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Inspection Planning in a Multiagent System for a Small Series Production

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Inspection Planning in a Multiagent System for a Small Series Production

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Resumo

Hoje em dia os sistemas de inspeções em linhas de produção enfrentam um grande desafio que é a inspeçoã de peças produzidas em pequenas séries. A produçoã em massa não tem os problemas da constante introduçoã de novos produtos e não tem que mudar a sua maneira de inspecioná-los, porque eles são sempre os mesmos na linha de produção.

A Hella é uma empresa que produz, entre outros produtos, faróis para carros e trabalha com uma grande variedade de produtos. Tinha uma máquina de inspeção em sua linha de produção para verificar a qualidade das lentes de faróis e tem enfrentado problemas na introdução de novos modelos e na falsa rejeição de faróis bons. A máquina não era suficientemente flexível e constantemente cometia erros ao descartar uma peça boa, ou o contrário, a aprovação de uma peça com problemas de qualidade. Assim, esta máquina foi doada ao WZL (Werkzeugmaschinenlabor) na RWTH Aachen University para realizar pesquisas com o objetivo de resolver os problemas de inspecionar peças na produção de pequenas séries.

Trabalhos anteriores ja foram realizados na máquina Hella utilizando a abordagem de multi-agente. Os resultados foram muito bons e com os agentes foi possível controlar a máquina e fazer alguns tipos de inspeções nos faróis.

No presente trabalho, propõe-se uma rotina de configuração automática para selecionar os parâmetros de foco, íris e zoom e as luzes da estação de Inspeção Flexível da máquina.

Abstract

Nowadays inspections systems in production lines face a big challenge that is the inspection of parts produced in small series. Mass production doesn't have the problems of constant introduction of new products and doesn't have to change its way of inspecting them because they are always the same in the production line.

Hella is a company that produces, among other products, headlights for cars and works with a big variety of products. It had an inspection machine in its production line to verify the quality of headlight glasses and has faced the problems discriminated previously. The machine was not flexible enough and constantly committed mistake of discarding a good part, or the opposite, the approval of a part with quality problems. So, this machine was donated to WZL (Werkzeugmaschinenlabor) at the RWTH Aachen University to perform researches with the objective to solve the problems of inspecting parts in small series production.

A previous work in the Hella machine using the multi-agent approach was already conducted. The results were very good and with the agents was possible to control the machine, and doing some inspections on the headlights.

In the present work, is proposed a auto setup routine to configure the parameters of focus, iris and zoom and the illuminations to a Flexible Inspection station of machine.

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List of Abbreviations

ADS	Automation Device Specification
AMS	Agent Management System
AP	Agent Plataform
BRAGECRIM	Brazilian German Collaborative Research Initiative on Manufacturing Technology
CAPES	Coordenação de Aperfeiçoamento de Pessoal de Nível Superior
DF	Directory Facilitator
DFG	Deutsche Forschungsgemeinschaft
DMC	Data Matrix Code
EVS	Embedded Vision System
FIPA	Foundation of Intelligent Physical Agents
GUI	Graphical User Interface
JADE	Java Agent Development
MAS	Multi Agent System
MTS	Message Transport System
PLC	Programmable Logic Control
PC	Personal Computer
PCB	Printed Circuit Board
RWTH	Rheinisch-Westfälische Technische Hochschule
TwinCAT	The Windows Control and Automation Technology
VIGILE	Visual Intelligent Glass Imperfections Looking Equipment
WZL	Werkzeugmaschinenlabor

1 Introduction

Nowadays, the consume of personalized products are increasing, and the costumers are looking for better quality and lower prices. Therefore the production systems need to be improved to reach these goals.

The industry need to be dynamic to satisfy the consumer. Ordinarily, personalized products are made in a small series then, the systems need to be flexible to adapt yourself to several products whit different characteristics. In this scope the industrial automation has been performed within remarkable flexibility. Although, the inspection's systems tasks have been automated, but it without the desired flexibility.

In this sense, agent-based systems can bring an innovative approach to split the responsibility of the accomplishment of different tasks. Agents are goal-oriented entities that interact constantly with each other in order to achieve a main collective goal. The modeling of production systems using an agent-based approach therefore strives for an autonomous and optimal use of resources and reduction of time an complexity.

The laboratory of Machine Tools and Production Engineering, WZL, has an automated inspection cell (Figure 1.1) developed by the company Automation & Robotics Inc. to detect defects in translucent surfaces, which is called VIGILE (Visual Intelligent Glass Imperfections Looking Equipment). The machine was donated by the company Hella to WZL because it was not flexible enough to deal with the constantly introduction of new product models to the production line and, also, it was very hard to configure the system to inspect new parts. Besides the machine had lack of robustness in evaluating the product's quality, rejecting, sometimes, a good part. As Hella produces a big variety of headlights, it was not possible to keep the machine working in its production line.

Other academic works were already conducted trying to give more flexibility for this inspection machine [1] [2] [3] [4]. One of this works has applied the multi-agent system approach to control the machine achieving good results. With this system was possible to transport and do inspections in the car headlights.

Figure 1.1: Industrial machine for the automated inspection of free formed surfaces.

1.1: Characterisation of small series production

In a small series production the products are manufactured in a big variety and in a low volume (possibly unitary). The time for producing a batch of parts is aleatory because different products have different complexity levels causing constant changes in the production flow. It often happens that a statistical control cannot be applied to balance the production capacity during the manufacturing, due to the lack of information acquired from the few manufactured products. The big diversity and the continuous introduction of new products in a small series production environment brings a series of problems related to the quality assurance, such as [5]:

- lack of predictability about the process and the product behavior;
- constant creation and actualization of quality documentation, such as inspection plans;
- increased set-up cycles and no, or just few, disposable products to be used for rigging processes;
- short time to observe and correct the process during production;
- difficulties for re-using information and performing corrective actions;

- lack of data for decision taking.

The quality assurance strategy that is used nowadays for mass production does not fit with the inspection flexibility needed for automated small series production. In mass production the measuring strategy is totally dependent on the fixed features of the few manufactured object variants and on process parameters that can be controlled/compensated during production time. The major challenge faced by quality assurance systems for small series production facilities is to guarantee the required quality level already at the first run (“first time right on time”), and therefore, the quality assurance system must adapted it self constantly to the new manufacturing conditions. The goal is to manufacture and assemble products with the same quality level since the beginning of the production.

The product development is seen as integrated part in this kind of production. However, inspection resources can not be purchased individually for every new type of product. They rather have to be flexible enough to allow the realization of the costumer-specific request variants, taking into account very demanding requirements, providing the performance for a broad spectrum of geometries and particularities. In addition, machinery and metrological resources must often be also suitable for manufacturing the next generation of products, since the break-even point for expensive investments in flexibility occurs after the end of the product lifetime.

1.2: Cognitive Production Metrology for flexible small series production - BRAGECRIM

The project developed in this work is part of a bigger project called “Cognitive Production Metrology for Flexible Small Series Production”. This project is a cooperation between WZL (Werkzeugmaschinenlabor), Laboratory for Machine Tools and Production Engineering, at RWTH Aachen University, Germany; CERTI Foundation, Reference Center in Innovative Technologies, at Federal University of Santa Catarina, Brazil, and S2i (Industrial Intelligent Systems), research group, at Federal University of Santa Catarina, Brazil, and will be conducted within the join call between DFG and CAPES for research projects within Brazilian German Collaborative Research Initiative on Manufacturing Technology - BRAGECRIM.

The objective of this cooperative research project has been defined as: “Development of a new generation of production metrology and quality assurance systems with a high degree of cognitive perception regarding the product and the process".

The focus of the project concentrates in two main research themes, which are extremely important for achieving the main objective:

- *Quality planning*: automatic and dynamic generation of inspection plans (including choice of adequate sensors) based on the product and process data, as well as prediction of quality of process and products, anticipating possible process parameter changes for dynamic production improvement.
- *Measurement systems*: flexible integration of different optical measurement systems into laboratory prototypes and demonstrators, which simulate an industrial environment, aiming at a more robust and reliable perception about process and product features. Conception of a new generation of optical measurement systems, able to combine 2D and 3D information acquired from different sources for a complete evaluation of the product quality.

The cognitive production metrology technology will be able to automatically and independently define an inspection task as well as autonomously apply it for a great amount of product variants, making use of different measurement and inspection systems. It will contribute directly for reducing the complexity of pilot production series, for speeding up the production start time, and assuring a maximum quality level for the process and product.

