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Digital Image Acquisition Systems used in Autonomation for Mistake Proofing

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Abstract
Digital Image Acquisition Inspection Systems are state of the art tools used to facilitate Autonomation of any manufacturing process though the institution of mistake proofing. These visual inspection system scan minimize scrap and improve the overall quality of any process by identifying nonconforming material or product. This paper will attempt to consolidate all of the information pertinent to the subject for any technically inclined individual to succeed at instituting a visual inspection system in any manufacturing process.

1. Introduction

Digital imaging was developed in the 1960s and 1970s. The way for Digital Image Acquisition Inspection Systems was paved when this technology was perfected; leading to integration of digital imaging with inspection methods that previously existed.

Initially, there were challenges to overcome associated with the high price of the camera, computer hardware, and software to run the systems. Technological advancements have lowered the cost of these items and allowed most manufacturers to utilize this technology.

Instituting these systems alone will not give the desired quality improvements most manufacturers seek. In order to come full circle; the Digital Image Acquisition Inspection Systems will need to have human intervention which completes the process. The equipment must inevitably be operated by a human who will add the necessary skill of taking many factors into consideration to allow the process to be flexible. Some of these factors are; adjusting of the quality thresholds, analyzing the non-conforming product the system rejects, and managing the flow of product through the system.

In this paper, the focus will be on how vision systems operate and how they are used in different areas of manufacturing. The industry that will be highlighted in this paper will be the textile industry as there are many different types of defects that can be encountered during the manufacturing process. This methodology is not limited to any particular industry and has been widely used in almost every manufacturing industry with tremendous success.

2. Vision Inspection Coming of Age

The comparison between how products were traditionally inspected and how the vision inspections systems of today operate is identical in nature; however; the major change is that a computer system makes observations and determinations based on digitally acquired images rather than a human visually inspecting the product based on a predetermined “concept” or “ideal specimen” of how the product should or shouldn’t appear.

The word *automation* was first used in the 1950’s to mean automatic material handling. As automation technology progressed, the term was used in a wider sense. Today automation refers to both services performed and products produced automatically and to information handling tasks. According to Webster’s New Collegiate Dictionary, automation is “The technique of making a process or system automatic”. [1]

In past years; the product being produced, whether it was food or material; needed to be inspected at some point during the manufacture or processing of that item. Humans were the obvious choice for visual inspection of the item to determine if the size, color, fit and finish were within the specifications that were outlined for quality acceptance levels.

The need to identify mislabeled products, ensure that labels for products are printed correctly and are legible, reject 100% of non-conforming parts, as well as check that product dimensions and colors are within tolerance became paramount with the increasing production rates for large companies. The increase in food production also led to an increase in the need to inspect the harvest since it was increasing in size almost indefinitely. As the population of earth increases, more consumers are added to society and the need for companies to produce high quality food and products has become a top priority.

The need for food and material products that have high quality is natural as far as consumer requirements are concerned. People want higher levels of quality and want to purchase products that are free from defects. These increased expectations have encouraged the manufacturing world to fire back with vision inspections systems that are faster, more accurate, and objective when it comes to making quality decisions, unlike their human counterparts. One aspect of these vision inspections systems is that they are non-destructive quality tests that are cost effective in the long run. Applications for this technology have expanded to include many new areas which are, medical diagnostic, automatic manufacturing and surveillance, remote sensing, technical diagnostics, autonomous vehicle, and robot guidance. The agricultural and food industry have also embraced this technology which includes the inspection of the quality and grading of fruit and vegetables. In addition, these systems can be used to analyze grain characteristics and evaluate the quality of pizza, potato chips, cheese, and meats.

3. Vision Inspection System Hardware

Vision Inspection Systems have two basic hardware components they use to get the job done. These components are the camera and the circuitry used to store and compare captured digital images. The cameras can be analog or digital in design. This paper will focus on only the digital camera image capture because it has the best resolution and provides the best results for a Digital Image Acquisition Inspection System.

National Instruments has a wide range of digital cameras available for purchase. They provide both color and monochrome cameras which have varying degrees of cost associated with each model; color being more expensive. The best bang for the buck can be found in the NI 1712 Smart Camera which is a monochrome model.

