Industrial Vision State of the Art

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Abstract. This paper presents the state of art of computer programs capable of assisting with vision in an Industrial site and its main topics. It also describes the development of an expert system to help the human decision in the computer vision field to integrate an optimal lighting and optics for an assembly line.
The aforementioned system will aid with light, lens and environment adjustments by pointing out their ideal setup thus providing an optimised and effective inspection of a certain object. The specific type of object meant to be inspected will drastically influence the configuration required due to its characteristics as well as the main objective of the production line, be it the detection of contours, colours, among others...

Keywords: Expert System · Expert · Knowledge · Artificial Inteligence · Knowledge Base · Inference Engine · Computer Vision.

1 Introduction

Expert System (ES) are computer programs that use Artificial Inteligence (AI) to mimic the knowledge and behaviour of human experts on specific topics. ES' are meant to help non-experts make better decisions without the need for the experts' constant presence, even so, they are not meant to completely replace these experts whose knowledge they mimic.
These systems have two parts, firstly a knowledge base, and then an inference engine. The knowledge base is composed by facts and rules described by the expert, the inference engine then applies these rules to the known facts to get a conclusion.
These systems are of course very specific to whatever field they pertain [1] [2].
Machine Vision (MV) and the field of AI are still relatively new technologies, but both have already moved past the experimental state and are now an industrial reality.
MV improves efficiency, quality and reliability of defect detection, an excellent optical illumination and suitable image acquisition are the prerequisites for obtaining high-quality images. Those systems are solving manufacturing problems in various types of industry.

The usefulness of a MV results on a improvement of the overall efficiency, since it reduces the need of an expert, which can be using said time improving

other parts of the production [3].
The lack of attention and care to lighting and optics may cause many failures and wrong classification of the proper parts (false-positives and false-negatives). With the wrong classification due to lack of image quality, it might result to a sales lost and hurt the reputation with the consumers. So, proper implementation of MV processes in an industrial context mandates that the input images fed to the MV models be as standardised and controlled as possible. Therefore, the development of an ES which aims to aid in solving MV problems regarding lighting and optics is important, and can save time and money.
This paper focus on a state of the art which will give guidance to a complete setup for industrial vision production lines. All the setup characteristics will be discussed in section 2. Section 3 focuses in describing some technologies that can be used to develop a ES. Then, in section 4, some solutions will be described, as well as our own.

2 Setup characteristics

A conventional industrial visual inspection system mainly consists of three modules: optical illumination, image acquisition and image processing. Cameras are used to transfer the target objects placed in the light field and transmit it to a computer. This represents the core element of visual inspection where the quality is very important [3] [4] [5].

2.1 Lens selector

It's relevant to know the size of the object being supervised to implement the most adequate lens.
The Focal Length (FL) of the lens can be calculated trough the Field of View (FOV) of the camera with the distance of the object that the camera will operate. This FL will dictate the lens size to be used so the object can be on focus. The Equation 1 shows how to calculate the FL [6].

$$FL = \frac{distance * sensorSize}{FOV} \tag{1}$$

For example: if we have an object of size 100 mm (FOV), the camera is mounted 550 mm ($distance$) of the object and the $sensorSize$ is 4,8 mm (1/3", typical industrial camera sensor), the FL will be approximately 26 mm, but a 26mm is not a standard FL lens, so it has to be used a 25 mm (in assembly lines it's more common to use fixed FL lenses).

