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Designing an Affordable System for Early Defect Detection Using Image Processing

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Abstract. The affordability of high technology inspection systems for Micro, Small and Medium Enterprises (MSME) is a big challenge since, if not implemented, it will affect productivity and quality of the product. A case study has been carried out to understand inspection practices at an MSME in India (at an orthotic footwear company), within its medical device industry where safety and risk management are critical. Raw materials are not inspected during the initial stages of production, due to which the whole product is rejected if any defect is subsequently found. Due to this rejection, manufacturing time and man hours are squandered at the expense of quality. To enable early inspection that is also economical, existing methodology is integrated to develop a system that can boot from a Next Unit Computing (NUC) with real time processing. The inspection system uses Fault Detection and Isolation (FDI) technique using 'canny edge detection algorithm' for image processing; defects are identified as blobs by convolving the image matrix. The images are captured by low cost off-the-shelf cameras arranged in-line perpendicular to the bespoke set up. A set of light sources is used for illumination and the algorithm is evaluated for its accuracy under different light conditions.

Keywords. Affordable, early inspection, canny edge, image processing

1. Introduction

In industrial production lines where thousands of objects are manufactured in a short period of time, quality control in inspection by visual method is cumbersome, inefficient and often an unreliable process. Quality check of products is carried out at intermediate inspections of the process and during manufacturing processes. Depending on the process requirement, the inspections might be of different kinds, from visual inspections to ultrasound inspections. However, not all the manufacturing organizations can afford the inspection systems that are most suitable during the various stages of production. A large number of Micro, Small and Medium Enterprises (MSMEs) in India are in shortage of funds and have limited access to relevant information. By trying to reduce costs and minimizing capital expenditure, the MSME sector is dormant when it comes to the use of latest technology and knowledge [1]. In accordance with the provision of Micro, Small & Medium Enterprises Development (MSMED) Act, 2006, the MSMEs are divided into two classes: Manufacturing enterprises and Service enterprises. The manufacturing

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enterprises are defined in terms of investment in plant and machinery. The limit of in investment for micro, small and medium enterprises is up to 10 Crore INR. Similarly, for enterprises engaged in providing or rendering of services, the investment in equipment limited to 5 Crore INR [2]. Affordability to high end technology becomes a challenge and often results in using nonstandard practices.

By not following standard practices of production, these companies run the risk of having to face quality issues and call products back for rework or exchange. This is particularly detrimental to industries where Quality Management Systems (QMS) are safety critical, like those in medical, automotive and aerospace companies [3].

This paper presents a case study of developing a highly affordable inspection system for a biomedical MSME in India. The inspection system comprises bespoke hardware, software and electronic components.

2. Case Study

To understand the present scenario, a detailed study was conducted in one of the MSMEs, an orthotic footwear manufacturer. The company produces a low risk orthotic footwear used to cure medical conditions like calcaneal spurs, corns, heel cracks, heel pain etc., by providing customized footwear with medial arch for flat feet, cushioned heel for heel pain, scooped insoles or offloading for ulcers, crow shoes and ankle shoes for specific foot disorders, outsole modifications for differential height, soft packed insole for corns, and so on.

The manufacturing process starts with acquiring raw materials from suppliers. The raw materials are then used for cutting, the sole, midsole, innersole and upper of the footwear, into desired shape, for different foot sizes. The parts are then assembled using adhesives and stitching processes. Then the footwear is heat-treated for a certain period time at a predefined temperature, to firm up the bonding between the soles and the upper. Excess materials are then cut and ground for soft finish. A quality check for any defects on the footwear is then performed, followed by rejection or rework before the accepted products are sent for packaging. At this stage of inspection, the product will not be able to undergo substantial rework and for such cases there is no other option than to discard it. The process flow is very lenient and flexible, with no standard form of quality check performed during the manufacturing process. To avoid wastage of resources and time, quality assessment of the raw materials should ideally to be carried out at the early stages of the production. Thus, it was decided to develop a smart, affordable inspection system using which incoming raw material sheets can be inspected for this MSME.