This solution is meant to be researched and validated inside two different scenarios: one in Brazil, by the assembly of printed circuit boards (PCB), and another in Germany, by the multi-sensor based inspection of free forms [6].

Figure 1.2 show both scenarios and the necessary tasks that must be performed to achieve the cognitive metrology.

1.2.1: Predictive Quality Planning

As it is common for small series production facilities, there is hardly time to react to production failure and quickly reconfigure the process parameters or even to setup the inspection equipment again, because the production batch size is not big enough to generate representative statistical data. That is why a predictive quality planning must be performed, based on information (product and process quality statistics) from the previous production experiences and also taking into account the current production

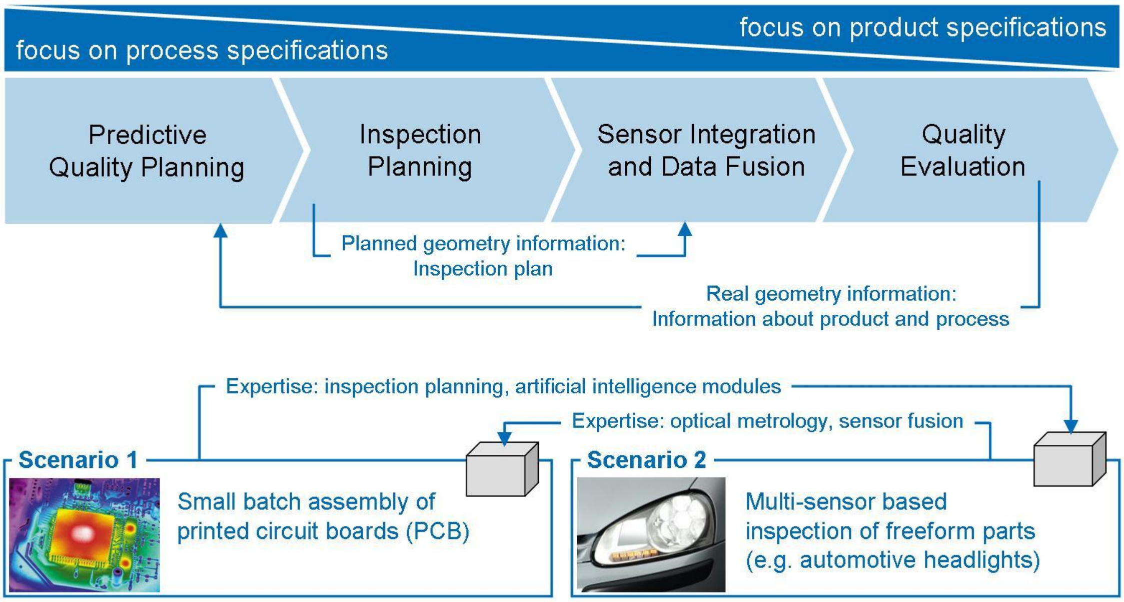


Figure 1.2: Steps to achieve Cognitive Production Metrology.

environmental conditions, so that the ramp-up time of the small production may be reduced.

The predictive quality planning will complement the dynamic inspection planning system (Figure 1.3). This tool will collect real-time performance data from the manufacturing system and use it to make a prediction concerning future behavior. For example, the predictive tool would collect data during the 10 first lots of a production and use it to make a quality prediction of the next lot. On small batch production, a trustable quality prediction tool can help to assure production success, allowing taking important decisions before the production start.

1.2.2: Inspection Planning

According to the current production state and product characteristics it must be provide an inspection plan for the current product. The inspection plan can be generated by analyzing the planned geometry information of the product contained on its model and the critical past inspection results of the product. It defines which main (critical) features of the product must be tested and inspected against its functionality and how these features could be measured according to sensor infrastructure available. For the case of small series production, the automatic definition of the inspection planning is a big challenge, due to the need for a dynamic redefinition of the sensors application, according to the product variant under inspection.

A new inspection plan must be generated each time a new lot is introduced. The inspection plan will be used to control process variables and to configure the optical metrology systems. While production is running, process and product information must be monitored. According to the status of this updated information, dynamical adjustments to the inspection plan will be performed, in order to optimize the inspection operation and to achieve optimum quality levels.

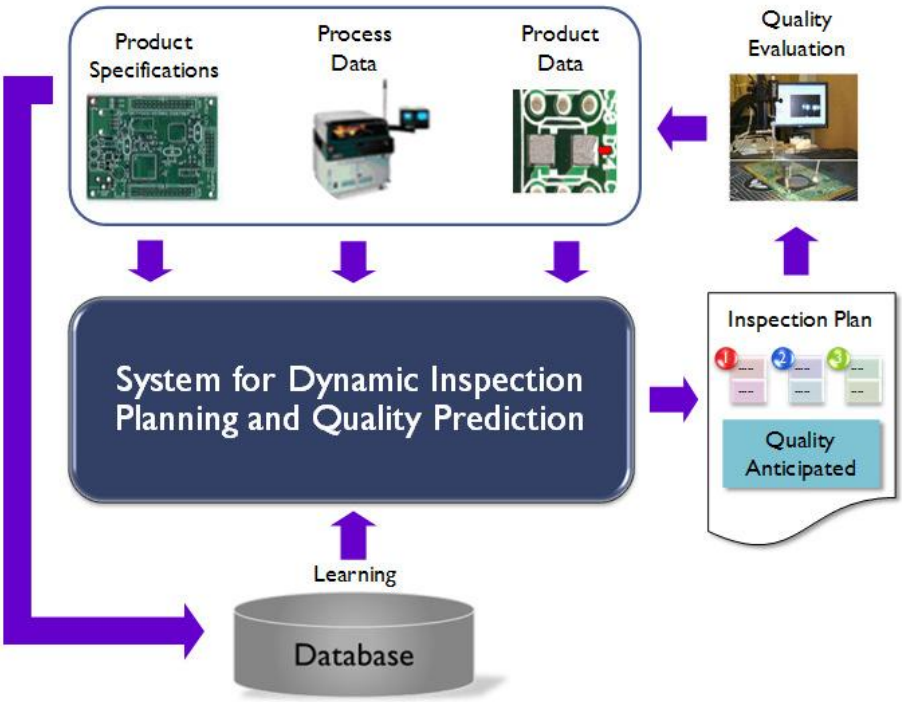


Figure 1.3: Overview of the system for dynamic inspection planning and quality prediction.

1.3: Objectives of this work

The objective of this work is to develop a routine of automatic setup of camera and illumination parameters at flexible inspection station. After identify the product model should be configured the type of illumination and the camera parameters to best highlight the defects of each kind of inspection to be realized on headlight.

1.4: Structure of the document

In the introduction of this document it was showed a little about the context of this academic project, the problems about the small series production, the cognitive metrology project, a cooperation between Brazil and Germany's institutions, and the main objective of this project.

Chapter 2 shows the state of the art related to this field of research, explaining technologies that are being used to solve the problem. In chapter 3 describes the machine and its characteristics, its internal systems and operations. Chapter 4 shows how was the machine and proposed a auto setup for camera and illumination systems. Chapter 5 shows how the validation was done and its results.

In the end, conclusions of the project and future works are commented.

2 Self-optimising systems

The recent research area of self-optimising technical systems strives for conceiving systems that are able to adapt themselves autonomously to new environment conditions, specially handling situations where new goals must be followed and the system must change its behaviour dynamically.

Self-optimising systems are intelligent systems that have the capability to react autonomously and flexibly to their surrounding environmental conditions, to the interference of the external user/systems, or also to their own dynamical behaviour by modifying their goals and adapting their parameters/structure in response to these dynamic factors. These systems are usually able to learn with their own experiences and remember from pasts events, which may help predicting new events and optimising their behaviour in future situations. By definition, self-optimising is characterised by the simultaneous and dynamic interaction of three factors [5]: 1) Analysis of the current system situation; 2) determination of the (new) system objectives; 3) adaptation of the system behaviour to the new surrounding conditions. Self-optimising systems are actually technical systems that are able to “think while acting” instead of “thinking before acting”.

By analysing the requirements that must be fulfilled by a self-optimising technical systems, it can be concluded that three main aspects are of extreme importance for conceiving such systems (Figure 2.1)[5]:

- *Flexibility and mutability*: to perceive the different relevant external stimulus from the environment and adapt itself to pre-defined or new work situations. **Sensor data fusion** is a relevant technology to fulfill these requirements;
- *Autonomy*: to react proactively against the environment changes and guide the system to desired and safe states of operation in an independent way, without the intervention of external operators. **Agent-based systems** allow introducing the desired autonomy factor for such technical systems;

- *Cognition*: to be able to learn from its own experiences, take intelligent decisions and act back to the environment in a safe an robust manner. **Knowledge-based systems** provide adequate tools to represent knowledge and allow reasoning and learning capabilities.

