Vision Toolkit for Legacy Machines – MTConnect® integration and industry implementation

8.1 Coursework integration at UC:

a) Integration into Robot Control and Design course – Use of the algorithms developed in the project for object recognition and collision-free robot path planning.
b) Integration in Manufacturing Processes course – Demonstration of CV Toolkit for interpreting data; demonstration of the process flow of using CV Toolkit with MTConnect and ShopFloorIQ for visualization of real-time data using the mock panel.

8.2 Raytheon

Raytheon is in the process of replicating the mock panel developed by the DMDII team (UC and TechSolve) which is a demo unit showing the current capabilities of the DMDII IIoT kit offered and installed on our production floor. Raytheon’s Advanced Manufacturing Center (AMC) is a research and development area which is segregated of our manufacturing floor (where union employees are present). The AMC is the location where Raytheon’s mock panel is being developed and the location where digital manufacturing engineers are using the mock panel to train manufacturing engineers. These engineers are responsible for programming the UC software and socialization of the new DMDII kits with the union operators to help with their guidance and understanding of the system as a whole.

8.3 TechSolve

TechSolve demonstrated the CV Toolkit using the mock panel during the JDMTP Advanced Manufacturing Enterprise (AME) Subpanel meeting held May 2-3, 2018. Members of this group included representatives of the Department of Defense military service and agency ManTech programs as well as invited large and small DoD contractors. TechSolve is also introducing companies to the technology via its Smart Manufacturing Initiative, a 2-year program sponsored by the Ohio Development Services Agency (ODSA). This Initiative is providing industry outreach through seminars, technology demonstrations, assessment services, and industry peer-to-peer roundtable sessions to assist small and mid-size manufacturers in discovering, evaluating and executing strategies for adopting appropriate Industry 4.0 technologies. Industrial Internet of Things (IIoT) technologies for production data capture, analytics and communication are prominent technology focus areas within this program.

IX. CONCLUSIONS

This project aims to develop an open source kit framework in which computer vision enabled cameras can be "plugged in" and configured to support a multitude of operations and produce information in the accepted and growing MTConnect format.

University of Cincinnati, TechSolve, and International TechneGroup Inc. (ITI) along with industry demonstration partners Raytheon, Faurecia, and Matdan Fasteners have developed an innovative, affordable and non-invasive toolkit that combines currently available camera, computing, and networking technology and components with a new software analytics platform. The Non-Invasive Computer Vision Toolkit has been designed to acquire data from various legacy machine components (gauges, readouts, dial positions, and other shop floor artifacts which are then converted into appropriate data. This system does not physically touch the equipment, require new operator procedures, or add physical sensors to existing utilities. Leveraging MTConnect®, the system will provide a flexible capability to acquire information which will be completely compatible with existing MTConnect® applications.

The developed toolset allows industries to instantaneously and continuously acquire shop floor data from legacy machines and make them available to personnel through a standard industry format. Industries can also perform analysis of the collected data to understand historical trends and prevent expensive out of control processes. The team envisions that this technology will provide tremendous value for Original Equipment Manufacturers (OEM) as well as small and medium size enterprises (SME) to troubleshoot shop floor problems on the fly, reduce scrap rates, as well as perform process control adjustments based on real data and trend analysis of historical data.

Future expansion of the toolkit could provide integration of additional sensor technology such as acoustic, vibration, and high-speed controller data developed through the community. The computer vision toolkit is non-invasive to the machine and operators and affordably provides the intelligence that the US industry needs to gain insight and make decisions from legacy and non-computerized equipment.

X. LESSONS LEARNED & RECOMMENDATIONS

10.1. What went well?

a) The overall communication between UC, ITI, and TechSolve went very well. This facilitated seamless development and integration of the CV Toolkit software with the MTConnect agents and adapters and finally with the ShopFloorIQ.
b) The CV Toolkit software design development proceeded uniformly and tackled all bugs in a systematic manner to provide a fairly robust software product.
c) The fabrication of the mock panel testbed proved invaluable in testing the CV Toolkit algorithms and fine tuning them in a variety of conditions before taking it live.