3. Methodology

To avoid defects that enter the process of manufacturing, the proposed method implemented an inspection system at the beginning of production. The raw materials are stored in an inventory and utilized only when the production demands it. Once received, the raw material will start undergoing production, skipping detailed quality check. To avoid this, it was decided to introduce an inspection stage between inventory and production. Most of the raw materials are sheets, which come in rolls and piles depending upon the thickness of the sheet. The following table enlists the different materials used and their sizes.

Table 1. Different raw Materials and their sizes and colors used during the manufacturing of the footwear.

Material	Color	Dimensions (m)	Thickness (mm)	
			max	**min**
Rexene	Black	1.5 X 50	2	1
	Brown	1.5 X 50	2	1
Ethylene Vinyl Acetate (EVA)	Black	1.5 X 2	12	10
	Red	1.5 X 2	12	10
Multi Cellular Polymer (MCP)	Brown	1.5 X 2	2	1
	Black	1.5 X 2	2	1
Counter boards	Brown	1.5 X 50	8	6

The usual defects that lead to rejection of sheets are through-holes, surface-holes, tear-off and cuts (see Figure 1). These go unnoticed if present in a large sheet unless a thorough inspection is carried out. The proposed inspection method which uses consumer grade camera to capture an image of the sheet, looks for any irregular edges and identifies these as blobs is proposed. Since the solution is aimed at MSMEs, any solution with expensive and industrial-grade cameras were not considered affordable.

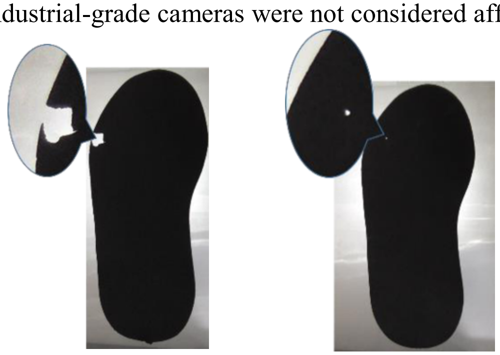

Figure 1. Common Defects found after cutting**.**

4. Design

The designing of the inspection system for this requirement and application was considered in two stages, one is the software-design, and another is the hardware-design. The software design consisted of developing a program that involved image processing, first capturing the image of incoming raw materials and then analyzing it for any defects using different methodologies. The program design started with reviewing commonly used methods by studying literature and implementing the one that provided the best results. While substantial work has been published on algorithms for image processing/ computer vision e.g. Automatic Visual Inspection (AVI) [4, 5], much less work is available on image acquisition [4]. Most research focuses on the edge detection algorithms to identify defects using canny edge detection algorithm [6, 7 and 8]. Some research is also carried out using SVM (Support Vector Machine) classifier for more than three types of defects [11, 12]. Since the defects considered in this work are only at the surface level and through-holes, canny edge algorithm was chosen to be the method for this work.

4.1. Program design

A stream of images are taken from a camera which is placed at the top on the inspection setup, see Figure 3. The pre-processing step is carried out by applying a bilateral filter on the captured image-stream so as to smooth the images without smoothing sharp edges. The surface is determined using canny edge detection and then by morphological transformation for better formation of the edges. Finally, blobs around the defective or faulty areas are formed on the surface images using contour formation technique, and 2D convolution masking is done for producing a binary image. Finally, blob detection method is applied on the binary image, the blobs' location being detected as output.

The program is written using Python language and OpenCV library (Open Source Computer Vision), which is an open source computer vision and machine learning software library.

4.2. Hardware Design

The design of hardware started with the selection of cameras. As the raw materials are in different lengths, the Field of view (FOV) of the camera had to be fixed. The materials are brought under the vision of the camera. As affordability was a major motivating parameter for this work, it was decided to go for off the shelf cameras (Logitech C525 HD 8 MP webcameras). To cover FOV, the placement of the cameras were critical.

