

FLEXIBLE INSPECTION SYSTEM FOR SMALL SERIES PRODUCTION BASED ON IMAGE FUSION

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Abstract:

In their pursuit for quality, companies in the production sector are confronted with the trend of ‘first time right on time’, thus requiring flexible production infrastructure for small series production. Regarding inspection tasks flexible metrology and highly flexible machine control structures are necessary. The primary goal of the presented project was the improvement, acceleration, and simplification of a machine vision inspection process of transparent free-form parts, such as automotive headlights. These parts have to be inspected for errors such as scratches, fingerprints, and dust. The inspection task is challenging, as common machine vision techniques such as line cameras and bright field or dark field illumination require dedicated setups for each product. The individual images are insufficient for the detection of non-conformances, thus requiring a different approach. The paper presents an approach using industrial standard machine vision and illumination strategies by applying sensor fusion, utilizing a single monochrome high resolution camera at different time intervals with different illumination. The project’s secondary goal was the flexibilisation of the machine’s control system by implementing a multi agent system replacing the existing programmable logic control architecture. The use of multi agent systems offers an innovative approach by splitting the responsibility of the accomplishment of tasks while relying on constant interaction among the agents to fulfil the production task.

Keywords: flexible inspection, image fusion, multi agent system

1. INTRODUCTION

In their attempt to remain competitive, companies in the production sector face the challenge of finding an answer to the trend of mass customisation [1]. This results in individualised products and small series production (SSP), i.e. a ‘first time right on time’ approach to production.

SSP has several distinctive characteristics that need to be addressed when designing production systems. These include the small (almost unitary) production volume, big variance, short lead time and often unknown and largely differing (partly random) processing times. [2] With regard to quality assurance, SSP brings up additional challenges such as the lack of predictability about the process, the lack

of data for decision making, and the short time to observe and correct the process during production. [3]

The concept of cognitive production metrology (CPM) is considered to be a viable approach for such a scenario. CPM systems combine mechanisms of quality planning and measurement systems to achieve cognitive capabilities within a technical system, thus allowing it to perceive and act upon its environment, to learn from past experience, and to plan and act out future behaviour. [2]

This research features the inspection of automotive headlight covers, which are transparent free-form parts that are generally a product of mass production. Due to their short product life cycle, large number of variants, variant dependant inspection processes, and inspection characteristics their production induces challenges similar to SSP.

Accommodating the challenges above requires a flexible production infrastructure, able to cope with SSP demands. The resulting inspection equipment must incorporate the mechanical integration of different types of metrology systems and its control system needs to accommodate different inspection sequences, test programs, and frequent changes to its components. In this paper a two pronged approach to flexibilise an existing inspection machine for automotive headlights is presented.

This paper is organised as follows. The related research work and general methodology, as well as a description of the inspection machine’s status quo are covered in Section 2. The implementation and realisation of enhancements of the machine are covered in Section 3 and their results are covered in Section 4. Sections 2 and 3 are split into subsections covering the inspection system and the development of the multi-agent system (MAS). Section 5 discusses the obtained results. Finally, Section 6 concludes the presented work and discusses future work.

2. RELATED WORK AND METHODOLOGY

2.1 Current Status of the Inspection Machine

The inspection machine that is being flexibilised is a standalone machine specifically built for headlight inspection. During inspection the headlights are inspected for scratches, dust particles, and finger prints. The machine features a closed loop conveyor system with several buffer stations, a loading and unloading station in the front, and a total of three machine vision inspection stations (IS) in the rear (Fig. 1). The inspection stations include a dark field and a bright field IS, equipped with dedicated conveyor belts

and synchronised line cameras, as well as the multi-vision IS equipped with multiple illumination systems and a high resolution monochrome camera. The multi-vision IS was added in previous works.

The dedicated conveyor systems for the dark and bright field IS as well as the rigid programmable logic controller (PLC) control system impede system reconfiguration and performance thus not meeting CPM requirements.

