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Towards a 3D Scanning/VR-based Product Inspection Station

Mohammad Azangoo[1], Jan Olaf Blech[1], Udayanto Dwi Atmojo[1], Valeriy Vyatkin[1, 2], Kamal Dhakal[1],
Mikael Eriksson[1], Miika Lehtimäki[1], Jonathan Leinola[1], and Pyry Pietarila[1]

[1]*Department of Electrical Engineering and Automation, Aalto University, Espoo, Finland*
[2]*Department of Computer Science, Electrical and Space Engineering, Luleå University of Technology, Luleå, Sweden*
Email: {mohammad.azangoo, jan.blech, udayanto.atmojo, valeriy.vyatkin, kamal.hakal, mikael.eriksson,
miika.lehtimaki, jonathan.leinola, pyry.pietarila} (at)aalto.fi

***Abstract*—Quality control of products plays an important role in various stages of the manufacturing process. In particular the final control of the quality of a product before being shipped to a customer is crucial for maintaining customer satisfaction and avoiding costly recalls. Automating quality inspection and integrating it into a seamless Industry 4.0 setting is therefore an important topic in factory automation.**

We present early work towards an automated product inspection station. Our inspection station features a 3D scanner as well as a Virtual Reality headset for remote human inspection. In addition, our concept provides for automated analysis of scans in the cloud. We present an architectural concept as well as an early prototype.

***Index Terms*—industry 4.0, automation, agile manufacturing, quality inspection, virtual reality, automatic inspection, visualisation, image processing**

I. Introduction

To remain competitive and sometimes satisfy legal requirements, manufacturers ought to maintain quality control of their production at a certain level, depending on the type of products they produce. Like any other systems, production systems are not perfect and there is a likelihood that the manufactured product may have defects at the end of the production line. This requires the manufacturer to introduce a mechanism to check the product whether it complies with the requirements. In case of defects, one needs to decide what to do with the product, e.g., take it off from the line to dispose or feed it back to a certain point in the line for reprocessing. One approach for inspecting products on the production line is to utilize visual-based sensing, e.g., high definition cameras or 2D, 3D scanners.

A relevant effort attempts to develop a mobile station for an Artec 3D scanner [1]. The work focuses more on the mechanical construction of the station. A similar concept in using 3D data generated by a 3D scanner for quality inspection in a production context has been suggested in [2]. The work has a focus on products made from rigid materials. Quality inspection for products with softer materials is covered in [3]. While the typical use case of 3D scanners is to have human personnel to move and orient the scanners towards the product, more automated approaches have been considered, e.g., involving robot manipulators [4]–[7]. In addition, [8] introduced an automatic solution to reconstruct a 3D model of a factory floor by merging different scanners and fly drones.

This paper reports on a work in progress on developing an automated product inspection station based on the use of a 3D scanner and related camera technology. The idea is to have the inspection station providing 3D data of the inspected product which can be used to construct its digital twin (e.g., 3D model) and can be viewed, e.g., via a normal PC screen or a Virtual Reality (VR) headset.

II. Production Island-based Factory Floor

The mobile production islands at our Aalto Factory of the Future (AFoF) laboratory [9], [10] are shown in Fig. 1. There are some production islands such as an automated assembly station, a collaborative robot connected to an AGV and a monitoring station with a human operator. The AFoF facility is used to research on flexibility enablers for Industry 4.0, including distributed automation architectures, OPC UA based factory data collection & monitoring system [11], digital twin implementation, and scheduling for movement of mobile robots.

The architecture of our automatic inspection station at the AFoF lab is shown in Fig. 2. The main elements of this architecture are listed below:

- **2D Cameras and 3D Scanners:** Camera and scanner are used to obtain the 2D or 3D images of the product.
- **Mechanical Infrastructure:** Sensors and actuators are installed within a mechanical structure where workpieces are positioned in a certain location. Our concept includes having a rotating table with controllable speed to generate a complete 3D model of the product using a 3D scanner.
- **Local Server:** 3D data is pipelined to the local server via wired or wireless networks. Also, the analysis algorithms are deployed on the server.
- **Bin Picking Arm:** The ”bin picking” arm is a robotic arm which can receive command from the server. The robot arm can transfer the product for final packaging if it passes the quality inspection. Otherwise, it will transfer the product to the trash for recycling.
- **VR Headset and Graphical Interface:** This interface is provided to allow the human personnel (on site or