$$F = 2d \tan(\theta/2) \quad (1)$$

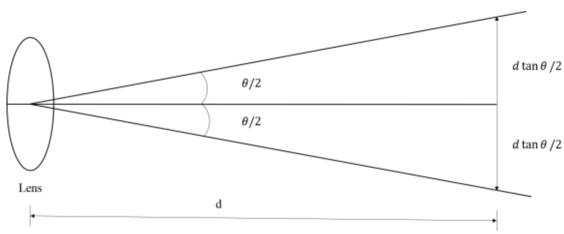

Figure 2. Field of View of Camera**.**

where, F is the field of view, d is the distance of the lens from the object and θ is the angle of view of the lens. Based on calculations, it was decided to place the cameras at a height of 800 mm. Another criterion for selecting the camera was the number of pixels with which the least measurable defect can be identified within an image. It was decided to identify a minimum of 1 mm defect on a raw material sheet. Considering the Field of View and sizes of the sheets and also the height required for the camera to be placed, a setup was designed which can fulfill all said requirements. The setup is simple, as a table is made of acrylic sheets with the field of view covered as diffusor. As the raw material sheets that come into the inventory are 1500 mm wide, the table width was designed for 2150 x 900 mm considering clearance to manage sheets. For front end of machine vision, lighting system plays an important role which directly influences the quality of the final result [8]. It is important to obtain well-illuminated and good contrast images by using appropriate lighting conditions as the images minimize the need for pre-processing steps required for removing background noise, eliminating shadows, increasing contrast etc.[9]

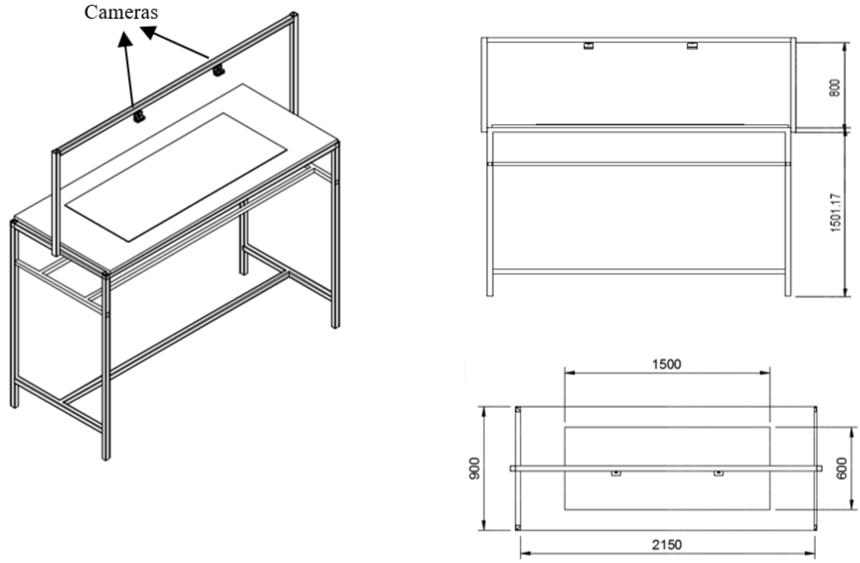

Figure 3. Inspection setup

5. Experimentation

To evaluate the algorithm, both black and brown coloured MCP sheets were used. The test-sheets, which had different defects with through-holes ranging from 1 mm to 6 mm, were placed on the table under the FOV of the camera. To obtain best results, the inspection process was carried out under different light conditions. As the contrast on the raw material is dependent on exposure to surrounding light for the camera; experiments were carried out under the following conditions:

1. Natural light,
2. Artificial light above the table,
3. Artificial light- below the table,

The light source used for experimentation was LED tube lights. The lights were arranged for surface lighting along the central bar beside and between the cameras and at the side. For bottom lighting, a tube light was placed on each of the two rods at a height of 300 mm below the table. The illumination range was decided after various iterations were carried out to allow maximum detection of the defects. The lux was identified using a lux meter by placing it at different places on the table and test area. The program was executed once all settings were finalised and processed images saved for future reference.

6. Results

The results obtained for the above conditions show the optimum light range for the setup for detecting a minimum of 1mm sized defect.