2.2 Optical Illumination

Visual inspection systems are based on an image, the key to the success lies on getting an high quality image. The main goal of an optical illumination platform is to overcome the interference of environmental light, ensure stability of the image and obtain a high contrast, highlighting the important features of the object and reduce undesired features. As mentioned in [3] Visible light is a common light source since its a multi-wavelength compound light, being suitable for colour image shooting when acquired with high brightness. The wavelength of visible blue light is between 430 and 480nm being suitable for to acquire a silver coloured background such as sheet metal and machining parts. The wavelength of red light is typically between 600 and 720nm, with a relatively long wave it can pass through dark objects, it can significantly improve the contrast of an image. The wavelength of a green light source is typically between 510 and 530nm, being used to highlight red or silver coloured backgrounds. Invisible light could be infrared light and ultraviolet light. The wavelength of infrared light is between 780-1400nm, having a long wavelength with a strong propagation, being appropriated to inspect Liquid Crystal Display (LCD). The ultraviolet light has a short wavelength with a strong penetration being strongly used in scratch detection of metal surfaces. The contrast of the image can be enhanced by selecting a specific wavelength of a combination of multiple wavelength, being influenced by the angle between the light beam and the object surface.

2.3 Characteristic of the Object

One of the most widely used illumination method [3] is the forward lighting, where the light source and the camera are located on the same side of the object, this will highlight surface defects, scratches and important features of the object. Forward lighting is divided into bright and dark field as shown in Fig.1,2. Dark field is a reduce in the incident angle of the light forming a low angle forward lighting, this will highlight the edge and height of the surface, providing a strong performance on the surface concavity and convexity.

A dome light is a method when the light is reflected on a rough cover to produce a non-directional and soft light as shown in Fig.3, being then projected on the surface which can avoid the strong reflection produced by direct lighting mode. Coaxial light source refers to a high-intensity uniform light passing through a half mirror as shown in Fig.4, this provides a more uniform that the traditional lighting mode, avoiding the reflection of the object, improving the accuracy of a machine vision system. This method is used to highlight defects in surface objects.

Back lighting is a source that is positioned behind the object as shown in Fig.5, this will highlight the shadow of opaque objects or to inspect the interior of transparent objects, this will clearly outline the edge of an object for measurement.

For 2D/3D measurements such as height, width or angle with a single camera, a laser profile sensor that collect height data across a laser line. It measures the profile of an object using laser triangulation as shown in Fig.6, the light is emitted onto the part and reflected to the camera to understand the height at numerous points across the line. By compiling profiles during a scan of a part, a high-definition 3D representation of the part can be rendered to complete 3D measurements and inspection.

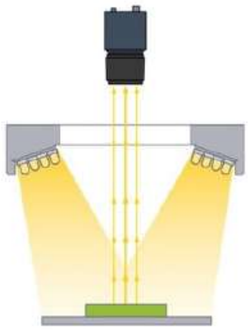

Fig. 1. Bright field [7]

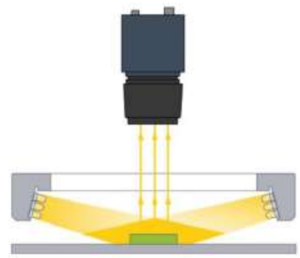

Fig. 2. Dark field [8]

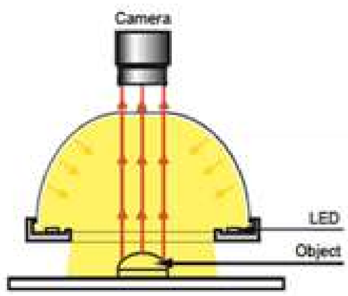

Fig. 3. Dome Light [9]

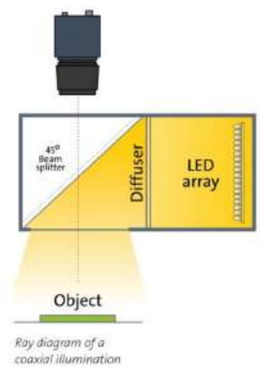

Fig. 4. Coaxial Light [10]

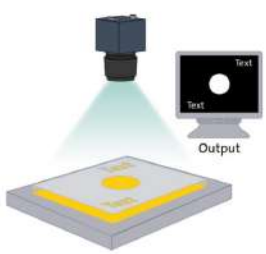

Fig. 5. Backlight [11]