The cameras acquire images of the product being manufactured which will be analyzed by the computer system to determine if the product conforms to certain manufacturing guidelines. The computer hardware consists of a computer which will house memory to store the captured images, a dedicated circuit which is used to perform the comparison of images captured to the library of acceptable images store in the computer.

Fig. 1 NI 1712 High-quality National Instruments Monochrome VGA Digital Camera (640x480) [2]

4. Vision Inspection System Operation

When setting up a Vision Inspection System, the rate at which you want to run product through the system must be balanced with the image quality you wish to achieve. Larger more detailed images require more time to acquire, store, and process. This will slow the system down and throughput will suffer. For this reason, the camera that is used should be matched with the desired speed of the system as far as production rates are concerned.

Vision Inspection Systems can be generally divided into two basic categories, Vision Sensors and Vision Systems. Vision sensors use Smart cameras which are dedicated sensors, either CCD or CMOS sensors that collect images and send them to a processing unit which determines the acceptability of that particular image. These systems are not flexible in nature and must be well thought out before they are put into use as they are specifically tailored for each application and offer very little flexibility.

The steps required to select such a system are as follows:

1. What sensor resolution is required for the task at hand?
2. What type of imbedded processor and memory will be used?
3. What type of Application Programming Interface (API) will be used?
4. Select the appropriate programmable I/O facility.
5. Choose the type of video output you will use as well as the networking capabilities and interfaces.

These choices are all driven by the need for high or low quality image collection, type of product, complexity of the image being analyzed, and the speed at which the process needs to run.

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Vision Systems are more flexible in their design in that they incorporate hardware and software that expands their ability to adapt to different vision inspection applications. They are a more fine-tuned approach to image processing and can be adjusted as needs change making them the best choice for companies that have a fast changing line of products.

5. Vision Inspection System Software

The camera captures an image which will be stored in the computer's memory. Once the image is stored, the software can access the image and run the program on the image which makes it more suitable for comparison to the stored images in the library. The first process that is carried out by the software is called digitization. During this process, the image is converted into a digital form of ones and zeroes.

The hardware that assists the software in creating this digital image is known as a frame grabber. The image is processed and analyzed by the software. Within the software platform reside powerful algorithms for defect inspection. They utilize adaptive thresholdingand binary filtering to detect defects. Noise is present in the images that are captured that must be accounted for and reduced. It has been found that the noise observed in these images has a distribution that is normal and the amplitudes are small. The analyzed defects are found to have a high contrasts which make them easier to identify.

6. Vision Inspection Imaging

There are many ways to use programming to analyze captured images in either a two-dimensional or a 3D image. Two of these methods are:

1. Grid array based systems using pseudorandom structured light systems
2. Laser triangulation, where a laser is projected onto the surfaces of an object and the deviation of the line is used to calculate the shape

Capturing of the image is done by utilizing a scanning motion, either by moving the work piece, or by moving the camera & laser imaging system. Stereoscopic vision is used in special cases involving unique features present in both views of a pair of cameras used to analyze the captured image.

After an image is acquired, it is processed. Machine vision image processing methods include:

1. Stitching/Registration: Combining of adjacent 2D or 3D images
2. Detecting defects; the measured size of the defects is compared to the maximums allowed by pre-determined quality standards

The process the software runs on each image depends on how the code is written. Figure 3 depicts a flow chart which details in block diagram the different stages of image processing by a complex software program. [3]

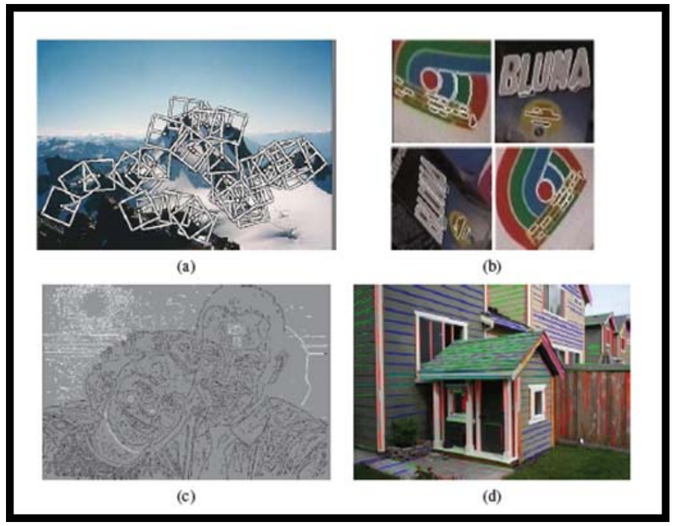

Fig. 2 Defect feature detection examples a-d [3]