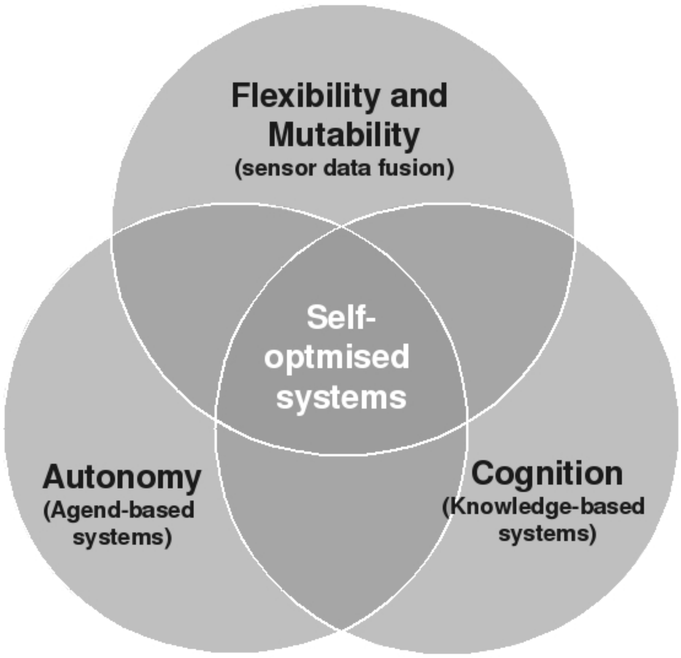


Figure 2.1: Synergistic combination of three important factors to achieve self-optimising systems.

The spectrum of self-optimising technical systems applications is vast, including automotive, railway, aeronautical and aerospace industries, energy management and the manufacturing field. Inside the scope of flexible manufacturing, self-optimising systems are more relevant for manufaturing and inspection requirements of small series production, by the synergistic combination of the above mentioned technologies (Figure 2.1).

2.1: Agent-based systems

Agent-based systems constitute a new research field, that is already considered as an important contribution for the flexibility improvement of manufacturing and logistic tasks in industry. Especially by flexible manufacturing systems, agents bring an innovative approach to split the responsibility of the accomplishment of different tasks, interacting constantly with each other in order to achieve the main goal, which is the production control. Modeling the manufacturing system using an agent-based approach strives for an autonomous and optimal use of resources and also for a reduction of the development time and complexity.

2.1.1: Agent and multi-agent systems

A simple and generic definition for an agent describes it as “anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators” [7]. In order to choose a specific action to be performed within its environment, the agent takes into account its current perception or even the entire perception sequence observed to date. That means that the agent behaviour is described by an agent function, which maps a given perception sequence to an action.

The agent concept provides a powerful tool for the development of complex systems with distributed functionality and interacting elements, which can be modeled and implemented as software modules. The development of software agents focuses on the decomposition and division of the whole problem into smaller autonomous agent elements (Figure 2.2), which follow some concepts in order to accomplish their local and consequently also shared global goals:

- *Encapsulation*: the status and behaviour of an agent are centralized within a unity (itself);
- *Goal-orientation*: agents orient their behaviour according to the goals they are meant to achieve;
- *Reactivity*: this is the ability to perceive its environment and react to it appropriately;
- *Autonomy*: this is the ability of controlling its own internal state and behaviour (decision taking). That means that the agent behaviour is defined by itself and not from any other external entity;
- *Proactivity*: this the ability to handle tasks in goal-oriented and anticipatory way (own initiative). Autonomy and goal-orientation are required, so that the agent can manifest this ability;
- *Interaction*: agents interact with each other in order to achieve their individual goals or to solve dependencies among them;

- *Persistence*: this is the ability to maintain continuously its own internal state during its life-cycle and decide for itself when an activity should be performed, independently from external influence;
- *Adaptivity*: this is the ability of an agent to adapt its behaviour according to its accumulated experience;
- *Intelligence or learning capability*: agents present learning capabilities when they are able to maintain, update and improve an internal model of their environment (knowledge base), meaning they can profit from their experience, plan and take decisions intelligently.

Most part of the conceived agent-based systems consists on multiple agents, which cooperate with each other, in order to solve their tasks. The flexible interaction between the agents imply in the following architectural requirements:

- the agents must be able to know if there are any other agents interacting in the environment;
- the activities performed by each agent interacting in the environment must be known;
- there must be a common medium of communication available for the interacting agents.

Following the FIPA (Foundation of Intelligent Physical Agents) Agent Management Reference Model, each multi agent system is provided with an Agent Management System (AMS), a Directory Facilitator (DF) and a Message Transport System (MTS). The AMS offers a kind of "white pages" service, where the identification and communication address of all agents of the system can be seen. The DF offers "yellow pages" services, where all the responsibilities, offered tasks and services of each agent of the system are described. The MTS represents the standard communication infrastructure used by agents to exchange messages among them and with the AMS and DF.

In flexible manufacturing environments, like small series production systems, agent-based systems introduce at least three positive factors:

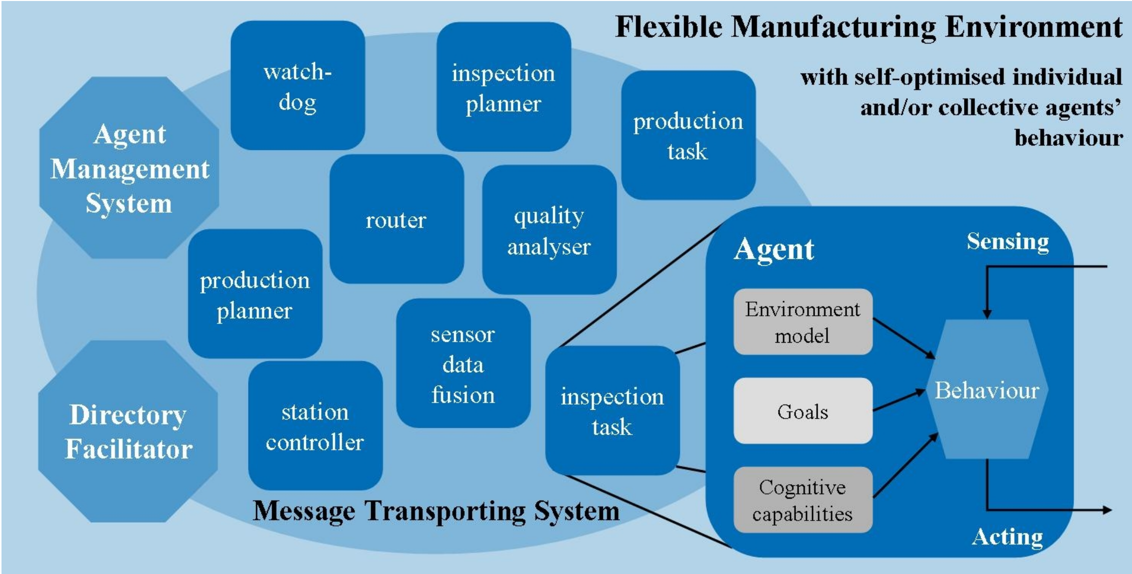


Figure 2.2: A possible agent-based model for a production system following the FIPA standards.

- the structure of an agent-based systems allows an easy insertion of new agents (software, hardware, complete production systems or inspection systems) to the current system, without the need of reprogramming its control logic;
- it allows basing the application over a distributed system with multi-platform characteristics and different type of hardware;
- the cooperation or competition among the different agents of the system brings a desired autonomy of operation.

In order to profit with such positive factors, agents must have their behaviour guided by some sort of cognition, which turn them capable of adapting themselves flexibly and autonomously into dynamic environments.

2.1.2: Classes of intelligent agents

Agents are grouped into five classes based on their degree of perceiving intelligence and capability [7]:

Simple reflex agents: simple reflex agents act only on the basis of their current perception of the environment. The agent behaviour is based on the condition-action rule: **if** condition **then** action rule. This agent function is only successful when the environment is fully observable.

Model-based reflex agents: model-based can be handle partially observable environments. Its current state is structured inside the agent which maintains some kind of structure that describes the part of the world that cannot be seen. This kind of agent keeps track of the current state of the world using an internal model. It then chooses an action in the same way as the reflex agent.

