Automated quality monitoring system for Ceramic Tiles

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Abstract. In the trending decade of automation in manufacturing, quality is keenly regarded as a driving force among the industries and consumers. Though sampling techniques were introduced after automation to increase productivity and to support mass production, they fail to match up the quality of 100 percent inspection of the components. From the observation at a ceramic tile manufacturing industry, it was found that among various problems faced, the diagonals of the finished tiles were measured manually using vernier callipers. The paper proposes an automation system using proximity sensors for efficient online measurement of diagonal dimensions of the ceramic tiles by sensing the proximity of the tiles moving on the conveyor system. The microcontroller checks if the diagonals are within the required tolerance limits and displays the lengths of the diagonals and also gives a signal if they are out of limits, leading to rejection of the particular tile. The system improves the speed, along with accuracy of quality monitoring system and reduces the intensive labour work required from the inspectors.

1. Introduction
With the fast growing technology related to production and manufacturing, it has become necessary for quality monitoring to find more efficient methods to improve accuracy and reduce the intensity of labour required. Even though technologies like image processing play an important role in quality monitoring, new technological advancements in the same field are occurring. These problems can be easily solved by any of the object based image capturing method, which only captures an image of the component and measures the possible dimensions. There are also video monitoring algorithms based on DAVINCI technology [1], which provide real time data processing capabilities, and also focuses on identification and positioning by using a tactile sensor. There are also image capturing techniques where only the defective or required areas of the components are analysed [2], thus improving the efficiency and reducing hardware required. Apart from these post production inspection techniques, there are also methods that use process signal data [3] to ensure quality control over the production process. Unlike these systems, the model proposed in the paper solves the problem of online dimension checking of the tiles in a simple and more cost efficient method. It uses two proximity sensors and an Arduino setup to measure the length of the diagonals and to decide if the tiles are to be rejected or to continue on the conveyor. The proximity sensor emits electromagnetic radiation and checks for changes of the received signal after being reflected by the target. This sensor can not be used to measure distance. Rather, it can be used for applications such as collision avoidance robot and machine automation. Proximity sensors are more commonly used in automatic sorting systems [4, 5].
where components are to be sorted based on their shapes and sizes. As the tile moves along the conveyor, the proximity sensors sense the tile and an Arduino setup is used to measure the length and check the equality of the diagonals. The tile is then accepted or rejected based on the processed data. If the tile is accepted, it moves along the conveyor, otherwise it is sent to the scrap or rework according to the nature of the defect. The proposed inspection system can greatly reduce the labour and time required for manual diagonal measurement of the ceramic tiles. The system not only enhances the production performance by improving the dimensional accuracy of the tiles but also reduces the cost of inspection by replacing human labour with automation.

2. Observed industrial problems
As the company manufactures a wide variety of tiles, there are large possibilities that the finished product contains one or more defects. One of the major issues faced by the industry is the inequality of the diagonals and their dimensional inaccuracy. The lengths of the diagonals were measured traditionally using vernier callipers which was both time and labour consuming. Moreover, diagonal inspection was done only for selected tiles by sampling technique. Another major problem observed was the permanent deformation of the tile surface during the gradual cooling process. There are several methods like the ultrasonic pulse method [6] that uses ultrasonic waves to find the planarity defects on the ceramic tiles. Even though it is very time consuming to check each and every product for dimensional accuracy, these defects if not rectified may result in improper laying of tiles, also affecting overall tile quality.

3. System description and research methodology
There are various data processing methods using several camera types that are used in image capture methods. When the data is analyzed by the image sensor, the system processes the observed series of data and the required output operation is given. Traditional image sensing methods involve acquiring images through the CCD, and storing this image to perform a subsequent processing for the measurement of all the dimensions.

The system proposed in the paper is designed based on the observations from an industrial visit to a ceramic tiles manufacturing industry. The setup is built for the inspection of (1ft * 1ft) tiles, but can be reprogrammed to inspect tiles of various shapes and sizes. The setup consists of a conveyor system which carries the finished ceramic tiles in a proper orientation for quality inspection. Two proximity sensors are mounted perpendicular to the diagonals of the ceramic tiles, to sense the tiles moving on the conveyor. The dimensions of the diagonals are measured by using the time for which the proximity sensors are activated. The proposed system development methodology is shown in figure 1.

![Figure 1. Methodology.](image-url)
4. System construction

The quality monitoring system is setup on the conveyor belt carrying the finished ceramic tiles before they are packaged. A spring operated roller mechanism is used to align the tiles in a proper orientation for accurate dimensional measurement. The prototype of the tile quality monitoring system is shown in figure 2 and 3.

![Figure 2. Semi finished prototype of the devised model.](image)

![Figure 3. Software design of the model.](image)

The conveyor system has two belts that are attached in parallel to each other on the rollers. The belts move on the series of bearing rollers that provide support during the motion of the ceramic tile. The conveyor system is provided with support at the corners and and one of the shaft is driven by a high torque DC motor, which runs at 10 rpm. The main setup consists of two proximity sensors which are mounted perpendicular to each of the diagonals of the tiles. The sensor provides a non contact detection, which can return the period of time for which the ceramic tile is in its proximity. The sensors are connected and controlled by two microcontrollers, which check if the diagonals of the tiles are within the required tolerance limits. If the lengths of the diagonals are out of the required tolerance limits, the microcontroller sends a signal which leads to rejection of the particular tile.