2.2 Image Fusion to Increase Inspection Flexibility

Multi sensorial systems and subsequent data fusion are used to increase the inspection range and flexibility of SSP systems and reconfigurable manufacturing systems [3-4]. Sensor fusion aims to improve the quality of the information, increasing the information's quality over that of the obtained original data. This implies multiple measurements that are either taken from different sources, i.e. sensors, or from the same source at different time intervals. [5] Data fusion can be classified by its level of abstraction. Signal level fusion processes the raw information, thus requiring that the signals can be combined. On the feature level extracted features or descriptors are combined, whereas high-level interpretations are combined on the symbols or decisions level. [6]

This work uses signal level data fusion of images, i.e. pixel level image fusion. Ideally, its goal is the complete representation of all visual information from a number of input images into a single one. For practical applications this is softened to the most relevant information, requiring the fusion process to identify the most significant features (e. g. edges) in the input images. [7]

There is a considerable amount of different approaches for image fusion, varying in complexity, robustness and sophistication, of which Pohl and van Genderen [8] provide an extensive overview. Of these methods the image pyramids method has been chosen for its performance with regard to the spatial and spectral quality of the fused image.

In this work, fusing a dark and a bright field illuminated image of the headlights aims to obtain high-quality images for improved defect detection. The image fusion can also be used to generate multi-focus images. Image fusion requires spatially registered images thus necessitating lengthy calibration and compensation of lens distortion or images that were taken using the same setup. This work aims to mitigate this problem by using a new flexible illumination system within the multi-vision IS to take dark and bright field images with one camera setup. This approach requires less space and speeds up the recording process as the entire headlight can be photographed in one shot, eliminating the need for synchronised dedicated conveyor systems.

2.3 MAS for the Flexibilisation of Production Systems

Even though the paradigm of agent-based systems has been researched for several years, its application in the domain of production systems is relatively new. They are considered to be an important contribution in the effort to increase the flexibility of manufacturing and logistic

systems. The use of agents in control systems is an innovative approach to distribute the responsibility of a task among multiple simple elements. [9] Agents are fully or at least partially autonomous and have a limited local view, thus requiring interaction and coordination to fulfil a task. This decentralisation allows agents to remain simple and requires means of self-organisation within the MAS. [10]

The benefits of using MAS in production systems include the easy insertion or removal of an agent from the system, the ability to employ distributed systems with multi-platform characteristics by using communications protocols and standards, and a desired amount of autonomy in operation. These abilities require a certain amount of cognition to maintain the capability of flexible and autonomous adaptation. [11] The development of MAS can follow either a hierarchical or a heterarchical approach, though the heterarchical approach is generally preferred as a hierarchical approach partially conflicts the principles of proactivity, autonomy, and goal orientation. [2]

The suggested control architecture follows a hybrid approach, thus combining stability and determinism of hierarchical structures whilst maintaining dynamic flexibility and autonomy. Agents are used for all machine functions and are assigned to levels that span responsibilities from product planning to the control of sensors and actors. Planning agents are part of the coordination level and use input production parameters, such as product variant and lot size, to plan the production process for each product (see Fig. 1). Agents of the production planning level plan processes and routing within the machine. Production task agents serve as interfaces between the planning levels and the work level by translating commands. Work level agents, such as robots, sensors and products, are mostly reactive agents and provide information and execute commands. The higher an agent's level, the higher is its complexity.