10.2. What went poorly?

Installation of the CV toolkit at the demonstration sites was challenging and took longer than expected for the following reasons:

a) There was insufficient understanding of the CV toolkit requirements for site infrastructure preparation. The plant personnel did not perceive the importance of network drops close to the workstation. This was important due to the fact that the processing computer had to be stationed in close proximity to the camera and communicated through the network.
b) There was a need for establishing a static IP address for each workstation so that ShopFloorIQ can access the data using a web-server. This resulted in delays at each installation to have the static IP allocated by the IT personnel.
c) For each workstation, the location of the cameras and the mounting hardware had to be planned ahead of time to ensure a clear line of sight for the cameras and good image quality for the CV Toolkit. This required coordination with maintenance personnel to go through a trial-and-error process to locate the camera within a reasonable distance for image acquisition while not impeding the operator.
d) The first time training of the CV Toolkit was contingent on obtaining good images and adjusting the image processing operational sliders to allow the system to learn the artifact recognition. This was a trial-and-error process and required knowledge of the system and the User Interface. At both Faurecia and Raytheon, additional inexpensive zoom lenses had to be installed to train an image that is good enough for the CV Toolkit software.
e) These concerns progressively eased up as the learnings from the previous site was put to use to remedy the problems. This significantly improved the installation time at the later demonstration sites.

10.3. What do you want to do differently?

a) Currently, the CV Toolkit and the MTConnect adapters and agents are two different pieces of software that communicate with each other. In the future, integrating the adapter and the CV Toolkit software will reduce the complexity of the system and simplify the installation.
b) For each artifact, the CV Toolkit UI is used for training the system for the local environment and its conditions. This is based on camera position, lighting, image, and other shop floor environmental factors. For the current version of the software, this training configuration is not saved except for the fixture artifact. Consequently, if the camera is moved or disturbed, the training has to be performed all over again. Future versions of the software should enable capturing the configuration of the training and saving it so that it can be recalled quickly.
c) The CV Toolkit software and the MTConnect adapter agents are currently written for Ubuntu Linux operating system due to its open source availability. Given that most organizations are familiar with Windows OS, and are heavily dependent on Windows applications, it makes sense to port the code to Windows OS. Using Windows should also simplify getting software approval in companies that have to adhere to DFARS Cybersecurity Requirements.

10.4. Problems Encountered

Although the installations at the production environments and the mock panel demonstration at DMDII Future Factory Technology Showcase were successful, the team faced some challenges initially which were overcome eventually. The items listed below indicate the challenges encountered:

a) During the initial development of the toolkit, UC Team realized that the open source OpenCV library is only compatible with USB interfaced cameras. Although this narrowed the scope of the hardware for the camera, additional security measures that were needed for a network-based camera were not required.
b) Due to the restriction to USB based cameras, the processing computer needed to be in close proximity to the camera. This proved to be challenging in a dusty shop floor environment.
c) Due to OpenCV restriction, the system could only handle one camera per toolkit machine. UC is currently investigating the possibility of connecting multiple cameras to one processing computer.
d) Installation at Faurecia demonstration site was difficult initially due to several issues in network drops, IP address configuration, and setting up cameras and processing machines.
e) After an initial visit to Faurecia for installing the toolkit machine, the cameras and the hardware were displaced by the factory personnel during regular operation and this warranted the team to make an additional visit to Faurecia.
f) Due to security restrictions at Raytheon, the team required more time to install and train the toolkit system and implement the toolkit at Raytheon. The initial set up of the processing machines was difficult due to network and proxy restrictions at Raytheon.
g) The team developed the toolkit on a Linux platform. This complicated the installation of the prerequisite environment and the team also faced some issues in the TkInter User Interface in Linux environment.