Goal-based agents: Goal based agents are model-based agents which store information regarding situations that are desirable. That allows the agent a way to choose among multiple possibilities, selecting the one which reaches a "goal" state.

Utility-based agents: Goal-based agents only distinguish between goal states and non-goal states. In the case of utility-based agents it is possible to define a degree of desirability for a particular state. This degree can be obtained through the use of a function which maps a state to a measure of desirability.

Learning agents: Learning agents are agents that initially have a "knowledge" and a set of rules that determine their behaviour. This type of agent can start their lives operating in unknown environments and then become more competent as their knowledge evolves and as they gain more "experience".

2.1.3: Agent environments

Environments in which agents operate can be defined in different ways. It is helpful to view the following definitions as referring to the way the environment appears from the point of view of the agent itself[7].

Observable vs. partially observable: To be considered an agent, some part of the environment, relevant to the action being performed, must be observable. In some cases (particularly in software) all the environment will be observable by the agent. This kind of environment, while useful for to the agent, will generally be true for relatively simple environments.

Deterministic vs. stochastic: An environment that is fully deterministic is the one in which the subsequent state of the environment is wholly dependent on the preceding state and actions of the agent. If an element of interference or uncertainty takes part, them the environment is stochastic. Note that a deterministic yet partially observable environment will appear to be stochastic to the agent.

Episodic vs. sequential: This refers to the task environment of the agent. If each task that the agent must perform does not rely upon past performance, and will not affect future performance, then it is episodic. Otherwise it is sequential.

Static vs. dynamic: A static environment, as the name suggests, is one that does not change from one state to the next, while the agent is considering its course of action. In other words, the only changes to the environment are those caused by the agent itself. A dynamic environment, otherwise, can change its state.

Discrete vs. continuous: This distinction refers to whether or not the environment is composed of a finite or infinite number of possible states. A discrete environment will have a finite number of states, however, if this number is extremely high, then it becomes virtually continuous from the agent perspective.

Single-agent vs. multiple-agent: An environment is only considered multiple agent if the agent under consideration must act cooperatively or competitively with another agent to perform some task or achieve some goal. Otherwise another agent is simply viewed as a stochastically behaving part of the environment.

2.2: Cognition and Knowledge-Based Systems

The insertion of cognitive capabilities into technical systems is desired especially for enabling such systems to take more intelligent decisions. The implementation of cognitive strategies makes extensibility use of knowledge-based systems, which provide the basis for knowledge representation, inference and learning skills that contribute for enabling adaptive capacities for technical systems.

Especially in the engineering and informatics fields, much of the work around the theme cognition, concentrates on investigating, modeling and developing technical systems (hardware and software systems) that are be able to perceive, to reason, to learn, to plan, and to act, in order to cope with what is currently happening. In this sense, much of this cognitive works are performed in sub-areas like mechatronics, information technology, control theory, artificial intelligence, sensor data fusion and smart sensor networks.

The following cognitive concepts are expected in intelligent technical systems:

- **Perception** is the acquisition of information about the environment and the current object under study. Part of this information is processed and new relevant features and information can be generated from it;

- **Action** is the process of generating behaviour to change the surrounding environment and complete the tasks that were designated to the system, according to the decisions that were taken about the environment perception;

- **Knowledge** consists of both a declarative and a procedural instance. Declarative knowledge means recognition and understanding the real information known about objects/events in the environment and their inter-relationships. Procedural knowledge handles the information regarding how to execute a sequence of operations;

- **Learning** is the process of acquiring information and reorganising it in order to derive new knowledge. The learned knowledge can relate to skills, experience, or being taught. Learning causes a change of behaviour that is persistent, measurable and specified. It is a process that depends on experience and leads to long-term changes in behaviour.

- **Reasoning** is a cognitive process by which an individual or system may infer a conclusion from an assortment evidence, or from statement of principles.

- **Planning** generates representations of future behaviour, to constrain or control current behaviour. It comprises reasoning about the future in order to generate, revise or optimise the intended course of action.

The challenge for introducing cognitive aspects to technical systems is the difficulty to provide them the abilities of reasoning about the knowledge they are able to perceive, learning from its past experiences, and responding robustly to surprises. Most successful approaches to introduce such capabilities into technical systems come from the research field of artificial intelligence, where different kinds of knowledge-based systems are used for such purpose.

The different knowledge-based system approaches are based on a common core structure consisting of a knowledge base, where important informations about the environment and generated by the system are stored. An inference component will process the system knowledge to reason and take intelligent decisions.

A knowledge base can be created with different kind of acquired or previously known information, which are usually expressed in two different classes:

- Case-based knowledge: this is a kind of knowledge based only on the current observed informations. It consists of facts (evidences), which result from observations and investigations about the problem/environment situation;

- Rule-based knowledge: this class represents the main part of the knowledge base, and consist of:

  - Specific knowledge, which represents the information about the investigated problem, from where the case-based knowledge information is processed. It may be theoretical technical knowledge about the system or also know-how acquired with experience;

  - General knowledge, which represents general solution heuristics or rules for optimising performance of the system, or even general knowledge about objects of the real world and their relationships.

The cognitive capabilities and knowledge-based systems can bring a lot of benefits to the research field of flexible metrology and cognitive quality management. They can help in the prediction of adequate process parameters and quality indexes, by the generation of automatic production and inspection plans according to the changes of the products and production demands, or even by the dynamic adaptation of the manufacturing and inspection system to the new product or environment conditions.

3 Description of the machine

The use of resources and time of using machines has been one the worries of the companies on last years. To optimize the use and make production cells more capable to performing different tasks at the same time. It need flexible, adaptable and intelligent machines. That way the production size of each product is smaller and different each day, resulting in difficulties to schedule and control the production.

3.1: About the Machine

This machine was developed by the System and Automation Company, located in Belgium. The Hella Company, one of the largest suppliers of parts for the automotive industry, bought this machine to use at end of the production line to check the quality of the headlights.

The machine did not work as was expected. Some problems happened: the machine was not "smart" enough do deal with small series production; have problems with pallets position inside the machine and this is cause of delay time in the inspections; and too much false rejects was happening on inspections. After detected these problems, Hella Company has donated this machine to WZL to make researches to turn this machine more properly to small series production.

Then a new way to achieve the requirements were searched and a multi-agent system was proposed and implemented to control the machine. With this system it was possible to flexibly move the pallets through the stations of the machine and perform inspections on products.

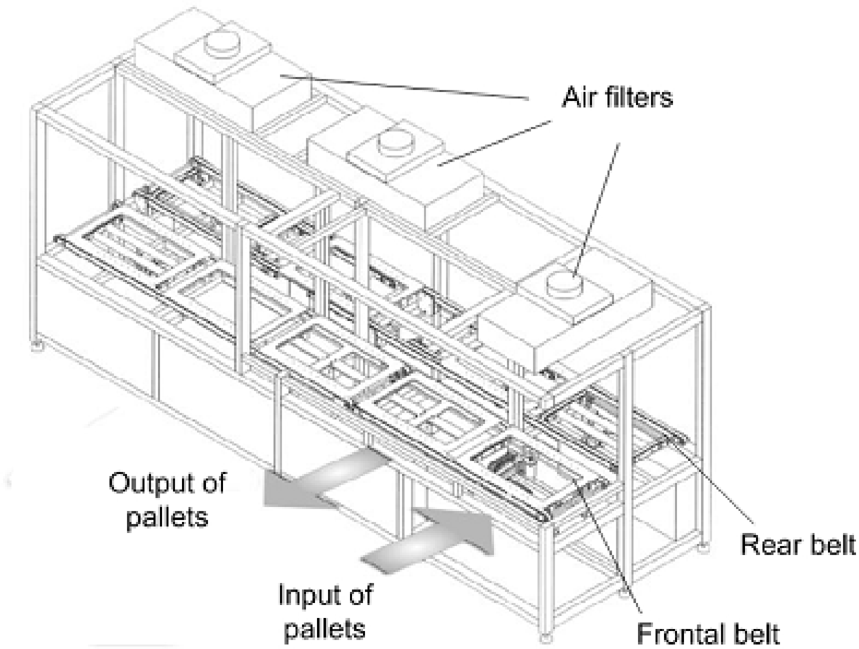


Figure 3.1: Perspective view of the machine.

