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Towards increased intelligence and automatic improvement in industrial vision systems

Oleksandr Semeniuta[a,*], Sebastian Dransfeld[b], Kristian Martinsen[a], Petter Falkman[c]

[a]NTNU Norwegian University of Science and Technology, Teknologivegen 22, 2815 Gjøvik, Norway
[b]SINTEF Raufoss Manufacturing AS, Enggata 40, 2830 Raufoss, Norway
[c]Chalmers University of Technology, Hörsalsvägen 9-11, Göteborg, Sweden

* Corresponding author. Tel.: +47-968-30-780. *E-mail address:* oleksandr.semeniuta@ntnu.no

Abstract

Robots and in-process inspection systems equipped with machine vision solutions are used for increased flexibility and quality in automated manufacturing. Although vision systems have found wide industrial use, there are still problems regarding optimization of vision system robustness and capabilities. This paper presents a comprehensive case study of vision system functions, techniques and capabilities in an automotive 1-tiers supplier. Based on the study, the paper further describes a method for systematic improvement of industrial vision systems on a continuous basis. This is proposed to be done by establishing a data store and data analysis system, based on training machine learning models in an off-line mode using the historical data, as well as on on-line stream processing.

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1. Introduction

The contemporary factories are constantly becoming more automated. Technologies like robotics and machine vision have already become an integral part of many production systems, but there is still room for a lot of improvements in their capabilities. New emerging technologies are being discussed in context of manufacturing automation under the umbrellas of cyber-physical production systems and several strategic initiatives, like Industrie 4.0 and Industrial Internet. Clearly, manufacturing is becoming a highly knowledge-intensive industry, where the required knowledge is diverse.

According to the outlook report on the future of European assembly automation [1], the potential of exploiting modern information technology is not fully realized, particularly in system development, which needs to adopt more holistic methodologies. Rapid deployability and effective adaptability are considered the main targets when developing new assembly systems. In addition, the importance of vision-based feeding and other flexible feeding approaches is stressed, together with links between feeding and joining.

Automatic assembly greatly benefits from application of sensor technology, mainly because of inherent uncertainty in products and production systems, which can be tackled by sensory feedback. Industrial sensory/measurement systems based on machine vision have gained popularity in the industrial context due to their inherent characteristics: the ability for contactless measurement, reconfigurability, and relatively low cost (comparing to tactile data acquisition methods).

Theres is a rich body of research within the fields of imaging, image processing, and computer vision. A particularly notable role of the above fields is within robotics. However, the complexity of some of the solutions, the lack of commercially available tools, and the lack of in-house competence result in slow adoption of the state-of-the-art research ideas. In addition, many challenges exist in the area of industrial vision, most notably high sensitivity of machine vision algorithms to exterior conditions and difficulty in accommodating industrial parts variability. Machine learning in this case appears as a promising alternative to hand-crafted programs with fixed thresholds, due to better accuracy of functions for recognition of complex patterns learned from data.

In most cases, solutions based on machine learning greatly benefit from *big* amounts of data used for training, testing, and validation. In the automated manufacturing context, it is often the case that data acquired on-line does not get stored for future processing. However, with a reduced cost of data storage hardware and easier access to elastic computational resources,

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it becomes more feasible to store and process intermediate on-line data. In the case of vision systems, it is of interest to keep a temporal database of images acquired during continuous system operation.

This paper is aimed at analyzing the current status of the production system and machine vision capabilities/requirements at a highly-automated plant in Norway, producing air brake couplings in high volume. Because of the high-speed and high-volume requirements, the considered production systems are limited in applicability of classical 6-axis robotic manipulators for assembly. Instead, the company employs dedicated transfer machines, optimized for performance.

A focus on a specific product family is made, with the associated quality requirements and currently operating assembly system configuration. Based on the study of the current state of production systems and the associated machine vision solutions at the plant, a number of solutions are proposed in a direction towards establishing a system for continuous improvement of the vision systems' capabilities. Despite the company-specific nature of this paper, the resulting analysis and proposed solutions can be generalized and used in similar cases.