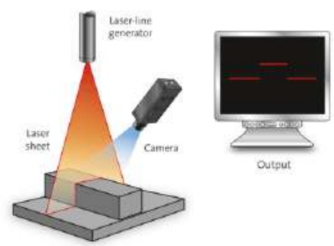

Fig. 6. Laser Profile [12]

2.4 Image Acquisition

Image acquisition technology focus on the specifications of the sensor and the Field of View (FOV). This is done with the use of a camera. By the sensor, the illumination energy is transformed into digital image. The image is represented by 2-D function f(x,y), being non-zero and finite quantity: $0 < f(x, y) < \infty$ [13]. Different cameras are used for different application. One of the main aspects of a camera is the resolution, that will dictate the minimum width and height of a pixel with a certain FOV, for example a camera with 128mm of FOV with a resolution of 1280 x 960 will have 10px/mm, this tell that a mm in the image corresponds to 10px, with this information we know the minimum resolution of the camera. Its important to know beforehand if the image acquisition will be made in movement or not, if the camera sensor doesn't have enough frame rate to meet the speed of acquisition it will create a drag in the image due to movement, resulting on noise in the image preventing a good image processing afterwards, to prevent this from happening its important for the light to operate in strobe mode, so the acquisition can me made in a blink, meaning that it will only turned on when the camera start the process of acquisition, preventing the drag effect on the object.

2.5 Influence of External Light

It is important at the time of acquisition that the system does not have any external light interference, because it may cause unnecessary reflections, creating noise in the image that may hide some desired feature of the part, or even decrease the contrast needed to recognise some kind of feature. The external light can manifest itself in various ways, and can be sunlight or even ambient light, in order to reduce the impact on image acquisition, it is necessary to use filters in order to cut the external wavelength, leaving only the necessary lighting for the image acquisition. In the case of the impossibility of using filters, the best solution will be to isolate the setup so that there is no external interference, thus having the best contrast possible in order to highlight the necessary characteristics of the part in question.

3 Technologies

At this section some existent technologies that are highly used to develop an ES approach for the industrial vision theme are going to be listed.

3.1 LISP

When it comes to the development of an expert system, the most widely used programming language is LISP.
LISP, acronym for list processing, is a functional programming language that makes possible to use with exclusivity mathematical functions as data structures. The main advantages that come with the use of this language are:

- LISP has an easy symbol manipulation rather than using numeric manipulation.
- There exists a complete equivalence of programs and data.

- As the acronym says, there are many convenient tools for knowledge representation such as Lisp storing the data as lists of characteristic properties and logical associations. This is more natural to human thinking processes than FORTRAN, for example.
- LISP brings a highly interactive programming environment for both users and program builders.
- There exists built-in tools to find and correct bugs.

[14] There are a low number of limitations associated with the use of LISP programming language for an Expert System. The main reasons that can led a team of developers to choose another language to perform an ES implementation, could be due to company restrictions, the popularity and subsequent knowledge in most common programming languages such as Java and Python, and the fact that those have a wider range of opportunities to build interactive and catchy User Interfaces.

3.2 Drools

Drools is a Rule Engine that uses the rule-based approach to implement an Expert System. It is used along with Java, an well-known Object Oriented Programming language. Some advantages of using the Drools to implement an Expert System:

- Drools is open source, what allows more evolution and a helpful community
- Drools exists at the Maven Central Repository and has an availability to run on any JVM. programs and data.
- The declarative implementation, the fact that the rules are defined in a declarative way and not by writing them in code.
- The fact that the data and logic are held separated in the application what helps centralising the knowledge allowing easier updates, fix's and maintenance
- Drools rule systems easily allow to implement explanation facilities, because it is able to log the decisions that were made during the use of the system.
- The rules are written in a very close to natural language way, which allows the expert, even if he has no programming knowledge, to make sure that the rules are correct or suggest updates to improve the system. [15]