3.2: General overview

To be transported inside the machine, the products are placed on pallets. The pallets are transported through the machine with the utilization of conveyor belts and elevators. There are, currently, three inspections systems in the back part of the machine: one to inspect scratch problems, one to inspect surface problems, and one machine vision system that allows more than one type of inspection on a product. The inspection systems to address surface imperfection and scratch problems work with a line camera, an elevator to move up the pallet, decoupling it from the main conveyor belt, and a conveyor belt that moves the pallet while the camera grabs the image. The machine vision system has an area camera and a big variety of illumination types. To minimize problems with dust and other particles in the air, there are three air filters over the cameras. Figure 3.1 shows a general view of the mechanical design of the machine.

There are distributed applications for controlling the whole machine. Two of them are installed in dedicated industrial computers and they are responsible for operating the VIGILE Scratch System and the VIGILE Wave System.

The inspection machine and its systems are controlled by a PC-PLC (Programmable Logic Control) framework, installed on a desktop computer.

The previous multi-agent system installed to control the machine worked with many different types of agents: a router agent, a stations agent, a product agent, a planner agent, a quality agent, a security agent, an inspection agent. The station agents were responsible for controlling through actuators and sensors. Whereas the router agent was responsible for calculating the best route and for transporting a pallet from one station to another. The request for a product transportation was done through an user interface where it was possible to chose the origin and destinations.

What is intend to be developed now, is an automatic setup routine for the multi-inspection station. After to identify a product this station will receive all the parameters of camera and illumination to do a inspection based on the features of the headlight. After that, the inspections on the product will occur, according the inspection plan.

By the system start up, a GUI (Graphical User Interface) it shown. In this interface there are options available to allow requests tasks from the system. A task can be ordered to a single product or it can be ordered to all products inside the machine. The four main options are: move a pallet/product from one to another, recognize product(s), inspect product(s) and manual inspection in a specific inspection system. The current place of each pallet and current state of the machine (which conveyor belt, cylinder or sensor is on or off) also it shown on the interface. After the product inspection, the results of the quality evaluation it shown on the screen.

3.3: Hardware description

The main hardware elements installed in the machine are:

- Soft PLC from Beckhoff Automations (norm IEC 1131), installed in a computer (called "PLC server"). The I/O unit is connected to the computer through an optical Fieldbus Network;
- 2 x Industrial computers connected to the Ethernet Network;
- 2 x computers, being one connected to the Ethernet and Fieldbus networks and the other being only connected to the Ethernet Network;
- 2 x line cameras SP14-02K40 Dalsa;
- 2 x Horizon LINK framegrabber board from i2s (Innovative Imaging Systems);

- 1 x area camera 8 Megapixels AVT Oscar F-810C;
- Several illumination modules (backlight, ring light, darkfield, ...);
- 1 x Embedded Vision System, a computer dedicated for image acquisition and processing tasks.

3.3.1: Stations and slots

The machine was conceptually divided in slots. A slot is a place that can be occupied by one pallet. This is due to a fact that physically two slots can overlap. In fact, this occur because the machine was originally built for only two inspections systems. And the retrofitting of the machine, with the integration of new sensors led to this case.

One or a group of slots forms one station. A station is formed by slots that similar functions. According to Figure 3.2, the machine is divided in the following way:

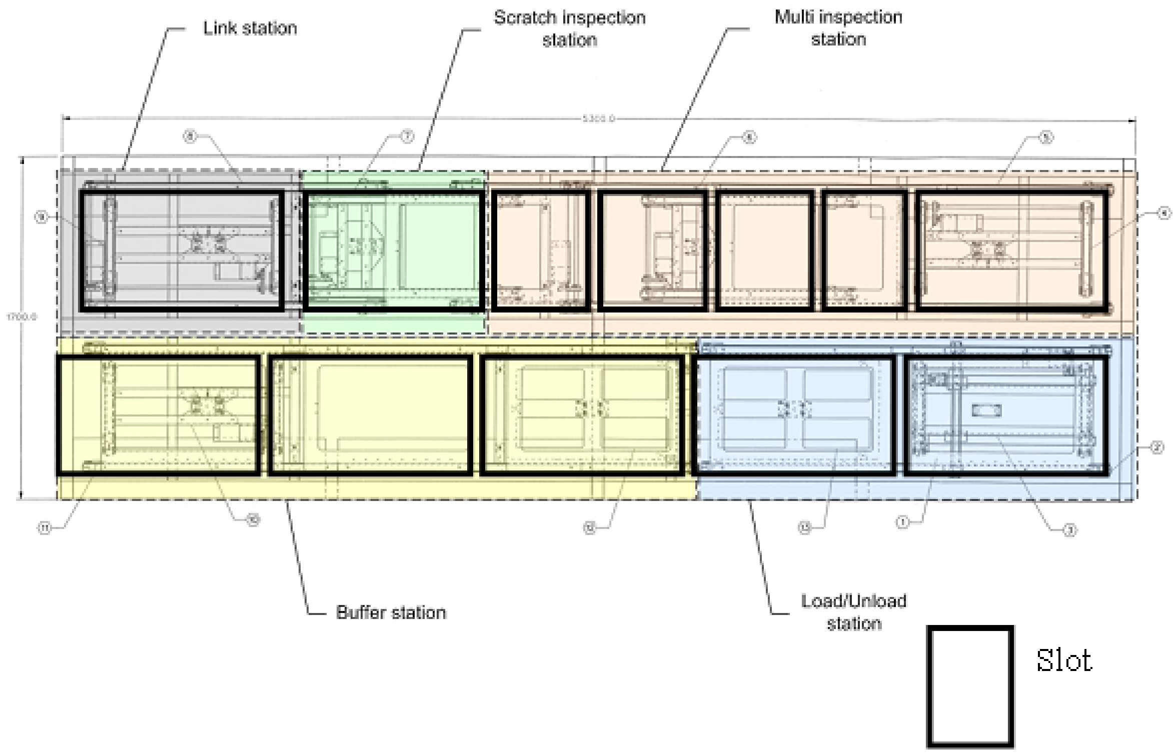


Figure 3.2: Top view of the machine, and location of each slot and station.

- Multi Inspection Station: is where most part of inspections systems are installed. it has five slots. the first is for pallet transfer from the front part to the rear part of the machine, while the others are for inspection systems. There is a Flexible Machine Vision system installed at the second slot, the VisiWave system installed at the third slot. The last, two slots are available to install, in the future, a Time of Flight system and a Stereo system.

- Scratch Station: This station has only one slot, and the scratch inspection system is installed.
- Link Station: is formed by one slot, which connects the rear slots machine to the front slots.
- Buffer Station: is composed by three slots. The station works as a buffer for the inspection machine. It can store pallets that will be inspected or pallets that have already been inspected.
- Load/Unload Station: is where the pallets enter and leave the machine. It has two slots, one for loading and another for unloading pallets.

3.3.2: Computers and Networks

The machine is equipped with two personal computers, two industrial computers, one image acquisition and processing dedicated computer, one Ethernet network and one Fieldbus network (Figure 3.3).

Inside the PC-PLC Server is where the TwinCAT control system is running and it is responsible to control the hardware of the machine, through the Fieldbus network. In the industrial computers were installed the software applications for the VIGILE inspection systems, the personal computer is used to run the MAS and the Embedded Vision System (EVS) softwares for image acquisition and processing are installed, and is connected to imaging systems through Firewire.

3.3.3: Softwares

Multi agents system (MAS) was an approach proposed by [8] in order to create a flexible machine control system. The goal of multi agent systems is to find methods that allow building a complex system composed of autonomous agents, who while operating at local scope, with limited knowledge and abilities, are capable of solving the desired global behaviour. This proposal proved to be successful in making the machine more flexible for adding new inspections or services.