10.5. Proposal Claim Deviations

During the development of the system, the team made some improvements and modifications to the system and its architecture, slightly deviating from the proposal. To start with, the team decided to deploy one toolkit (which constitutes a camera, mounting apparatus and a processing machine with necessary software installed on it) per legacy machine, as opposed to a central processing machine in the plant floor for all the legacy machines as proposed in the original scope. The main reason for this deviation from the proposal was that the concept of a toolkit with "one camera connected to a processing computer" using "off-the-shelf" components can be installed as a kit near the legacy machine environment. The initial proposal described a central processing machine for processing image data from several cameras. This was deemed to be not viable for two reasons: (a) the network bandwidth for transferring several images may not be available on the shop floor and (b) any failure of the central processing computer would bring the entire system to a stop and may result in loss of data. Having an assigned toolkit machine per artifact helped us overcome this issue thereby providing independent system process for all the installed toolkits. All the partners and the DMDII program manager agreed on this deviation.

The team also decided to use one camera per toolkit system because the open source library (OpenCV) that is used in the toolkit software does not support multi-camera input. However, the modification of using one camera per toolkit machine integrates well with the architecture modification of using individual processing machines for different legacy machine artifacts, thereby creating a more meaningful "toolkit."

10.6. Risks Realized

The following risks were realized and appropriately mitigated during the installation of the system at the demonstration sites.

	Risk	Impact	Mitigation
1	Poor and variable lighting in the work-center area	Image capture may be dull and lack sharpness	Multi-image/ Multi-template training was used for best template match
2	Longer processing time for identifying and interpreting gauges and control panel information	May not be possible to sample the images frequently	Fine tuning of image processing algorithms and installation of a camera with 30 fps
3	Image compression from inexpensive commercial cameras might result in loss of detail	Image capture may lack sharpness resulting in misidentifying information	Selection and installation of a camera with better resolution

XI. DEFINITIONS

- CVT – Computer Vision Toolkit
- UI – User Interface
- OCR – Optical Character Recognition

XII. APPENDICES

12.1. Deliverables

The team has provided the following list of items as the project deliverables. All the installation, instruction and user manuals are included in the list. The team has delivered them as separate documents that can assist in the successful installation of the toolkit.

1. Computer Vision Toolkit software
2. Ubuntu OS ISO file (with pre-installed prerequisite and MTConnect® environment)
3. Installation manual
4. User manual
5. Final report
6. Computer Vision Software Design Documentation
7. MTConnect® based Adapter and Agent setup instruction manual
8. MTConnect® based Adapter and Agent configuration manual
9. ShopFloorIQ setup

10. ShopFloorIQ documentation
11. ShopFloorIQ overview video
12. ShopFloorIQ custom stencils
13. Production environment information flow block diagram
14. Hardware requirements document
15. Workforce development presentations

12.2. Demonstration Environment

As part of this project, University of Cincinnati along with TechSolve built two identical panels consisting of artifacts that were identified at all three demonstration sites such as Raytheon, Faurecia and Matdan Fasteners. Each of these panels is referred to as a 'Mock Panel Test Bed'. The intent to build these Mock Panels was to emulate a real shop floor environment and test the efficacy of the algorithms for on-the-fly interpretation. The Mock Panel at University of Cincinnati was used as a test bed to refine computer vision algorithms, adapt to varying lighting conditions and camera positions. The testing of the equipment for identifying artifacts at the demonstration sites provided the appropriate real time validation. Figure 44 shows the Mock Panel Setup at University of Cincinnati.