The main downsides of using Drools as the programming language for an inference engine is that if the complexity of the problem demands a large amount of rules and hypothesis it can be difficult to organise them in a single drools file. Also the updates on the rules or at the Drools itself can cause bugs and errors when using it to develop an expert system. [**?**]

3.3 Prolog

Prolog is one of the first logic programming language. This programming language has been associated with artificial intelligence and due to this, it has been used for many AI applications such as theorem proving, experts systems and others. Throughout the years, many implementations of Prolog have been developed, one being SWI-Prolog. SWI-Prolog added many features to problem, including the constraint logic programming paradigm, multi-threading, unit Testing, GUI, interfacing to Java, a web Server, developer tools including and IDE and GUI debugger and GUI profiler and extensive documents, and many more features. However, SWI-Prolog doesn't have the needed built-in functions to develop an Expert System.

3.4 Python

Python is a high-level, multi-paradigm, general-purpose programming language. The goal of Python is to have a programming language that combines power with a very easy to use and friendly to people without a lot of programming experience syntax. This made Python a popular language which led to development of different of many libraries and frameworks to extend it's functionality whilst keeping the language accessible. For the development of an expert system, Python offers many libraries. However, this article will focus on the two that the authors found more prevalent. The first library is called Experta and the other is called PyCLIPS. Both of these libraries are inspired by the CLIPS tool for building expert system and bringing its features to Python.

4 Some MV Solutions Already Implemented

4.1 Defect Detection Based on Machine Vision

The goal of this solution [3] is to detect defects and process images. This ES can be somewhat complex because of the texture patterns, surfaces, direction and/or shape of an object. The method that was thought to create this ES was through deep learning. With this method, the system learns all by itself through convolutional neural networks from raw data.
The main purpose of image processing is to remove the unnecessary noise from an image. This can be possible through spatial domain and frequency domain methods algorithms like grayscale transformation, histogram equalisation and various filtering algorithms based on spatial and frequency domains.
The easiest way to convert from a spatial domain to a frequency domain is through the Fourier transform, that, in a two-dimensional discrete, can be represented as:

$$F(u,v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y)^{-j2\pi(ux/M+vy/N)},$$

and the inverse discrete Fourier transform as:

$$F(x,y) = \frac{1}{MN} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} f(u,v)^{-j2\pi(ux/M+vy/N)},$$

in which $f(x, y)$ represents the digital image size and $F(u, v)$ represents the frequency domain.
Other good way to remove noise, is by applying the wavelet transform which provides the localisation analysis of time or space frequency and gradually refines the signal by scaling and translation.
A defect classification was created with the purpose of knowing if certain defects exists or not. There is a variety of methods that can be use for this classification. Other important factor is the localisation of the defect. The ES needs to locate the exact localisation of given defect to be able to mark it in the defect category and many other factors need to be considered when looking to detect defects.
All in all, MV serves as a detection, although it is difficult to achieve this detection in real time if the object has complex features. Other aspect is the anti-interference of vision detection systems, which should increase the robustness of the detection to reduce the dependence on the image environment that is being acquired.

4.2 Identification and classification of materials using MV

When using AI solutions in an industrial context few problems would be as basic as that of the identification of the material that constitutes an object by an automated industrial machine. Having machine tools be capable of performing this function and then make proper decisions relating to the industrial processes based on this has the potential to be implemented in various fields across manufacturing industries, smelting industries, etc.
Some of the most recent implementations of solutions to this problem in the new Industry 4.0 context involve machine learning and in specific deep learning algorithms.
A setup proposed in this solution [16] presents a general use of Deep Learning AI for this problem. In it the authors use a SVM, a type of deep learning algorithm, as the classifier after thorough training based on a data set of the surfaces of 4 types of materials (Aluminium, Copper, Medium density fibber board, and Mild steel). As summarised in Fig.7 below, after proper illumination the picture taken is then run through RGB extraction before being fed to the SVM. After the model predicts the type of material presented the information is then made available to the controller so it is used for decision making.
References are also made to the still high cost of feature extraction applied to the problem of material classification as well as the difficulties in the application of computer vision in an industrial context.

