Augmented reality, artificial intelligence and machine learning in Industry 4.0: case studies at SI-Lab

Antonio Bruno, Simone Coscetti, Giuseppe Riccardo Leone, Danila Germanese, Massimo Magrini, Massimo Martinelli, Davide Moroni, Maria Antonietta Pascali, Gabriele Pieri, Marco Reggiannini, Marco Tampucci

Signals and Images Lab, Istituto di Scienza e Tecnologie dell'Informazione "A. Faedo", ISTI-CNR

{name.surname}@isti.cnr.it

Abstract

In recent years, the impressive advances in artificial intelligence, computer vision, pervasive computing, and augmented reality made them rise to pillars of the fourth industrial revolution. This short paper aims to provide a brief survey of current use cases in factory applications and industrial inspection under active development at the Signals and Images Lab, ISTI-CNR, Pisa.

1 Introduction

Industry 4.0 is demanding new solutions to manage the multiple resources available in a production plant integrating and orchestrating all the flows that should be performed. Besides the general production –which is often assumed to be the default mode– maintenance is of key importance since, in principle, it has to be performed so as not to interfere with production, keeping productivity at optimal levels and guaranteeing the expected quantities of processed product. In this context, technological solutions that can improve such aspects should also be sought in consideration of the request for superior safety levels and the presence of human operators.

Industry 4.0 pillars are firmly planted on a vast ground of technological advances, including horizontal and vertical integration, additive manufacturing, internet of things, simulation, augmented reality and big data and analytics. Notwithstanding this variety, artificial intelligence is a ubiquitous ingredient that can corroborate these pillars.

In this paper, we aim at providing some ideas of the possibilities opened by the convergence of multiple technologies by presenting research topics under development at the Signals and Images lab, a multidisciplinary research team, and describing related projects and case studies in Industry 4.0.

2 Research topics

2.1 Pervasive systems and augmented reality

In order to be efficient, modern production lines should guarantee a smooth operation without any machine stop. Monitoring the process and knowing the status of subsystems and components in real-time is thus of crucial importance. The Industrial Internet of Things (IoT) offers answers in this direction thanks to integrated solutions for sensing, transmitting and aggregating data. At the SI-Lab, a great interest is played by approaches based on pervasive vision, where sensors equipped with cameras and integrated logics can provide quantitative data about the process they are observing. Anomalies in the form of precursor signs of possible faults can then be either recorded in the Supervisory Control and Data Acquisition (SCADA) system or directly notified to operators. For instance, anomaly detection in a video stream detected by a camera can be used to warn an operator, requiring intervention in a segment of the line. In this context, an integration with Augmented Reality (AR) interfaces for troubleshooting is beneficial for the actual deployment of the solutions in real scenarios. To this end, in the project IRIDE, an integrated system based on pervasive vision and AR has been proposed and then tested in the tissue converting scenario. A network of cameras is capable of collecting data from the converting line. Each video stream is analyzed by embedded components capable of analyzing and detecting anomalies. When an event occurs, cameras automatically notify the SCADA, also collecting a video chunk documenting the circumstances. Through an adapter, the notification reaches the operators on their mobile devices (e.g. rugged phones or tablets). Operators can see the generated alarm and explore the line using augment content. In particular, an AR experience is offered where the operational parameters of the line in real-time are made available as tags. Interactive troubleshooting is also provided to help the operator find a solution or start the necessary maintenance of the line. Tests of the AR system have shown encouraging results [Coscetti *et al.*, 2019; Coscetti *et al.*, 2020] and a demonstrator has been implemented [Moroni *et al.*, 2022].

2.2 AI and acoustic for predictive maintenance and adaptive control

It is common to say that an engine or machinery sings, meaning that the sound they emit is representative of perfect operating behaviours. Noise and vibrations are hints correlated to the maintenance status of non-visible or not otherwise appreciable parts and components of machinery, such as bearings, or the process the machinery is performing, such as cutting and grinding a product. Thanks to artificial intelligence, acoustic and vibrational analysis in the factory environment might provide relevant information about a plant during its operation. For instance, information collected by accelerometric sensors might be used to assess the Remaining Useful Life (RUL) of a bearing. At the same time, acoustic data obtained by directional microphones permits the collection of precise contactless information from the area of interest of a machine. Ongoing experimentation shows that acoustic AI might be an ally of industrial IoT applications, allowing predictive maintenance and adaptive control of production processes.