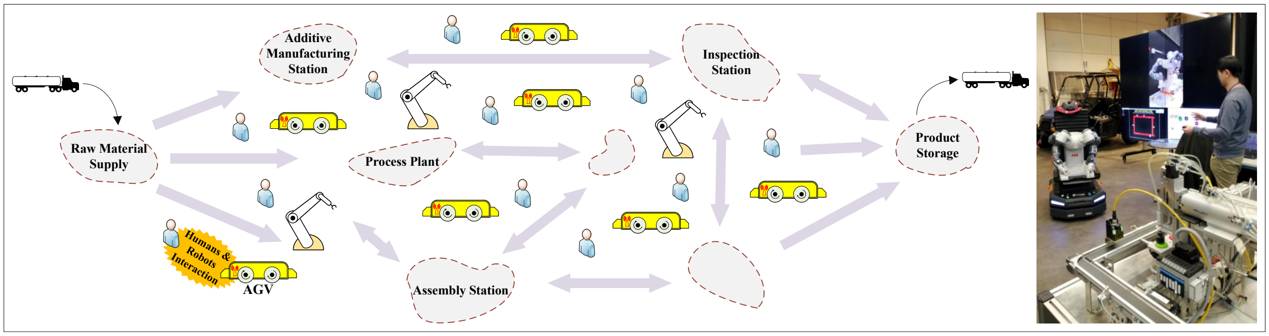


Fig. 1. Island-based production cells concept in the Aalto Factory of the Future.

remotely) to assist and give input to the quality inspection process. It is possible for human personnel to use this interface to monitor the operation of the inspection system.

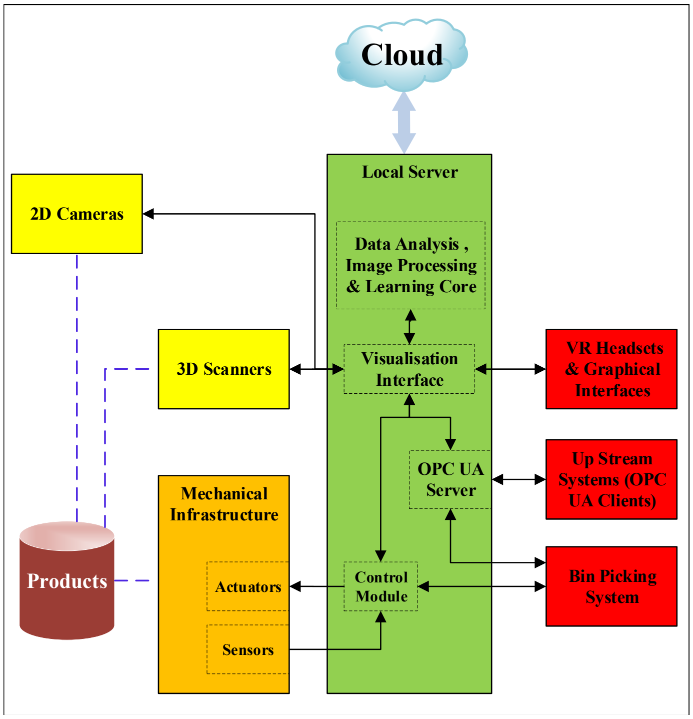

Cloud
Local Server
2D Cameras
Data Analysis , Image Processing & Learning Core
3D Scanners
Visualisation Interface
VR Headsets & Graphical Interfaces
OPC UA Server
Up Stream Systems (OPC UA Clients)
Mechanical Infrastructure
Products
Actuators
Control Module
Bin Picking System
Sensors

Fig. 2. The architecture of the automatic inspection station.

III. Current Progress and Initial Results

This section describes the current progress in implementing the architecture presented in Figure 2. The software running on the local server is implemented in C++ and utilizes different libraries [13]. Development considers the use of free, open source libraries wherever possible.

Currently, the following elements are part of the existing prototype: 3D scanners, data analysis, image processing & learning core, and the visualization part in the local server. Fig. 3 shows the example of the 3D scanner (left) and VR headset (right) as one visualization interface considered in this work [12].

A. 3D Scanning

We consider two types of 3D scanners in this project, an Artec Spider 3D scanner (also shown in Fig. 3 on the left) and a Microsoft Kinect V2 device. The volume capture zone for available Artec Space Spider 3D scanner in AFoF is about $2000cm^2$ which is suitable to scan the small objects in the factory floor. However, currently more implementation and results from Kinect than Artec Spider scanner are available. Fig.4 shows the effectiveness of Artec's provided outlier algorithm for better and smoother surface extraction. Different examples of scans are presented in Figs.4-6.