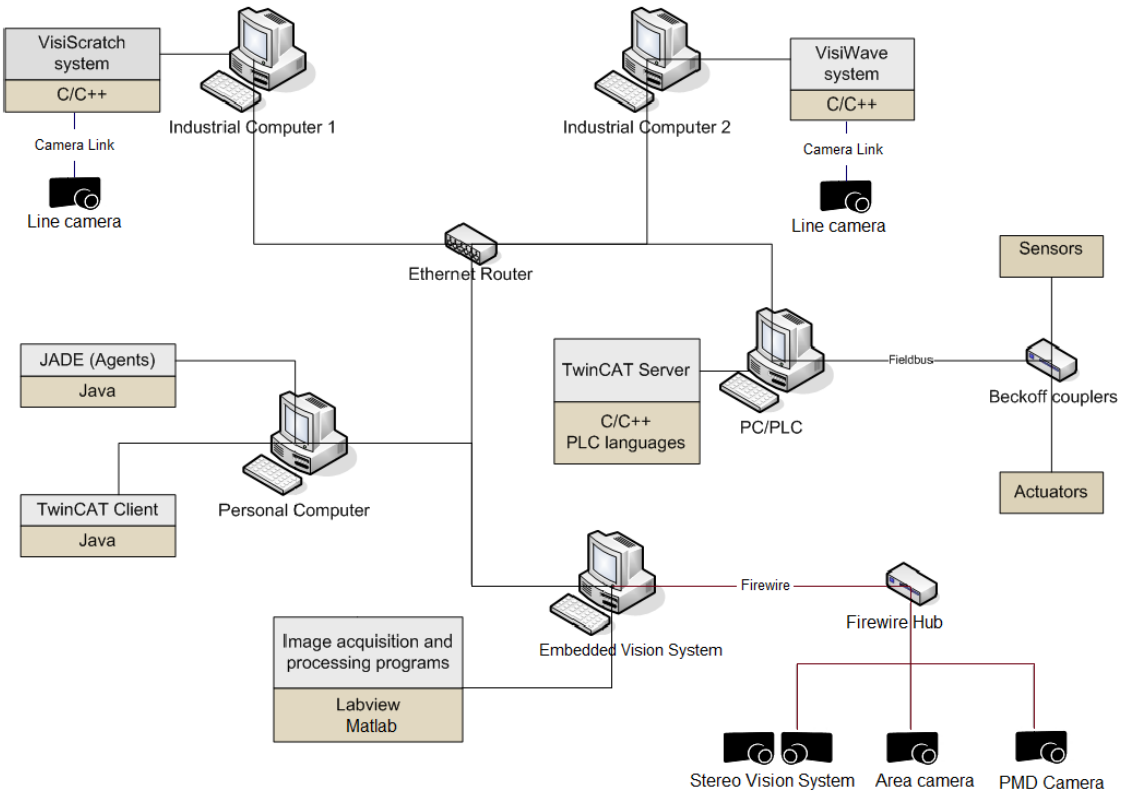


Figure 3.3: Layout of the computer network installed in the machine.[4]

3.3.3.1: Multi-agent system as control platform

Small series production high variety of production, with low-volume of each of the products. Also, product development and production happens almost in parallel. This requires that the system must adapt itself to these changing conditions, i.e. it must be ready for the next batch quickly as possible. To cope with this challenge, inspection systems have to be flexible and adaptive, enabling many features to be inspected and also allowing new sensors to be installed.

Each inspection system could be seen as an agent. So, to add a new inspection system to the machine, it will be only necessary to create a new agent to control it, and to register its inspection services in the system, without the needing of reprogramming the existing control code of the machine. When some product needs to be inspected by this new inspection system, it only needs to request to the system what agent can provide the service. And this works not only with inspection systems. When something must be added to the system, that has a specific purpose, it can be encapsulated in an agent and have its services registered within the system [1].

Each station was modeled as an agent, being responsible for actuating over the transport system. i.e. the conveyor belts. Also, each product is modeled as an agent, carrying the information regarding product type and inspection results for each product. Other important agents are the *RouterAgent*, who is responsible for choosing the best path for the desired destination of the requesting product; *PlannerAgent*, who is responsible for determining which inspections has to be performed in the requesting product; *QualityEvaluationAgent*, who decides if the product has an defect or not; *InspectionConfigurationAgent*, who set up the illumination configuration for the desired inspection and the *ImageAcquisitionAgent* who performs the image acquisition task. For the implementation, JADE Framework was used.

3.3.3.2: Operation mode

The control platform enables the machine operation in two different modes:

- Manual;
- Automatic.

The manual operation mode, allow tests to be performed in the machine. This mode requires an intensive interaction of an operator. Each action is selected individually. When the action is completed, the machine waits for the next action.

Possible actions to be performed are move, recognition and inspection. Move just transports a pallet from one station to the desired. By calling this action, the machine organizes itself to reach the desired station, i.e. when there are other pallets blocking the way, the agents change messages and the blocking agents are also moved to a station where they do not interfere.

Recognition is the action to recognize the product in the pallet. In this action, the pallet is transported to the multi-inspection station, moving any other pallet that is blocking the way, and there the data matrix present in the pallet is grabbed by the flexible machine vision system and processed, in order to recognize the product. Once the product is recognized, the *ProductYAgent* (where Y is the product number associated by the machine) checks the *products.xml* file, to load which inspections are associated with this product.

Inspection performs the selected optical inspection. In the manual mode, it is possible to inspect a product by any inspection system, even without performing a recognition before. This is because manual operation mode is meant to be used for tests.

As the machine is excepted to operate in an industry as an automatic inspection machine of a production line, an automatic mode was also developed. In this mode, the product will be first recognized by the inspection systems. Then, the Product Agent will receive an inspection plan, that is dynamically generate by the Planner Agent. Finally, the Product Agent will be inspected by the necessary Inspection Agents and have its quality evaluate by the Quality Agent.

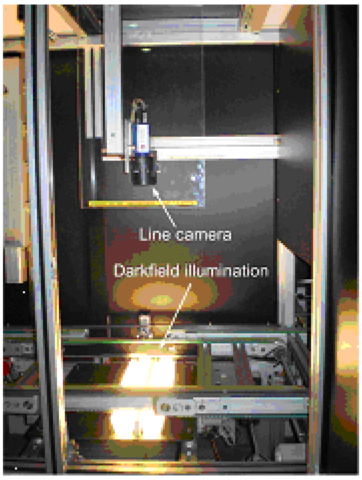
3.3.4: Inspection Systems

The inspection machine is equipped with three different inspection systems. Two of them were originally installed in the machine: the VisiWave system and the VisiScratch system. The other system was design to be as flexible as possible, allowing the acquisition of images with different kinds of illumination.

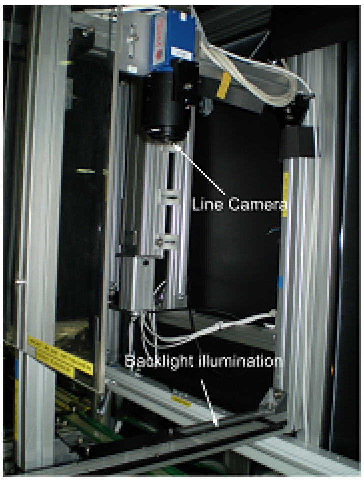
3.3.4.1: VisiScratch and VisiWave systems

The VisiScracth (Figure 3.4(a)) and VisiWave (Figure 3.4(b)) systems are very similar. Both have a SP14-02K40 camera from the Dalsa Company (linear camera), a Horizon LINK framgrabber board from i2s, a cylinder with a conveyor belt on it, and proximity sensors. The big difference between them is related with their illumination. The VisiWave system has a *back-light* illumination whereas the VisiScratch system has a *darkfield* illumination for enhancing different kinds of product features.

Line cameras can only grab a single image line. To build the entire image of a product it is necessary that the product keeps moving while the camera is grabbing. This is possible through the utilization of the elevator and the conveyor belt that the inspection systems have. The elevator lifts the pallet and then the conveyor belt is turned on. The speed used to acquire the image is defined by the synchronization of the conveyor belt speed and the frequency that the camera grabs the image. The proximity sensors installed inform the inspection system when it must start and stop grabbing image lines.



(a) VisiScratch system



(b) VisiWave system

Figure 3.4: Original inspection systems installed in the machine.

3.3.4.2: Flexible Machine Vision

To give more flexibility for this machine and also to allow the inspection of more features on products, it was designed a special machine vision system with different kinds of illumination (Figure 3.5). The illuminations are turned on through the combination of outputs in the PLC. The camera type that is used in this inspection system is an area camera 8 Mega pixels AVT Oscar F-810C, and the illuminations available are: *back-light*, *darkfield*, *brightfield*, *ring illumination* and *spot light*.

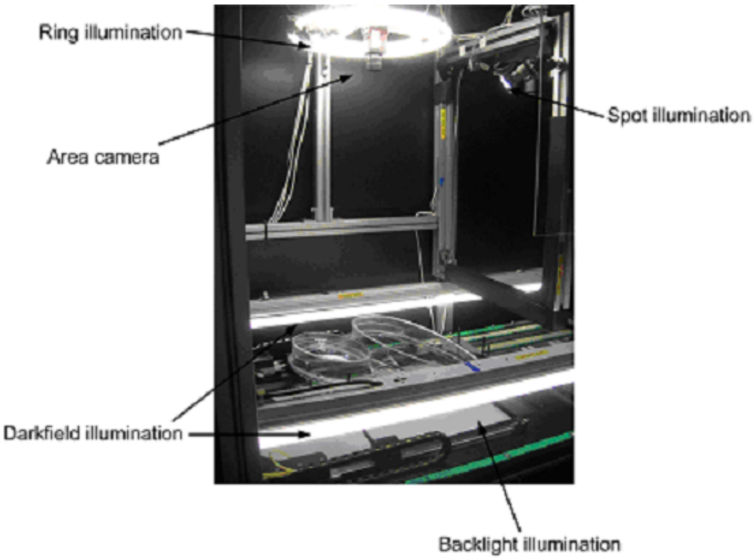


Figure 3.5: Machine Vision system.