Different ways to detect features to describe, analyze, and match images: (a) Point-like interest operators (b) region-like interest operators (c) edge detection (d) straight line detection [3]

Color and shaded renderings of a depth map produced by an image capturing system; (a),(b)detail views; (c) resulting surface if disparities are rounded to integers; (d) resulting surface without novel sub pixel and self-calibration components [4]

Some of the methods used to massage the data captured in the imaging process are:

1. Filtering (morphological filtering)
2. Thresholding (thresholding starts with setting or determining a gray value that will be useful for the following steps. The value is then used to separate portions of the image, and sometimes to transform each portion of the image simply black and white based on whether it is below or above that grayscale value)

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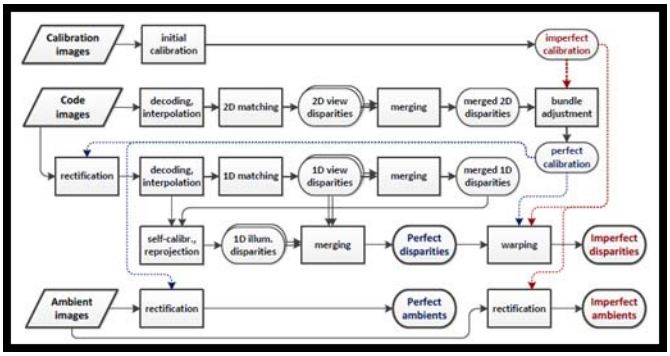

Fig. 3 Typical Software Processing Block Diagram [4]

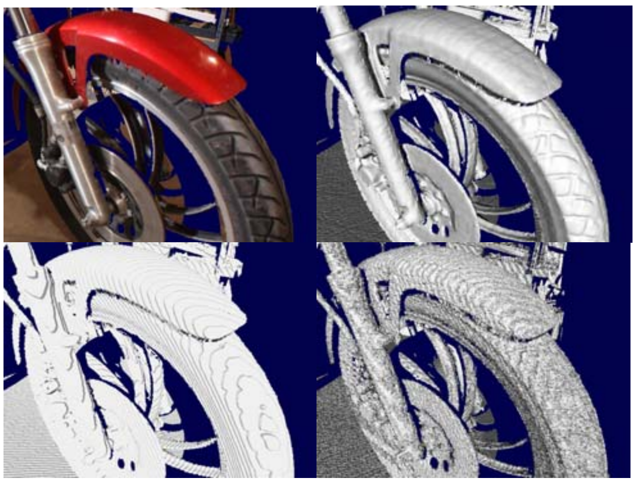

Fig. 4 Filtered Images.

3. Pixel counting (counts the number of light or dark pixels)
4. Segmentation (partitioning a digital image into multiple segments to simplify and/or change the representation of an image into something that is more meaningful and easier to analyze)
5. Edge detection (finding object edges)
6. Color Analysis (identify parts, products and items using color, assess quality from color, and isolate features using color)
7. Blob Discovery &Manipulation (inspecting an image for discrete blobs of connected pixels (e.g. a black hole in a grey object) as image landmarks.
8. Neural Net Processing (weighted and self-training multi-variable decision making)
9. Pattern Recognition/Template Matching (finding, matching, and/or counting specific patterns)
10. Barcode, Data Matrix and "2D Barcode" Reading
11. Optical Character Recognition (automated reading of text such as serial numbers)
12. Gauging/Metrology(measurement of object dimensions, (e.g. in pixels, inches or millimeters) [4]

This data analysis is done to compare the captured image against target values to determine a "pass or fail" or "go/no go" result. As with a code or bar code verification, the read value is compared to the stored target value. When gauging a part, a measurement is compared against the proper value and tolerances. For verification of alpha-numeric codes, the optical character readers value is compared to the proper or target value.

7. Vision Inspection System Investment

Vision inspection system investment is typically justified through a return on investment (ROI) based on reduced waste, increased productivity, and reduced labor requirements. The investment can also be justified by saving from rework or lost business caused by defective product getting out the door.