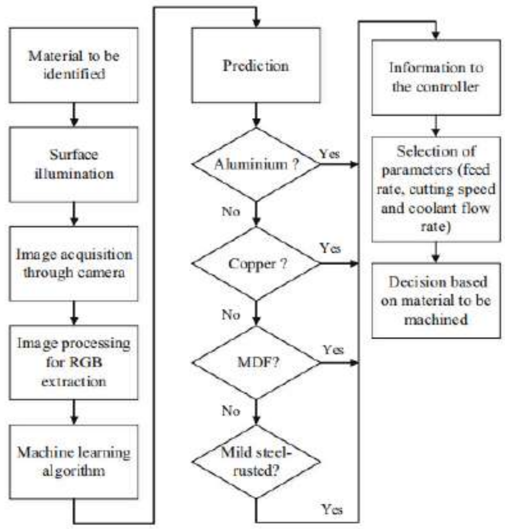

Fig. 7. Identification and classification methodology [16]

4.3 Lighting Advisor Expert System

The Lighting Advisor Expert System [17] was created to help solving lighting and optics problems for small parts assembly verification, designed for users with little or no lighting and optics background.

The ES asks various questions to the user, through a menu with multiple choice answers, and then the output will give the user directions to solve a given problem or a conclusion. For easy to understand the interface presents illustrations for non-expert users.

This solution aims to provide conclusions for lighting techniques, light sources, camera lenses and possible colour or polarised filtration, with more than 300 rules.

Although this solution has some years and didn't got useful conclusions, it's still relevant in today's world, because the assembly lines still got the same problems, and it's necessary a platform to bridge the knowledge gap between the experts and the future experts or non-experts without overloading the experts time.

4.4 Our Solution

The goal of the Industrial Vision Aid-ES is to properly inform the user on which setup is needed for each specific application. The system will not only make it possible to capture good images with ideal contrast, so that image processing is more effective, but also provide information on what lens will be needed to best capture the width of a part and the wavelength and format of the light required to achieve the best contrast in order to highlight what the user wants to process.

Therefore, the use of our ES will make it possible to save time mounting to setup a specific MV application needs and it will also help the developers in their algorithms since the image will be taken properly highlighting that which the user indicated was most important.
The main objective of the project is to implement an ES with the purpose of assisting the overall setup for industrial vision production lines. This system aims to achieve this goal through a set of rules that will allow the provision of the best combination of lens, lights and filters, to achieve the best possible image regarding all the aspects of object being inspected.
The ES will also have an explanation module to answer any questions that users may have.
This explanation module brings turns to the ES into an educational system, allowing the user to learn and develop his skills through the setup process. An "why not explanation module", a module that explains why specific conclusion was not obtained is also part of the ES. With this feature the user can go beyond and understand why certain conclusion or solution was not obtained for the setup. It is expected that this system can be used to educate new users and to aid the decision of industry collaborators.

4.4.1 Rules and Flowchart The essential elements to consider during the acquisition of an object are:
The size of the object, which relates to what lens is most appropriate. The type of material, which allows us to know which light wavelength will be needed to best inspect the object. If the acquisition will be made through movement, this information will specify if the light will be in strobe mode or not. If there is any ambient light that might create noise in the image, with this input we will know if it's needed to use a filter or to enclose our setup so there is no interference from the outside.
Our system will gather all the inputs needed trough questions made to the user and with his inputs, our system will return the best solution.
The inputs available to the user are the following:

Size:
There will be 3 options in which the user can choose depending on the object width:

- up to 100mm the lens needed for the application is 25mm.
- up to 200mm the lens needed for the application is 16mm.
- up to 300mm the lens needed for the application is 12.5mm.

External Light:
In a industrial site it is normal for there to be external light interfering with the ES setup.

- If there is light influence:
  What is the External Light type?