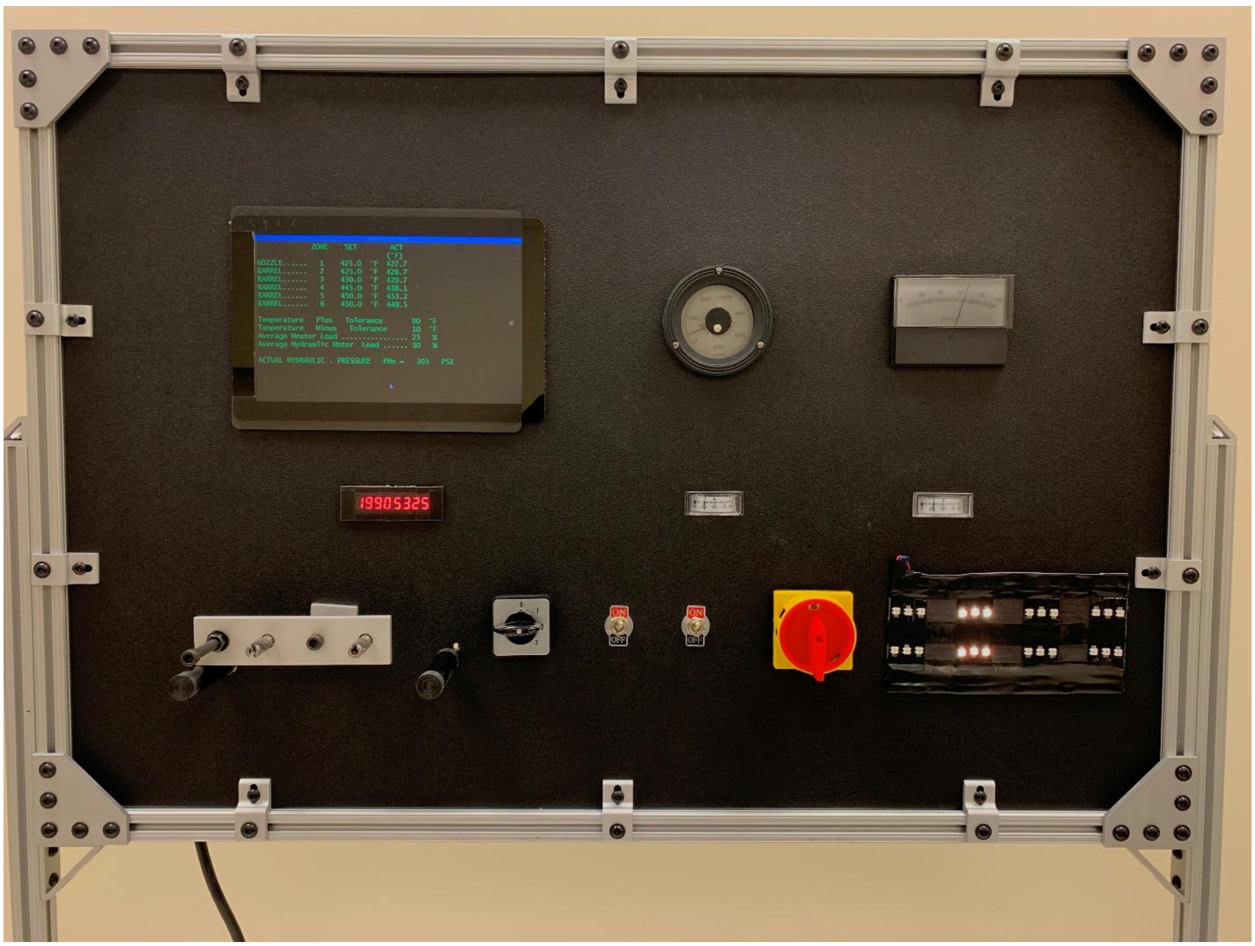

Figure 44: Mock panel

The Mock Panel has the following artifacts installed on it:

1. 10” LCD Screen: This artifact simulates the rising hydraulic injection pressure of a plastic injection molding machine (similar to injection molding machines at Faurecia). The LCD was programmed to simulate multiple cycles of hydraulic injection pressure in PSI. A Raspberry Pi computer was programmed to systematically change the values of the LCD akin to the real shop floor environment. The CV toolkit software was trained to recognize the characters displayed in the region of interest and capture the peak pressure of the plastic injection molding machine.
2. Analog Circular Gauge: This artifact simulates the rising hydraulic injection pressure of a plastic injection molding machine. It is driven by the same Raspberry Pi programming unit as the LCD screen.
3. Analog Arc Gauge: This artifact simulates the velocity of a conveyor belt in FPM or parts moving on a material handling system typically found on factory floors. A Raspberry Pi was programmed to change these values randomly.
4. Horizontal Linear Gauges: There are two horizontal gauges installed on the Mock Panel. The gauge below the circular gauge simulates the Average Heater Load in ‘%’ and the other gauge simulates the Average Hydraulic Motor Load in ‘%’ of the plastic injection molding machine at the Faurecia site.
5. Seven Segment Display: This artifact simulates digital readouts on typical CNC machine tool consoles, Thermolators, etc.
6. 4 Position Knob: This artifact simulates different types of multi-position knobs found on HMI panels of machine tools on the factory floor. The positions of the knob can be changed manually by an operator.
7. Toggle Switches: These are the most common binary switches found on HMI panels of machine tools on the factory floor and the positions can be changed manually by an operator
8. 2 Position Knob: This artifact simulates a 2-position lever on machine controls and the positions can be changed manually by an operator.
9. Safety Lights: The LED lights are programmed to simulate the stack lights attached on a machine tool.
10. Matdan Fastener Parts: A properly machined and an improperly machined part are attached to a mechanical lever, which can be can be rotated manually to simulate the Matdan Fasteners test case.