This paper is organized as follows. Section 2 overviews the fields of automated assembly, machine vision, and machine learning. Section 3 presents the applied method. Section 4 describes the case company, the case product, and vision systems capabilities in the considered production facility. Section 4.3 proposes a technical solution for future development.

2. Preliminaries

2.1. Automated assembly

Assembly constitute a vital part of modern manufacturing systems, and is concerned with producing compound products from individual parts and sub-assemblies. Because many assembly processes require high level of dexterity, they are often performed manually. However, because of requirements in higher quality, speed and repeatability, automated assembly is being introduced in manufacturing companies.

The main operations in assembly processes are parts mating, parts joining, parts handling, parts recognition (position and orientation of randomly-fed parts), and inspection [2].

Material handling has a special role in automated assembly. Typical material handling processes are handling of pieceparts into the system, handling of palettes, fixtures and tools, removal of the completed products from the system, accommodation of operations external to the assembly cell, and transportation of partially finished products to and from rework [3,4].

Feeding has always been a challenging process within automatic assembly. Though a widely-accepted industrial practice is to apply dedicated feeding solutions with a built-in mechanism for correct part positioning, an important research direction is towards flexible feeding approaches, including vision-based feeding. In relation to this, an attention is placed on the link between feeding and joining, as well as interfaces for modular system architectures [1]. Another approach to designing feeding systems (and also applicable to sorting, assembly and inspection) is *algorithmic automation*, focusing on using formal models of part behavior and computational geometry algorithms for rigorous specification, analysis, and synthesis of automated systems [5].

Assembly planning constitutes a high-level set of activities intended for mapping formalized assembly instruction to robot operations. These activities include CAD modeling of parts, tolerance modeling, workcell planning, sequence planning, mating pose determination and others [6]. When the results of assembly planning are mapped onto robot operational level, uncertainty becomes an inevitable part of the process, and sensory feedback serves the primary role of tackling it. Typically used types of sensors in assembly are force, torque, and tactile sensors, sensorized compliant devices, vision systems, optical sensors, mechanical probes, positional sensors, as well as sensors for measuring temperature, pressure, acoustic emissions, and acceleration [2].

2.2. Machine vision

2.2.1. Principles of industrial vision systems

Machine vision constitute an engineering field applying image processing and computer vision solutions for the industrial needs, particularly for automatic inspection and robot guidance.

In a general vision system, a camera acquires an image, which is then enhanced to simplify the later processing steps. After that, certain parts of the image are segmented, and the obtained parts are further used to detect the desired features. Such process is also referred to as feature reduction: a vision algorithm reduces the original features, i.e. large array of image intensities (or several arrays for color and multi-spectral images) to a small vector of the application-specific features.

The common characteristic of industrial vision systems is the actuation function that impacts the controlled process. In addition, vision measurement in the industrial context is typically performed under controlled conditions with the appropriate lighting and low noise [7].

The application domains of machine vision include the following [7]:

- Defect detection: determining product defects, differentiating between different types of defects, including acceptable and unacceptable;
- Guidance and alignment: providing a robot control program with visual estimate of an object pose or geometric displacement;
- Measurement: deriving metric estimates of geometric features of a physical object;
- Assembly verification: determining the correctness of an assembly process.

On-line vision system, which constitute a part of the production process, provide the necessary information (e.g. pass/fail classification or robot movement coordinates) at the cycle time of the process. Conversely, off-line vision systems are used for recording information and further analysis [8].

Typically computer vision applications utilize images from sensors that capture visible light (some applications benefit from IR and UV imaging). Though many modern computer vision algorithms aim at analysis of arbitrary scenes (e.g. outdoors), in the industrial settings one typically establishes highly controlled lighting environment, and appropriately choses suitable light sources.