2.3 AI and localisation services

In the factory environment, indoor localisation technologies can support the exploration, monitoring and maintenance of the plants, for instance, in conjunction with the methods reported in Section 2.1. There are different generic technologies to achieve localisation based on radio frequency systems, either active or passive, or vision methods. Within the latter, the images acquired by a camera are used to locate oneself by performing appropriate triangulation procedures with respect to feature points identified in the images themselves. It is envisaged that indoor localisation technologies, such as Ultra-Wide Band (UWB), might provide context-dependent information and support employees in their work. An additional dimension is investigated in the Smart Converting 4.0 project: safety. Indeed, the combination of localisation services and artificial intelligence can bring advanced safety features, especially in the presence of collaborative robotics, such as Automatic Guided Vehicles (AGV) or non-segregated robotic arms. Trajectories of operators, robots and devices can be tracked and analysed on a suitable multi-level architecture. When a real-time response is needed, processing can be done by *ad hoc* embedded devices directly connected to robots and vehicles. In such a way, their behaviours can be promptly modified, for instance, reducing the speed of a robotic arm or avoiding a collision between an AGV and an operator. Tracking objects such as Personal Protective Equipment (PPE) can also assure that operators are wearing adequate protection by checking the correlation between human and PPEs trajectories. In general, pattern analysis on the set of trajectories and business logic allow defining and applying adaptive safety policies (see e.g. [Calabrò *et al.*, 2019]). Collection of the trajectory data and pattern analysis permits a better insight into historical data, understanding the behaviour of operators, identifying areas where most of their effort is spent and possible bottlenecks, and devising improvements for a more efficient process. A demonstrator in the tissue converting scenarios is under active development.

2.4 Infrastructure monitoring

Monitoring critical infrastructures such as buildings, plants, pipelines, powerlines and railways is a relevant application of industrial and societal interest. The need for pervasive, more accurate or continuous monitoring is increasing for improved safety and more reliable access to services and resources. Intelligent systems might help automate most tasks and perform extensive data analysis. At the SI-Lab, this is achieved mainly through the introduction of smart cameras, to be deployed as fixed nodes in a network for in situ observation, or on vehicles, either Unmanned Aerial Vehicles (UAV) or Underwater Autonomous Vehicles (UAV - see, e.g. [Allotta *et al.*, 2015]). Specifically, an application of artificial intelligence at the edge has been showcased using UAVs equipped with smart cameras in the domain of power line inspection. An ad hoc deep learning model has been trained to detect fault components in towers such as broken or corroded insulators. Cameras on UAVs have also been used to assess the health of buildings, for instance, monitoring the evolution of cracks by using photogrammetric techniques [Germanese *et al.*, 2018]. In this case, the approach was integrated into an IoT system for Structural Health Monitoring (SHM), featuring a Virtual Reality (VR) interface for real-time interaction with collected data [Bacco *et al.*, 2020]. In railway monitoring, edge computing and computer vision have also been used to detect fast failures in remote areas [Fantini *et al.*, 2015; Leone *et al.*, 2016] and analyse vehicular traffic around level crossings in cities [Magrini *et al.*, 2015].

2.5 Thermographic assessment

In industry 4.0, computer vision might be used for analyzing images beyond the visible spectrum. At the SI-Lab, infrared imaging has been used to characterize the status of conductors in powerlines. First, the location of cables was detected through standard RGB images. Then, the condition of wires was analyzed in the co-registered infrared images, permitting to identify hot spots that are very likely representative of damage [Jalil *et al.*, 2019]. Other applications include non-destructive testing and characterization of novel electronic and photonic components [Hussain *et al.*, 2020].

3 Conclusions

In this paper, we have presented a brief survey of research directions in Industry 4.0 based on the convergence and interplay between artificial intelligence, computer vision, pervasive computing and augmented reality. The presented case studies show a wide application range of the proposed technologies in a variety of plants where the reliability of processes and efficiency play a relevant role, both to guarantee *just in time* production as constancy in the provision of essential services. Proactive and predictive systems, integrated with intelligent user interfaces for displaying context-adaptive content, are seen as key in smooth interactions between humans and machines. Additionally, the theme of safety is nowadays more and more relevant. We believe that intelligent systems favouring a high level of safety, beyond procedural prescriptions, should be encouraged and required in modern production environments to allow for the coexistence between humans and robots and drive the transition to collaborative environments.

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