A Computer Vision Toolkit including cameras was setup in front of the Mock Panel to detect the values from all the artifacts installed on the Mock Panel. Figure 45 shows the camera recording of all the artifact data from the Mock Panel. The detected data is sent through MTConnect® based Adapters and Agent all the way to ShopFloorIQ as shown in Figure 46.

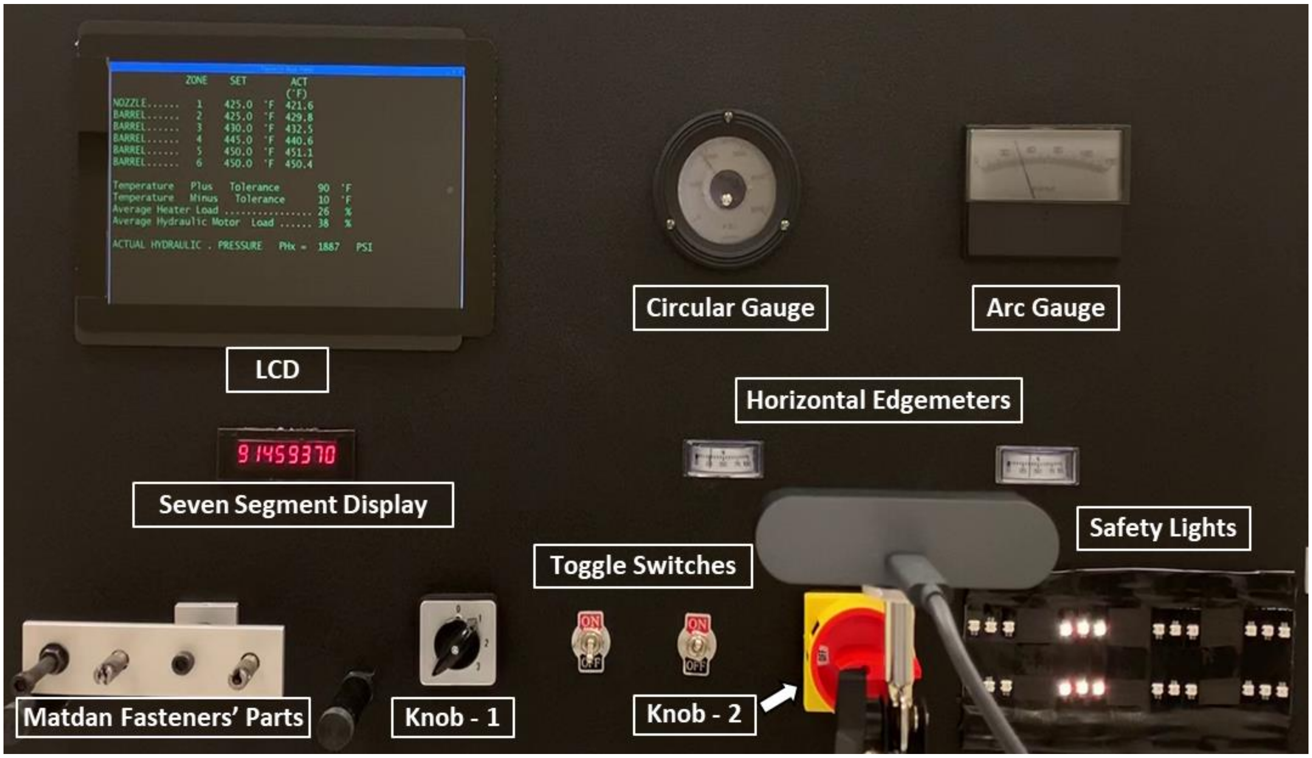

Figure 45: CV Toolkit Camera capturing data from all Mock Panel artifacts

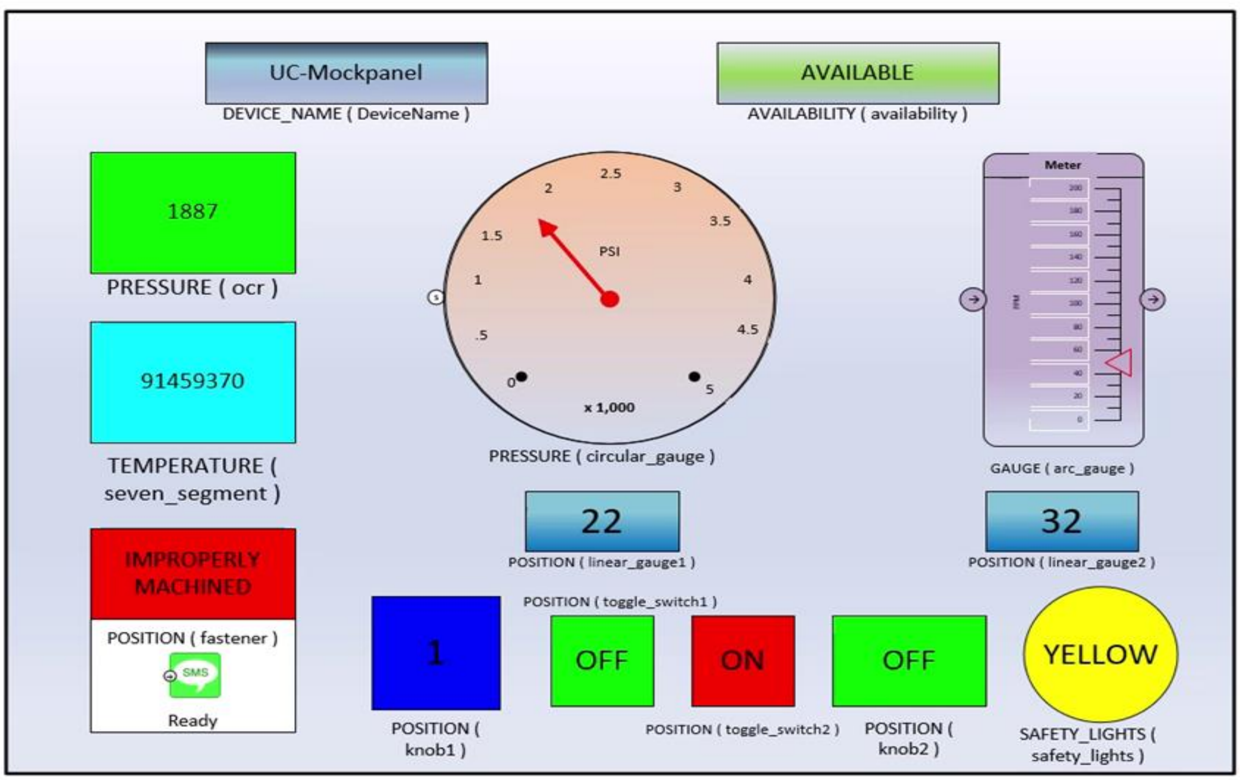

Figure 46: ShopFloorIQ Output Display

12.3. Validation & Testing

As a part of the validation, the team created the mock panel test bed as described in section 12.2 to demonstrate the working of the toolkit. The team further demonstrated the working of the toolkit using the Mock Panel at DMDII Future Factory Technology Showcase at Chicago on November 13-14, 2018.

The team successfully installed several toolkits at the three production environments, Raytheon, Faurecia, and Matdan Fasteners. Additionally, the team also assisted with the installation of the toolkit for detection of a gauge artifact at the DMDII site in Chicago as a piece of permanent demonstration equipment. This is currently on display at the DMDII site in Chicago.