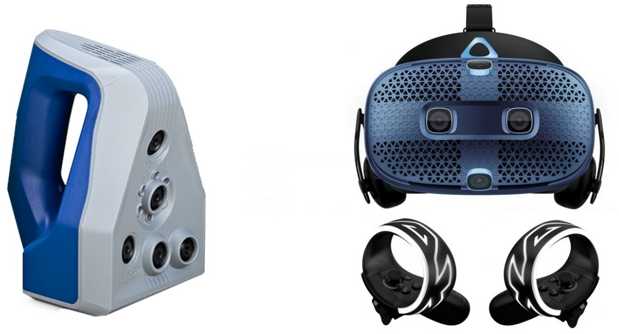


Fig. 3. Artec Space Spider 3D scanner (left) and HTC Vive Cosmos VR headset (right).

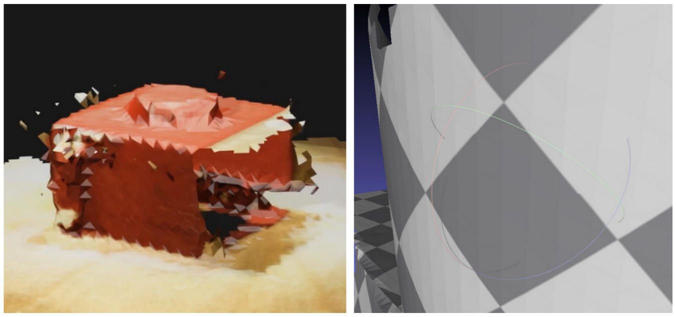


Fig. 4. 3D scan of a 3D printed product without outlier algorithm (left) and close-up of a 3D scan of another product scanned (right) by an Artec Space Spider 3D scanner.

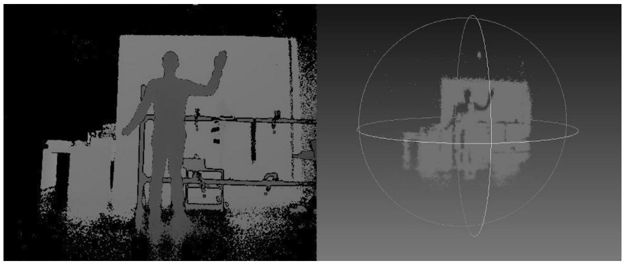
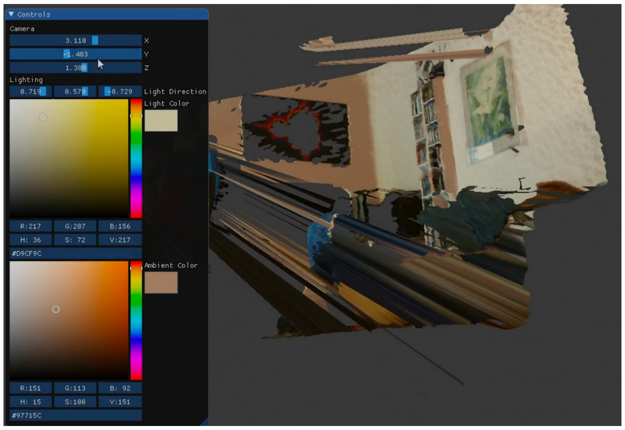


Fig. 5. Offline Kinect V2 scan (left) and 3D point cloud projection (right).



3.110 X
-1.483 Y
1.388 Z

0.719 0.579 -0.729 Light Direction

Light Color

R:217 G:207 B:156
H: 36 S: 72 V:217
#D9CF9C

Ambient Color

R:151 G:113 B: 92
H: 15 S:100 V:151
#97715C

Fig. 6. Real time Kinect V2 scan with textures on the desktop UI.

B. Shape Detection

We implemented a simple shape detection for the product. The shape detection utilizes an open-source library, *OpenCV* [14], with RGB-D image frames obtained from the 3D scanner using the *libfreenect2* library. The shape of the product in 2D can be obtained from edge detection techniques and the contours of the object are marked and the shape of the objects can be recognized using the shape of the external edges of the contours. Samples for round shape detection are shown in Fig.7.

C. Scratch Detection

Scratch detection uses the *NEU-Seg* defect dataset which is a standardized high-quality database collected by [15] to include 6 kinds of defects on a steel surface. The dataset consists of 1800 images of 6 different classes with their corresponding annotations. For better scratch detection, the dataset is used to train by faster region-based convolutional neural networks (Faster R-CNN) [16] and the TensorFlow[1] object detection API [17]. The pretrained model was downloaded and it was used as a base model for our training process. The configuration file of the Faster R-CNN model was modified according to our dataset with all the necessary path settings. The model was trained for 30000 steps. The procedure for training the Faster R-CNN model is listed below:

1) Dataset fetching
2) Curating the dataset
3) Converting the dataset into CSV format
4) Build the dataset into tfrecord format and split into training and validation sets
5) Download the pretrained Faster R-CNN model to exploit the lower level features of the images which can be used to fine tune the network.
6) Download the configuration file from TensorFlow and modify accordingly according to the path settings and required hyper parameters.
7) Train the model and export it for inference
8) Run inference

The RGB images from the Kinect were used for the inference. A PC with an Ubuntu 18.02 LTS operating system with NVIDIA GTX 1080Ti graphic card is used to run the inference and detection algorithm.