    - If there is Infrared (IR) (from sensor or industrial machines), there must be a filter that blocks the wavelength of IR and let trough the setup light, so with that purpose in mind it should be used an 700nm filter.
    - If the light is Ultraviolet (UV), there a filter must be present that blocks the UV and also that lets other wavelengths trough, with this purpose in mind it should a 400nm filter should be used.
    - If another type of light is present, the setup must be enclosed so that there is no influence from the part of the external light.
- If there is no influence of external light, there is no need for the use of filters or to isolate the setup.

Material:
The type of the material dictates the colour of our light in order to create better contrast between the object and the background.

- Doped with UV fluorescing agent it should be used an UV light;
    - If exists UV as external light, the setup must be enclosed.
- Black rubber it should be used blue or white light;
- Black plastic it should be used white;
    - if there's no IR as external light, we can use IR light.
- Glass/transparent plastic it should be used red;
    - if there's no IR as external light, we can use IR light.
- Semi-metallic it should be used white or red;
    - if there's no IR as external light, we can use IR light.
- Metallic it should be used white or blue or green or red;
    - if there's no IR as external light, we can use IR light.
- Different colour pieces it should be used white or RGB light.

Is the object moving?
If the object is moving, the light should be in strobe mode, meaning the acquisition will be made in a blink, also making the light work in his maximum intensity. This method will prevent a dragging effect.

What is supposed to be enhanced?
With this question, the user will decide what he wants to measure on the object being captured.

- if it is the height of the object, there should be used laser light with 60º of camera related slope.
- if what is supposed to be enhanced is the holes or dimensions of the object, there should be used back light.
- if it is the shape of the object, there should be used dark field (light with an incident angle).
- if it is the colour, it is necessary to know the characteristic of the material.
  What is the characteristic of the material?
    - if the object material is reflective an coaxial light should be used.
    - if the object material is shiny Dome light (uniform incident light) should be used along with a polarised filter.

- if the object is made from other material direct light (ring or bar should be used.

With all these inputs, the system is supposed to combine the above rules and associate them as guidelines for the user to perform the best camera setup possible for the conditions he is facing. All this rules and though process can be followed with the flowchart presented on the figure 8.

4.4.2 Technology used: Prolog was used to develop this project, since it is a logical programming language, it comes in handy for the construction of a ES. This software will ask questions to the user everytime he needs any help while building a new setup. Following the flowchart 8, the application will know the best conclusions and give them to the user.
A Explanation Module was implemented to interact with the user in case he wants to know in more detail why such conclusions were achieved. For this to work, the software has a "How?" functionality, so the user can also learn why certain conclusions were obtained. A "Why Not?" feature was also implemented with the aim to teach the user why certain combinations were not viable for the setup he was building.
The system also implements a function to show all the setups on the knowledge base, so the user can consult them and a function to block any duplicated object names.