In the last two decades, machine vision has been applied slowly but surely to a variety of manufacturing challenges, the main goal being improving quality and productivity in the manufacturing process. Industries in the Semiconductor and Electronics fields were quick to adopt this technology. Currently companies in these areas account for about half of the machine vision applications found on the factory floor. Vision Inspection Systems have gained acceptance and are growing quickly throughout the manufacturing sector. These systems are now in place in food processing, pharmaceuticals, wood and paper, plastics, metal fabrication and other industries.

There have been some growing pains along the route. Vision Inspection Systems were first marketed as a newfangled, must have technology for manufacturing automation in the early 1980s. At this time this technology was not in the spotlight because artificial intelligence and automated robotic assembly were the stars at that time. The main idea was that a mechanical system (hardware and software) would take the place of a human in terms of visually inspecting manufactured goods and materials. This was a good concept but created expectations that could not be immediately filled. Many of the first companies to get on board with this technology saw complex programming requirements, difficult installations, reduced functionality, and reliability issues. For the time being, this technology would still be in the development phases and much work was required to get a system up and running that could produce the desired results that were necessary to implement such a system successfully. Most companies would have to wait for years to pass before that technology became standardized and user friendly.

Fast forward to the present day; these systems have gone through the painful phases of product maturation and are now available to most manufacturing companies. With the lower initial costs to set up visual inspection systems, more and more products will be subjected to this improved inspection technique which will set into motion many upgrades for both the manufacturer and the consumer. Manufacturers will see less defective product going out the door which will lower overall production costs since returned items cost money to process as well as the cost of possible losing a customer because of the defective product. Consumers will enjoy higher quality in the items they purchase which will save them money and time in the long run.

The Textile Industry is using Vision Inspection Systems with great success as part of their manufacturing process. One way this is being accomplished by that industry is in the area of defect detection. The implementation of automated visual inspection systems for defect inspection in the textile industry is of high importance. The fabrics are made on looms in which the product moves through the process at rates of ranging from 20 m/min to 200 m/min. The web material is typically 1–3m wide and with the high speed at which it moves through the process it is very difficult for a human to detect even 60% of the defects on any given production run. Human visual defect detection can only cover fabric that is less than 2 meters wide which introduces limitations with throughput efficiency. The Textile Industry has identified over 235 types of defects and their possible causes which becomes the goal for the automated visual inspection system to be able to detect, classify, and reject.

The following is a detailed explanation of the proposed inspection architecture requirements necessary to operate a successful automated visual inspection system analyzing textiles that are being produced for defects. This information is quoted from the citation "Real-Time Vision-Based System for Textile Fabric Inspection" as it contains information that is highly technical in nature and must be presented in its' original format to retain the full meaning.

8. Overview of the Proposed Inspection Architecture

The overall system for fabric fault inspection has been developed through its experimental and industrial phases. The architecture of the experimental system is the unwinding machine, lighting system, image processing hardware, and software. The unwinding machine, which simulates the cloth inspection table, consists of the five degrees of freedom mechanical set-up and fabric feedingmechanism.For the lighting, a specular illumination technique is employed. An air-cooled fluorescent tube provides a2200–6460 Lux intensity and operates at 40–50 KHz in order to avoid flicker. The tube is about 10 cm away from the fabric. The fabric is scanned in ''warp direction'' by a 2048 element line-scan camera LC1912 (EG & G Reticon), enabling an acquisition speed of up to be 7000 lines per second. The power and timing signals are provided by a modular camera controller RS1910 (EG & G Reticon). The line-scan processor boardDT2856 (Data Translation) is used for the line acquisition and low-level data pre-processing. A DSPboard DT2878 is used for high-level data processing, including a statistical texture features computation and neural classification. An FPGA (Field Programmable Gate Array)-based synchronization trigger board and an incremental encoder enable synchronization between fabric movement and line acquisition rate. A Pentium-based machine is used as a host computer for system coordination and control, binary image processing and industrial network support. Al the software, including board programming and image processing algorithms, has been developed in the ''C'' language in a Microsoft Windows environment.[5]