3.3.4.3: Embedded Vision System

For a more efficient image acquisition and processing, an Embedded Vision System (EVS) from National Instruments (Figure 3.6) was integrated to the machine network. This EVS has inputs for Firewire and Gigabit Ethernet cameras. Through these inputs, it is connected with the flexible inspection system camera.

Figure 3.6: National Instruments EVS.

This device runs a Windows 7 with LabVIEW program that can easily communicate with these cameras. This program is responsible for image acquisition and processing. The LabVIEW interface can be seen on the Figure 3.7.

Figure 3.7: LabVIEW interface with the headlight's processing.

3.3.5: Machine Vision Illumination

In machine vision the importance of illumination, generally, is underestimated. It is very difficult to choose between illuminations techniques, which is better for each situation to get the right light to emphasize the features of a part.

It is the most critical part of an imaging system. Cameras are far less versatile than the human eye and lighting conditions need to be fit and optimized for a camera to pick up details that the human eye can often detect in uncontrolled conditions. This is particularly so when dealing with complex shapes/reflective components.

In this machine there are three sort of source of lights: fluorescent, halogen and LED. These source light are available within different techniques of illumination.

3.3.5.1: Dark Field

Dark field illuminators provide effective low-angle lighting to targeted regions. These machine vision lights enhance the contrast of surface such as laser embossed or engraved marks or surface defects.

Figure 3.8: Embossed logo on a metal surface: Low angle illumination provides a high contrast [9].

3.3.5.2: Ring Light

Ring lights are a cost-effective, easily integrated solution for diffuse illumination of surfaces. With subtle adjustments to working distance and angle of light delivery, ring lights can deliver good image contrast for a minimal investment. Packaging and mounting advancements put the emphasis on durability and versatility for use in any lighting application.

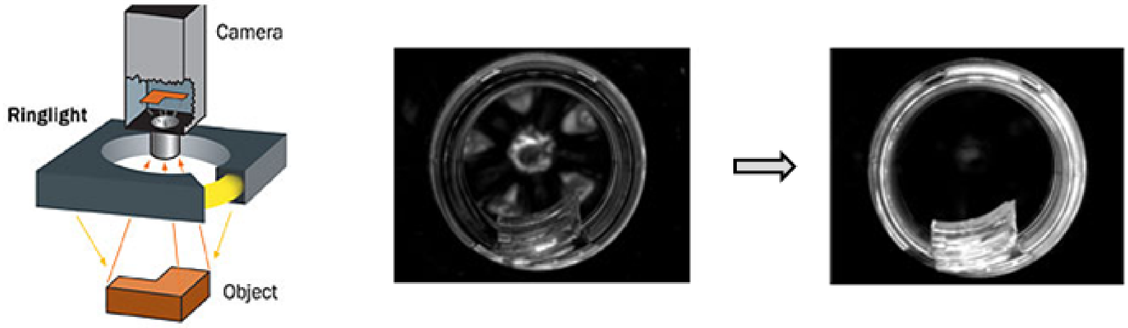


Figure 3.9: Plastic bottle: Defect on top of a plastic bottle is clearly identified.[9].

3.3.5.3: Back Light

Back light illuminators provide sharp contrast to outline a part's shape, find edges and view openings such as drilled holes. High intensity and uniformity are packed into a low-profile industrial package for optimal thermal management.

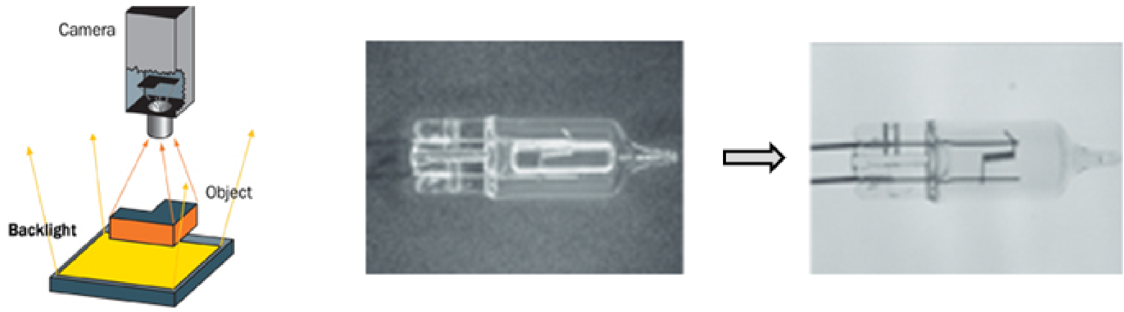


Figure 3.10: Light bulb: Resulting image clearly shows silhouette of filament inside the bulb [9].

3.3.6: Camera and Lenses

Originally the machine came with a Oscar F810-C 8 Megapixel and a 8 mm lens. This configuration was not flexible enough, because was not possible to change features like focus, zoom and iris automatically.

In the previous work [2] a program was written to work with automatic lens and the Oscar camera. The model of this lens is a Pentax C52546-C6ZM-5P [10], with 3 motors and its use is normally dedicated to security systems but it has some interesting tools like to control focus, zoom and iris that could be use in machine vision.

Therefore it was decided to work with this lens, but there was a problem with

(a) Motorized Lens (b) Spacer rings

Figure 3.11: Pentax lens motorized and Spacer rings.

the minimum distance object that is 1.0 meter and the station has no more than 0.85 meter in height, starting from the headlight. A solution was to use thin spacer rings, which increases the distance between the camera and the lens, decreasing th minimum distance of an object.

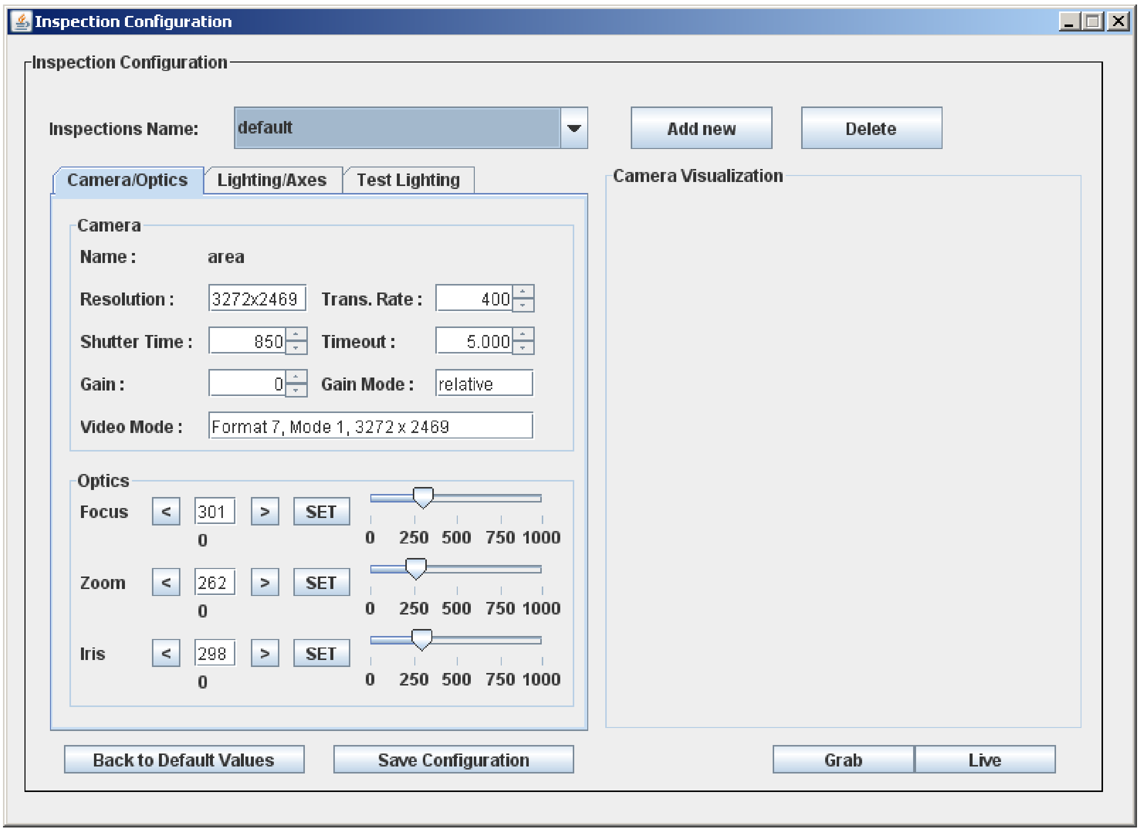


Figure 3.12: User interface of the Inspection Configuration.