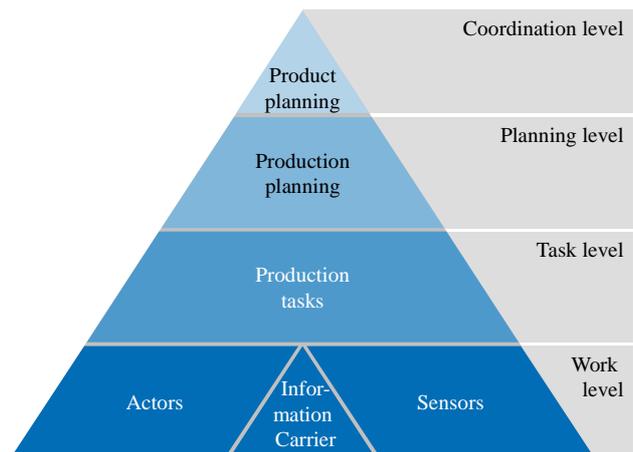


Fig. 1: Levels of the agent-based control structure

3. IMPLEMENTATION AND REALISATION

3.1 Implementation of the Multi-Vision Station

The machine's multi-vision station was partially remodelled to accommodate a new illumination system. The old backlight system, based on fluorescent tubes, was

replaced by a LED RGB matrix panel, usually used for video walls. The micro controlled system has 32 x 16 LEDs and uses simple bitmaps to display patterns.

To mimic bright and dark field illumination, a black and white stripe pattern is used. Diffuse light from the illuminated stripes gets to the dark areas under a sufficiently low angle to achieve basic dark field illumination, as shown in Fig. 2. Two images, using alternating patterns, are taken in rapid succession, ensuring that both bright and dark field images exist for the whole image. The width of the stripes was determined through experiment.

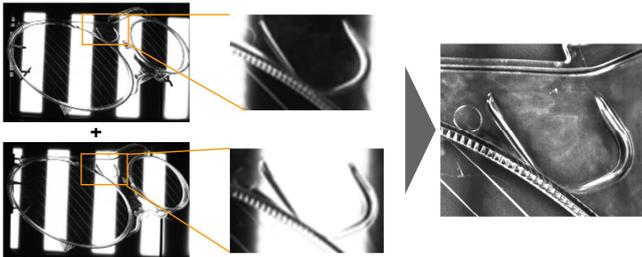


Fig. 2: Obtained images (left), enlargements of dark and bright field area (centre), and fused image (right)

Unless geometric inspection is required, the correction of lens distortion is not necessary as both images are taken using the same camera setup and pallet position. This also eliminates the need for spatial image registration. Both obtained images are then fused using contrast pyramids as implemented in the 'Metapix' fusebox for MatLab. The process was automated using LabView. Defect detection is done using LabView and enhanced by self-learning capabilities.

3.2 Implementation of the Multi Agent Control System

As the existing machine's architecture was already based on a software PLC (Beckhoff TwinCAT), the implementation of the MAS system was achieved without major changes in the control hardware. The communication between the work level agents and the PC-PLC is done using an UDP based interface. This approach allows focussing on the agent development without the need to develop the required infrastructure such as an agent

messaging service. The agents are developed and run using the JADE framework and JAVA.

The agents for the basic operation of the machine were implemented first. More complex functions (i.e. coordination and planning) were integrated through additional agents or the replacement of former simpler versions. As all functions of the machine are implemented in the form of individual agents, the actual implementation of agents becomes less complex as tasks are done through the exchange of information between agents. The process undergone to determine the causes for found non-conformances is described below and was added well after the detection process had been implemented.

For defect determination, a product agent requests the inspection of its assigned product at the quality agent which in turn will trigger the actual inspection, involving a routing process to get the product to the inspection station, the actual inspection, and the detection and classification of defects. The quality agent will then send a list of defects, if any were found, to the product agent and will simultaneously tell the cause specialist agent to start its process to determine the defects cause. The specialist agent gets the required information from the product agent, who is responsible to manage all information on its product, and will, using Bayesian networks, determine the defects' possible causes. This information is also sent back to the product agent and remains available for further processing and display.

4. RESULTS

The obtained fused image includes surface defects (dust, fingerprints, and scratches) made visible through dark field illumination and edges visible through bright field illumination. The images are taken in the same station using the same setup. Figure 4 gives a comparison of the obtained images. The dark and bright field images were taken using the existing inspection stations, respectively. By contrast, the fused image taken in the reconfigured multi-vision station shows dust and fingerprints more clearly. The detected defects are shown in part (d) of Fig. 3.