4.1. The specifications of the proximity sensors are as follows

The proximity sensors used for the proposed prototype model is shown in figure 4 and their specifications are as follows

1. Input voltage : +5 volts DC
2. Current consumption : 25mA (minimum) ~ 100mA (maximum)
3. Sensor dimension : 1.7cm (diameter) x 4.5cm (length)
4. Sensing range : 3cm to 80cm
5. Working temperature : -25 °C ~ 55 °C
4.2. Software system
The setup is programmed and controlled using two microcontrollers. The two controllers are connected using I2C (Figure 5) communication protocol. The reason for using two controllers instead of one is that since the time period of activation of two proximity sensors are required, two timers have to be run simultaneously on the controller. Since two timers cannot be run on one UNO controller, two of them are used, one being the master and the other being the slave.

For the I2C connection, the Serial Data Line (SDA) and the Serial Clock Line (SCL) of both the microcontrollers are connected together and also they share the Ground. Usually the A4 and A5 pins of the controllers represent the SDA and SCL respectively. Both the master and slave controllers are programmed with their respective codes using Arduino IDE software. A small snippet from the code that calculates the length of the diagonal is shown in figure 6.

Both the proximity sensors send the period of time for which they were held activated to the respective controllers and these controllers convert the time into the length of the diagonals using the known speed of the conveyor belt. The master controller then sends the value to the slave, where both the values are evaluated and checked for accuracy. The tile proceeds on the conveyor if it passes the test; otherwise it is rejected or sent for rework.

5. Working
As the tile moves along the conveyor with a known speed (v), the proximity sensor is activated for a particular period of time (t). The microcontroller is programmed to return the value of time period for which the proximity sensors were in activated condition.
The product of the conveyor speed (v) and time of activation (t) gives the length (L), as shown in figure 9.

\[ L = v \times t \]

Since the angles of the diagonals are known by the design provided by the manufacturer (45 degrees in our case), the length of the diagonal (d1) is the cosine component of the length (L).

\[ d1 = L \times \cos(x) \]

where x is the angle made by the diagonal with the edges near and away from the sensors. The microcontroller checks for dimensional accuracy of the diagonals with the user given tolerance limits.
6. Result and discussion
After the time period of activation of the sensors is obtained, it is converted into the lengths of the diagonals with suitable mathematical calculations. If the dimensions are above the upper limits, the tile is sent to rework for grinding. If the dimensions are below the lower limits, the tile is rejected and sent to scrap. The tiles which pass the quality check continue on the conveyor system for packaging.

To check the actual performance of the model, three tiles were obtained from the industry and were inspected several times. The actual and measured dimensions are shown in table 1. The error in the measured diagonals as well as the mean error were calculated and graph was plotted, which is shown in figure 10.

Table 1. Error analysis.

| TILE | Experiment number | Measured dimensions | Actual dimensions | Error | Mean |
|------|-------------------|---------------------|-------------------|-------|------|
|      |                   | Diagonal 1          | Diagonal 2        |       |      |
| Tile 1 | 1 | 421.9             | 420.8             | 423.8 | 424 | 1.9 | 3.2 | 2.55 |
|       | 2 | 419.2             | 422.6             | 423.8 | 424 | 4.6 | 1.4 | 3   |
|       | 3 | 420.7             | 422.8             | 423.8 | 424 | 3.1 | 1.2 | 2.15 |
|       | 4 | 421               | 421.7             | 423.8 | 424 | 2.8 | 2.3 | 2.55 |
| Tile 2 | 5 | 420.7             | 420               | 423.7 | 423.9 | 3 | 3.9 | 3.45 |
|       | 6 | 419.9             | 421.8             | 423.7 | 425.9 | 3.8 | 2.1 | 2.95 |
|       | 7 | 421.6             | 419.3             | 423.7 | 423.9 | 2.1 | 4.6 | 3.35 |
| Tile 3 | 8 | 418.8             | 423.5             | 423.7 | 423.9 | 4.9 | 0.4 | 2.65 |
|       | 9 | 418.6             | 419.4             | 423 | 424.4 | 4.4 | 5 | 4.7 |
|       | 10| 421.1             | 423               | 423 | 424.4 | 1.9 | 1.4 | 1.65 |
|       | 11| 420.5             | 420.3             | 423 | 424.4 | 2.5 | 4.1 | 3.3 |
| Tile 3 | 12| 419.8             | 422.1             | 423 | 424.4 | 3.2 | 2.3 | 2.75 |

7. Conclusion
Optical sensing techniques are not only becoming more efficient in quality monitoring systems, but are one of the most cost effective ways of monitoring even for surface inspection of components. We have presented an automation method of quality monitoring system which is based on sensing the proximity of the ceramic tiles moving on the conveyor. The system provides a large improvement in the quality inspection process as it involves monitoring of every tile on the line, instead of “one in a lot” monitoring process, which was previously observed at the industry. The improvement in quality is efficiently done without sacrificing the time factor. In fact, the inspection time is effectively reduced by replacing human labour with automation. The proposed system can greatly reduce the labour and time required for manual inspection of the ceramic tiles, thus improving production performance, accuracy of the tiles and thereby reducing cost. The system can be developed by integrating with technologies such as Active speed controlled conveyor for improving the performance of the inspection. The system can be further optimized in the future for further improvement in accuracy and for quality monitoring of various other components.

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