The Figure 3.12 shows the interface to control the camera parameters, where can be changed the focus, zoom and iris automatically. This allows pre-configuring a setup depending of the product and changing it without having to manually assembly the system, thus increasing much more the flexibility.

4 Development of Auto Setup

This chapter will describes how was the development of a automatic setup routine for parameters of camera and illuminations in the flexible inspection station. Initially will shows the state of machine at start of this project and then, what were need to fix before to start the goal of this project.

4.1: The machine issues

Many academic studies are developed in this machine for more than 5 years to improve and do the machine more flexible to deal with small series production.

The previous works describe a complete sequence of functionalities, i.e. how to operate and get the results from the machine. Though, when we started to developed this project not everything worked how was described on previous reports.

When we start to operate the machine a series of non-expected problems occurred. These problems and his solutions are described in the sequence.

4.1.1: Automatic Inspection

The automatic inspection, it is the sequence of operations to recognize, do inspections and return results of one product. This sequences of actions was not working properly. Once the process started, pallet was transported to flexible inspection station, then when the process of recognition was done, the pallet was kept stopped into the station. The operations in sequence were not run.

In the Flexible Inspection Machine code, was tracked a fail between the messages changed among the agents. In the class "Automatic Inspection Behaviour" where the "Data Matrix" image is sent to EVS computer to be interpreted and the message with this information is sent back after the recognition process was not being use to give the name for product under inspection. This lack caused the processing halting.

The parameter with the right message was selected. Now, the information is used to nominate the pallet/product and the complete sequence of automatic inspection is performed.

4.1.2: Processing and Evaluation on Wave and Scratch Systems

The machine are doing the complete transportation of pallets between all the inspections systems, though the results at EVS computer shows different images from that ones are captured. And consequently, when makes the analyses, do over wrong images.

On the Labview script was detected that image captured by the *VisiWave* and *VisiScratch* system doesn't used to do the evaluation quality. What is happens is the image acquired by systems is saved, and the *ImageAcquisition* agent sends a message to EVS system but this message is never read by EVS. Actually the image evaluated was done over one stored in the EVS computer, not that one acquired. The EVS did the evaluation over this old image, and shows the results about it.

A sub routine was added on Labview script “Evaluation:wave”, “Evaluation:scratch” to save/load the actual image instead to use the stored one. Now, the “Processing:wave” and “Processing:scratch” are picked up the correct images to do the evaluation and shows the correct images at EVS computer.

4.1.3: Data Matrix

The products recognition is done through a Data Matrix code located over the pallet. When the pallet is inside the Flexible Inspection Station this code is grabbed and sent to EVS where it is processed. The problem is, this image captured was not on focus and it was very difficult to read the DMC at EVS. Frequently, the code was not readable or was read with a wrong content. Then the data needs to be inserted manually.

First, was detected that lens installed at Flexible Inspection station was the old model, a non-motorized 8 mm lens. Then, we change the lens for a motorized 12 mm lens. This motorized lens have a problem with the minimal focal distance. The support of camera and lens inside the machine has only 90 cm of height, and after installed the distance between the lens and the headlight is less then 75 cm. This 12 mm lens need at least 1 m of distance focal to acquired a good quality image.

To solve this situation was introduce a spacer ring between the camera and lens. We tested spacer rings of 0.25 mm, 0.5 mm and 1 mm. The best results were obtained with a 0.25 mm spacer ring, this spacer ring allows to capture good quality image of the DMC and it is possible too capture an image of whole pallet.

After solve the lens problem and made the DMC readable. It is necessary to send the message from EVS system to a agent who is label the product with the right information. The message come from EVS to ImageProcessing agent, who is responsible to label the pallet, in this way, the other agents know what inspections this product needs.

4.1.4: Lightning system

The lightning system at Flexible Inspection station is controlled by a PLC, but the LED module is not under PLC control. This module is controlled over a serial port.

All the lights are described by their address at PLC. However, the LED module has added in latest year and works manually, in the other words, the XML file that defines the inspections and illuminations systems can't setup the LED module. So, when an inspection is request and we need light, the LED module just turn on in the first color, in our case, red.

To the LED module works together with the other light was need to change the XML writer and parser to interpret the code for the LED module. In this way, now it is possible to set and save different colors to LED module and it is possible to read this from XML file and then get the right setup to do the inspections.

4.2: Auto setup

The auto setup is an configuration for the lens and illumination parameters of Flexible Inspection station. After an product has been identified by the Image Processing agent. The flexible inspection station should be prepared with this parameters to do the image acquisition for the desired inspections.

We modify the current agents behaviours to add this services. First we changed the Image Processing agent, now after to receive the information in the DMC from the EVS system, this agent call a Bayesian agent.

The Bayesian agent was developed and added by a master student of the project, Camila Pontes. This agent receives the product name and based on the weights and results of evaluations from previous inspections, it return the parameters to setup the lens and lights of Flexible Inspection station.

The lens parameters are: focus, iris and zoom. This parameters values are send to Inspection Configuration agent, who is responsible to set these parameters in the hardware.

4.2.1: Scenarios

The scenarios are set of values to focus, iris and zoom, and types of illuminations that are used to do an inspection. We were predefined four scenarios, these scenarios were chosen among a many possibilities of parameters because you can combine the parameters and create thousands of scenarios. The four scenarios (table 4.1) chosen are that ones we considered good enough for each kind of inspection and it depends of course the characteristics of each headlight. The scenarios are save in the XML file, called Inspections.

The Bayesian agent was trained with the number of defects found in each kind of inspection as being the parameter that define if an scenario is “good” or “bad” for a headlight inspection. When a determined scenario finds more defects than another, this scenario is marked as better for inspection that kind of headlight.

Table 4.1: Parameters of scenarios for auto setup.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Focus	650	330	500	700
Iris	770	550	400	300
Zoom	350	400	550	700
Lights	LED Green	Led Stripes 5	LED Red	LED Blue
	RL 10	Spot 5	DF 1	Spot 5
	RL 11	Spot 6	RL 12	Spot 6
	RL 12	RL 10		

The Bayesian network agent receives the feedback after each evaluation to keep the network updated. This message came from EVS system and contain the number of defects found at determined scenario with this information the Bayesian network rebuild your choices.

5 Evaluation

The evaluation of auto setup was made over the communication between agents, in other words, if the messages were received and sent and if the correct settings were applied on hardware.

The message with the model of product is receives from the EVS system by the Image Processing agent, and it is resend to Bayesian agent. The Bayesian network processing the data for to choose the best scenario and sends this message to Inspection Configuration agent.

This agent call the routines to make the desire setup, turn on the lights and move the lens to the desired parameters. Normally this happen in less then 30 seconds, it depends how many lights need turn on.

The scenarios have only the purpose to test the changes of parameters and doesn't represent the best choices to inspect the headlights, mainly because the evaluation system need to be improved.

6 Conclusion

The Hella machine was a great challenge to work. Before start the development of the project was need to fix the machine and this was the most difficult part because the previous documentation was not complete. This build reverse to tracking the functions and make the machine work at minimal way to bring the machine to the mode where it to able to really develop new functionalities.

The auto setup routine showed the possibilities to keep improving the machine to make more flexible and with capabilities to receives new models of products in a easy way. The Bayesian network it is a good approach to put new models on the machine. But, each model needs to be trained during a time before be able to run on the machine.

6.1: Futures works

There are many issues to be developed in the machine like the recognition of product, needs to be improved by changing the recognition of product by a DMC to do with a real vision machine and do the recognition of product by the shapes.

The hardware control could be improved to make the pallets able to run in both directions. And new other inspections systems could be installed like as a 3D vision, to make easy the shapes recognition.

The process to evaluate the images need to be improved, mainly in the classification of defects. It is important to find the exact number of defects because this is the main key to select the scenarios.

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