After experimental evaluation, the main part of the system described above (except the unwinding machine, lighting and motor drivers) is mounted on the standard fabric inspection machine. For the lighting, a fiber optics illumination is employed. It consists of two quarts halogen fiber optics illuminators and FIBERLITEline light configuration with rod lens that can provide a stripe in excess of 50.000 Lux at 1m. An internal regulation circuit provides constant light with a variation of +/2% for a range of mains voltage of200–280V AC. A Pentium II/200MHz machine is used as a host. In an industrial environment, as opposed to an experimental situation, the following problems present themselves:[5]

(1) The inspected surface of the fabric is not ideally smooth, and the winding mechanisms are not sufficiently synchronized, resulting in wrinkled fabric particularly at the beginning and the end of the roll. Usually, the wrinkles run in the direction of motion.[5]

(2) The illumination fluctuates with respect to time during machine activity. Sometimes, the voltage drops (generated by motor activity) are so great that the

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light regulation cannot work properly. Also, ambient light influences the entire light intensity by 1.5–2%.[5]

(3) The electronic motor drivers induce a high frequency noise that sometimes interferes with the camera signals.[5]

(4) The fabric produces impurities (dust). Usually, it flies between the lens and the fabric, or settles on the lens.[5]

In many standard solutions the wrinkling is avoided by using a special machine or mechanisms for stretching the fabric, rapidly increasing the system cost. In order to escape additional mechanical constructions we describe wrinkling as a separate ‘‘wrinkle’’ error and recognize it using appropriate algorithms in the inspection procedure. The illumination problem is solved by adaptive thresholding, described in the next section, while a fan mounted over the scanning area removes the dust [5].

9. Image Processing Approach

Process requirements and defect characteristics

As previously mentioned, the processing time and accuracy rate of defect detection and recognition can be considered as crucial, restricting criteria in the final choice of the algorithms for automated fabric inspection.[5]

Consider a 1m wide fabric moving at a speed of 2m/s,and containing defects of 1mmin size. If a defect must be represented by a minimum of two pixel sin both directions (i.e. a spatial resolution of 0.5 mm/pixel) then it is necessary, in real-time data acquisition, to realize a data flow of 8 MB/s for a line-scan camera of2048 pixels. For applications demanding full data processing, defect detection and classification must be also considered.[5]

Furthermore, a typical defect detection and classification problem involves a large number of defect classes, and the system must be able to deal with a few dozen to a few hundred classes. Sometimes, a single class of defects may vary widely in appearance and may have members that closely resemble defects in another class. On the other hand, small changes in the production process can result in entirely new classes of defects; therefore a useful classification system should be dynamic, with the ability of continuous on-line learning.[5]

The above items make initial system design very difficult, and very fast hardware and suitable software solutions must be implemented to achieve this task. Towards this aim, we examined many approaches using the described experimental set-up. Also, the experience of human inspectors, textile experts and industrial statistics yielded the following conclusion, which can simplify the design task:[5]

Approximately 80% of fabric defects have a preferred orientation, either in the direction of motion (i.e., warp direction) or perpendicular to it (i.e., pick direction).[5]

Many defects are caused by machine activity such as holes, oil spots, wrinkle or dirt. On the other hand, warp or pick defects tend to be long and narrow, while slubs can produce point defects. Generally, they change image intensity and apparent texture of the weaving pattern in local fabric areas. Following this logic, the defects can be classified into groups that are formed using different criteria (i.e., Marks & Spencer System). For example, slubs, knots, tangles and dirt can be considered as a ‘‘dark spot,’’ big loops and skipped threads as a ‘‘light filling,’’ while double warp thread can be seen as a ‘‘dark warp’’. In our approach, we use eight groups for defect description, which will be discussed in a later section.[5]

Following the above facts, as well as general demands that have already been mentioned, we propose the following inspection algorithm.[5]