The trained model was then exported and the test images which were not part of the train/validation dataset were tested using the trained model. Some of the results are shown in Fig.7.

D. Visualization interface

3D real-time visualization is done with a custom-built OpenGL wrapper library called *GraphicsUtils*, providing basic building blocks for real-time graphics application development. For the desktop user interface, a free open source OpenGL-based library *imgui* was utilized. VR support was implemented using Valve's *OpenVR* framework [18]. OpenVR is an API that allows access to VR hardware from different vendors without specific hardware background knowledge. *OpenVR* was selected due to its good hardware support and availability of usage examples. It also supported direct rendering with *OpenGL* without the use of game engines or similar tools.

The VR implementation uses the *GraphicsUtils* library [19] to render a scene twice into textures which are then submitted to the headset. A slightly different camera angle is used to account for eye separation. The camera is controlled using head tracking data from the headset and analog joystick data from the VR controllers. Also, a VR viewer was implemented and controller input data is processed to provide full collaborative interaction with a human inspector.

IV. Conclusion & Future Works

This paper describes our ongoing effort in developing an automated product inspection station based on a 3D scanner. The station is connected to a normal monitor screen and also a VR goggle to allow personnel to view the 3D model of the inspected product.

Future works will include further development needed to make the system do fully functioning automatic/semi-automatic quality inspection. 3D scanning, VR and computer vision algorithms should be fully integrated and the features should be further developed. In the computer vision side, different kinds of neural network architectures should be investigated. Finding or building a proper dataset based on

[1] TensorFlow is an end-to-end open source platform for machine learning.

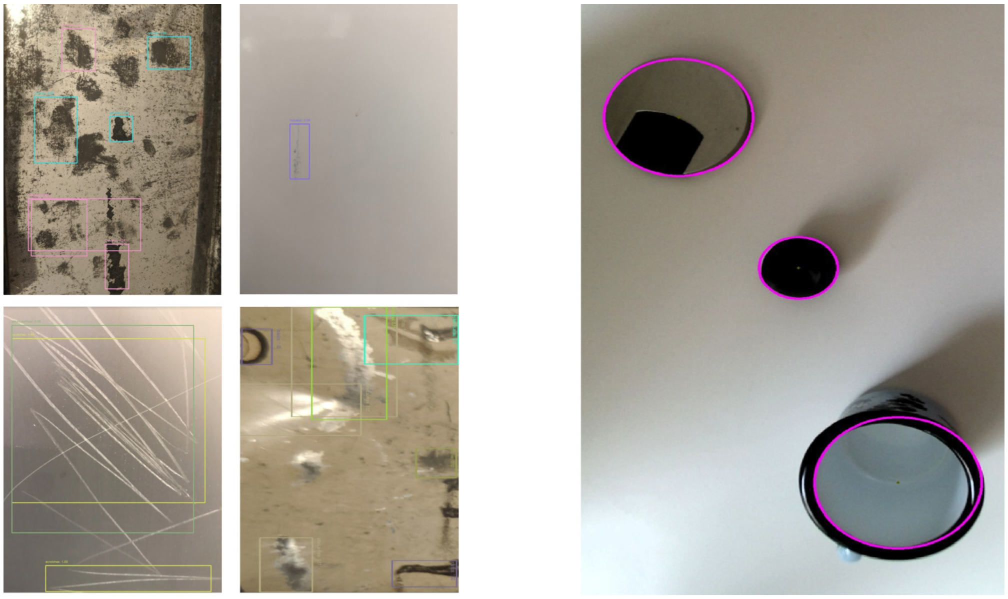


Fig. 7. Scratch detection by machine learning (left) and Round shape detection from KinectV2 RGB-image stream (right).

the problem statement would help a neural network to better classify and detect scratches along with other defects. In addition, on the VR side, some features could be implemented: remote use, support for environment textures, and visualization to pinpoint scratches in an object. OPC UA support was not yet implemented and adding it would enable the system to communicate with other devices in the environment. Then for example the 3D scanning could be done with a robot arm or turntable to take a full 360° scan of the object.

In addition, for the rendering a more out of the box framework like Unity might be considered but it might put some limitations on the real-time rendering of the scanning results that we tried to achieve in this project.

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