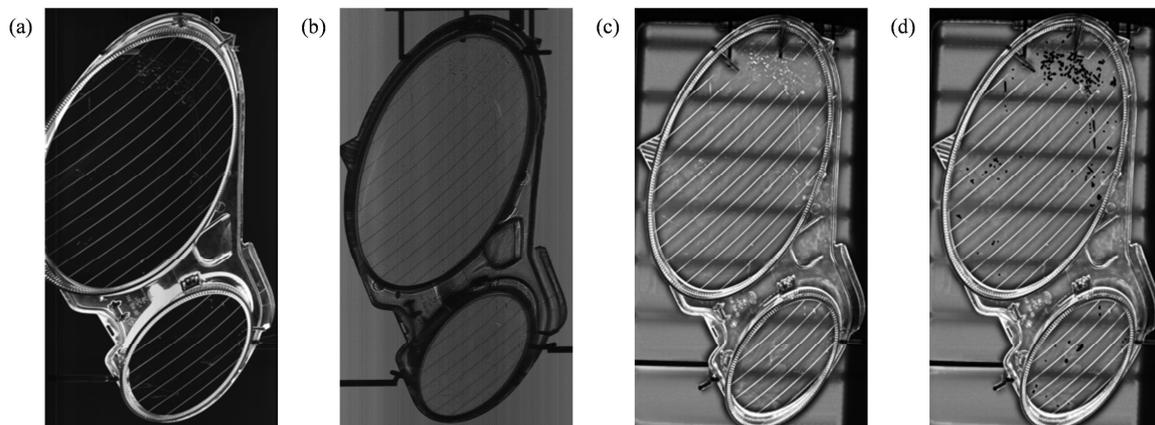


Fig. 3: Comparison of obtained images (left to right: dark field (a), bright field (b), fused image(c)) and detected errors (d)

Defect detection for this particular examination was restricted to particle detection in specified regions of interest. The fusion approach using one inspection station takes about three seconds, as opposed to the two times six seconds processing time required using the original inspection stations. Transportation time is also reduced.

The implementation of the agents was done subsequently, adding more complex functions in later steps of the development. The process of defect cause determination as described above demonstrates the simplicity of adding additional functions. The machine's initial configuration involved merely the fundamental agents for test running the machine. Any additional processing of the inspection information was added at a later point of time without having to change existing agents.

5. DISCUSSION

The approach to flexibilise the inspection process has been successful. The required space for the inspection station and the processing time were reduced, while the image quality was enhanced and the setup of the inspection station was simplified. It is important to note, that abstaining from using line cameras limits the maximum size of the inspected product, as the whole area that needs to be inspected must be visible for the camera at once.

The goal to increase the flexibility of the machine's control system using a MAS approach was met. The belated addition of advanced functions was demonstrated in multiple cases without having to change the existing agents. In theory these additions could be done without interfering with the running production system. However, test runs involving the interaction with hardware level work agents are necessary thus requiring a break in production. The current setup running all agents on a dedicated computer and having a PC-PLC on a second system proved itself to be convenient for this research project. Achieving true plug and produce functionality requires relocating more intelligence to the actual hardware level aiming to mitigate the need for middleware.

6. CONCLUSION

Albeit focussed on metrology tasks, the concept of cognitive production metrology can be applied to any small series production scenario that involves the use of complex machines. Through the combination of flexible inspection systems and self-organisation in machine level production planning and control, a significant increase in flexibility can be achieved. The presented approach using image fusion has improved the inspection quality whilst requiring less time and space. The MAS allows for an easier reconfiguration of the inspection machine, including the establishment of different test processes and sequences and changes in routing.

Additional work will be done to further improve the cognitive abilities of the inspection system regarding autonomous setup and the processing of the obtained product information such as error detection and distinction. Further efforts to standardise the communication between intelligent sensors are required.

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