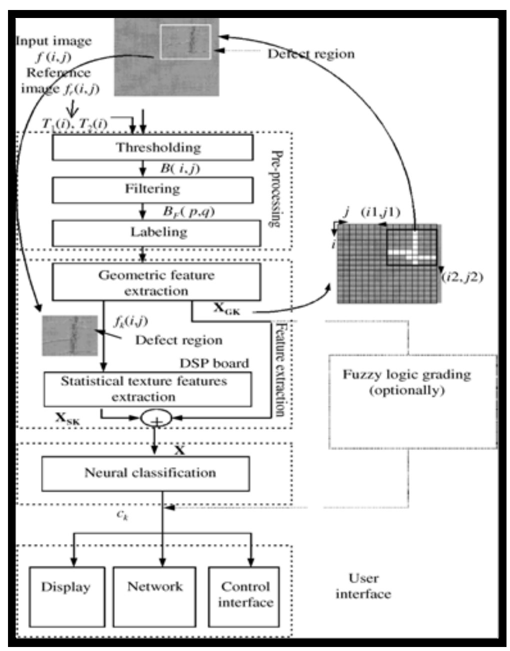

Fig. 5 Flow diagram of the proposed inspection algorithm [5]

10. Moving Forward with the Process

As the previous explanation of the proposed inspection architecture requirements shows; this highly complex process is very detailed as well as process specific. The next part of the process is the creation of the inspection algorithms. This is composed of two algorithmic modules, the defect detection and the feature extraction module. As these algorithms are tremendously time consuming and complex to derive, this paper will not explain how this process is done in detail. A short explanation of the process is as follows:

- The pixels in the captured digital image are mathematically determined to form a digital footprint
- Then they are compared against a known "acceptable" example that is stored in the computer's memory
- Any imperfections that are identified through mathematical pixel comparisons are noted and those sections of the material are flagged as defective

11. Intensity imaging

Several inspection systems have been presented which are based on gray-level intensity data for inspection. The reflected light collected by the camera sensor forming the intensity image depends on the reflection properties of the surface and the chosen illumination setup. The lighting system is a critical point of intensity imaging of metallic surfaces [6].

The light needs to be provided in a controlled manner to accentuate the desired features of the surface. Designing the optimal lighting setup is one of the most difficult parts of a surface inspection system, which requires a lot of intuition and experiments. There are a rich variety of lighting techniques that may be used for intensity imaging in machine vision[6].

They can be summarized into three general categories:

- Front lighting
- Back lighting (This technique is normally used for viewing the silhouette of opaque objects or for inspecting transparent objects)
- Structured lighting. This method is used to acquire the three-dimensional shape of an object [6].

12. Initial Phase of Involvement in Vision Inspection Systems

Here is an example of how the author of this paper would approach a Vision Inspection System application. This "beta phase" testing of these systems can be embarrassing if system does not operate as planned and must be removed from the manufacturing floor. This example is typical of a manufacturing company initially starting a Vision Inspection component of their manufacturing operation to improve quality and customer satisfaction.

Example:

<u>A Machined part that is being mass produced</u>

1. Establish the PPM rate at which you desire to inspect the feature location and dimensioning of the part
2. Select the appropriate hardware for your needs
3. Select the appropriate software for your needs
4. Generate algorithms to analyze the digital image capture feature orientation and dimensions
5. Locate the feature to be inspected on the part
6. Measure the dimensions of that feature
7. Compare the features location and dimensions to the corresponding correct orientation example stored in the systems library of images
8. Upon system approval, give signal for the part to proceed to the next machining operation
9. Devise a plan to systematically reduce the number of nonconforming parts being produced
10. Invoke a Continuous Improvement Strategy

13. Conclusion

The Autonomation Process converts manual processes to the use of complex systems that not only automate the manufacturing process but also automatically monitor and control it. [7]

Historically there has been a problem of trying to replace human inspectors who rely on visual inspection techniques to QC manufactured or processed products and materials. Vision Inspection Systems have evolved to the point where this problem has been eliminated.

There is a large amount of work to be done on the software side of the equation even though off the shelf hardware can be purchased and adapted to most applications with relative ease. The work to be done is with relation to the image analysis creation and pattern recognition which will accurately locate, identify, and determine which class of defect has been observed.

Once this is accomplished, the throughput of the system will need to be tuned to run at the pace for the expected product flow through the manufacturing process. With a large database that stores the images needed to compare and analyze produced product against this library all that needs to be done at this point is to start up the production line and categorize any defects that the system kicks out. As the process matures, these defects can have a root cause analysis performed on them which will eliminate this particular defect from occurring.

This type of Autonomation through Mistake Proofing will allow any company to raise their quality levels while they decrease the amount of defects being produced. Concurrently, their customers will enjoy a higher level of quality products being put on the market which can increase sales and lead to new customers over time.

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