Table 2. Result of detection of defects under different light conditions for black MCP test sheet

Light Condition	Lux range (lx)	Actual Defects	Detected defects	Detecting 1 mm hole
Natural Light	241- 350	15	8	NO
Surface Light	681- 768	15	9	NO
Bottom Light	3050- 3190	15	14	YES
Surface + Bottom Light	694- 774 2860- 2940	15	15	YES

Table 3. Result of detection of defects under different light conditions for brown MCP test sheet

Light Condition	Lux range (lx)	Actual Defects	Detected defects	Detecting 1 mm hole
Natural Light	173- 255	9	0	NO
Surface Light	648- 668	9	1	NO
Bottom Light	3120- 3130	9	5	YES
Surface + Bottom Light	637- 664 2960- 2920	9	4	YES

Using artificial bottom light conditions, the results obtained were satisfactory for the detection of 1 mm sized holes. This light condition proved for both brown and black colour sheets. The defects were displayed as blobs and numbered along the blobs, such as shown in figure 4. Defect number 5 is a 1 mm sized through hole defect. The image after processing were displayed on a screen; and the user was made aware of the defects on the raw material sheets.

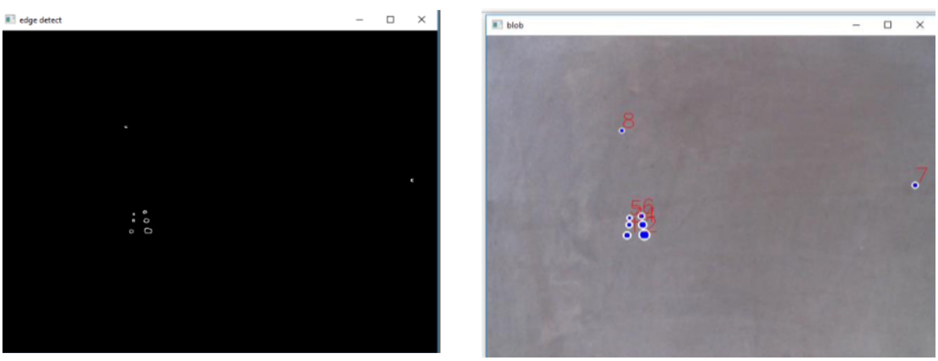

Figure 4. Edge detection and blob detection by bottom light condition**.**

The accuracy of the algorithm was calculated against the lux intensity of illumination (see equation 2). It was found that the optimum illumination to detect 1 mm defect lies between 3100 lx to 3250 lx which is provided by the bottom light source.

$$\text{Accuracy} = (TP + TN) / (TP+TN+FP+FN) \quad (2)$$

Where, TP= True Positive, TN= True Negative, FP= False Positive and FN= False Negative.

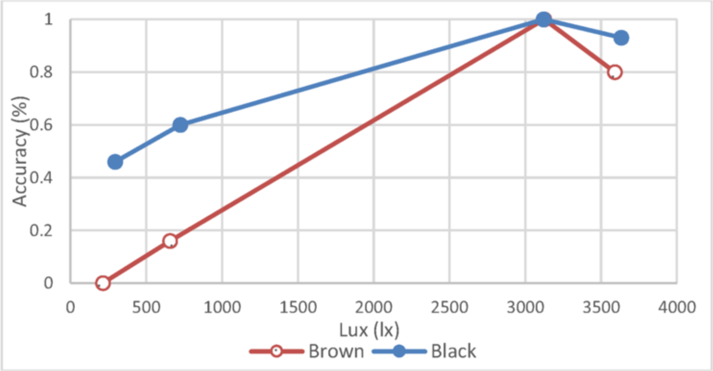

Figure 5: Accuracy of the algorithm to detect 1 mm defect under various lighting conditions

7. Conclusion

This paper presents an affordable defect detection setup, which has been designed for the purpose of affordable defect detection at early stages of production in MSMEs. The setup consisted of an inspection table for which two off the shelf consumer grade cameras were attached. The raw materials were placed on the table and under the field of view of the camera. The camera acquires an image, pre-process the image, identifies its defects by contour and blob generation, and displays the image to the user. The proposed system can successfully identify as small as 1 mm defect on the raw material by using the bottom light condition. The whole setup is highly affordable for MSMEs, where it can be used for inspection at any stages but essentially for large area to be covered.

Future work involves designing a pointing mechanism that can point out the specific defective locations, and the user can highlight the areas using a conventional marking mechanism. This will be a caution for the user to avoid the area for further production sequences. With varying light intensity and effect on image processing experiment have to be conducted.

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