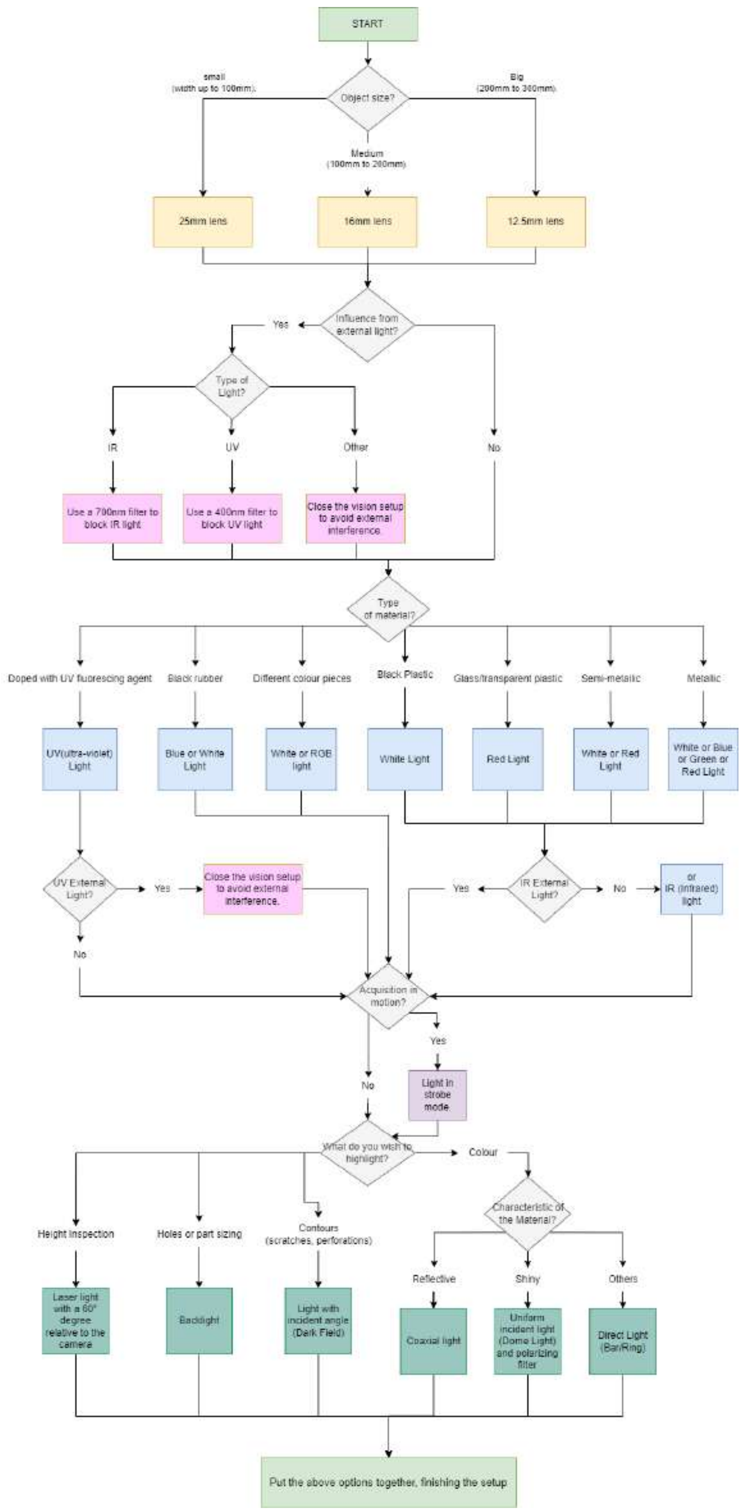

Fig. 8. Project FlowChart

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Glossary

Artificial Intelligence A type of computer technology which is concerned with making machines work in an intelligent way, similar to the way that the human mind works. The abbreviation AI is also used . 14

Computer Vision An artificial analogue of human vision in which information about the environment is received by one or more video cameras and processed by computer: used, for example, in navigation by robots and in the control of automated production lines . 1, 14

Expert A person who is very skilled at doing something or who knows a lot about a particular subject . 1, 14

Expert System A computer program that can offer intelligent advice or make intelligent decisions using rule-based programs . 14

Inference Engine A component of the system that applies logical rules to the knowledge base to deduce new information . 1, 14

Knowledge Information and understanding about a subject which a person has, or which all people have . 1, 14

Knowledge Base A self-serve online library of information about a product, service, department, or topic . 1, 14

Acronyms

AI Artificial Inteligence. 1, 7, 8, 14

ES Expert System. 1, 2, 5, 7–10, 12, 14

FL Focal Length. 2, 14

FOV Field of View. 2, 4, 5, 14

IR Infrared. 11, 14

LCD Liquid Crystal Display. 3, 14

MV Machine Vision. 1, 2, 7, 8, 10, 14

RGB Red, Green, Blue. 8, 11, 14

SVM Support Vector Machine. 8, 14

UV Ultraviolet. 11, 14