

Acoustic Based Defective Glass-Ware Detector

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Abstract – *Glass-ware play a vital role in industry and household. There are many defects that can develop in a glass container during the manufacturing process. It is important to detect defective containers to deliver a quality product.*

A methodology is proposed to overcome costly systems available in industry for detection of defective glass containers. This investigation is through frequency spectrum analysis of non-defective containers and defective containers which is implemented in MATLAB software. Acoustic features are extracted from recorded soundtracks and compared with the non-defective templates available in a database. The frequency spectrum is obtained using the Fast Fourier Transform (FFT) and the features are extracted using Cross-Correlation and Mel Frequency Cepstrum Coefficients (MFCC) to identify the defective containers from non-defective containers. The comparison process involves the use of the Euclidean distance which measures the percentage of dissimilar bits out of the number of comparisons made.

The proposed system includes a striking device to excite vibrations on the glass container and the sound signal thus generated is detected by a microphone sensor and amplified. The amplified signal is passed through a band pass filter to obtain a narrow signal envelop as it facilitates the process of comparison of defective signals with a non-defective signal.

Keywords: *Cross-Correlation, FFT, Feature Extraction, MATLAB, MFCC*

1 INTRODUCTION

Glass-ware plays a vital role in industry and household. Glass containers are essential in many areas such as food industry, drink manufactures and medical packaging. It is important that containers normally in the form of bottles must be damage-free. The packages which contain perishable food or drink items must be airtight as the presence of air can cause bacterial spoilage and other health concerns. In the medical stream non-defective glass containers are essential as any leakage will cause health issues to the patients as well as the operators. The Fig. 1 shows an example image of a defective glass container.



Fig. 1. Defective Container (Dented Body)

There are many defects that can develop in a container during the manufacturing process such as cracks, air bubbles, freaks etc. (Anon, 1967). So, it is important to detect defective containers to deliver a quality product. Glass ware defects due to faults in the manufacturing process, packaging and delivering, cause difficulties to the consumer.

In most of the production lines detection of defective containers is done by human operators. Manual inspection process is slow, time consuming and prone to error. In recent years, image analysis techniques have been increasingly used in industry for surface inspection, where small defects that appear as local anomalies in material surfaces are detected (Mohan and Poobal, 2017). But these systems are expensive.

An automated and cost-effective detection method is essential to deliver a quality product in the glass-ware industry.

2 LITERATURE REVIEW

2.1 Manufacturing Process

Glass is super cooled liquid that can create marvellous objects. Silica is the main raw material, which is taken from sand filtered to eliminate CaCO_3 , MgCO_3 , and Na_2CO_3 . To form different kinds of glass containers, raw materials are melted and passed through various metallic moulds to obtain different glass-container designs. Fig. 2 shows the manufacturing process of glass containers.

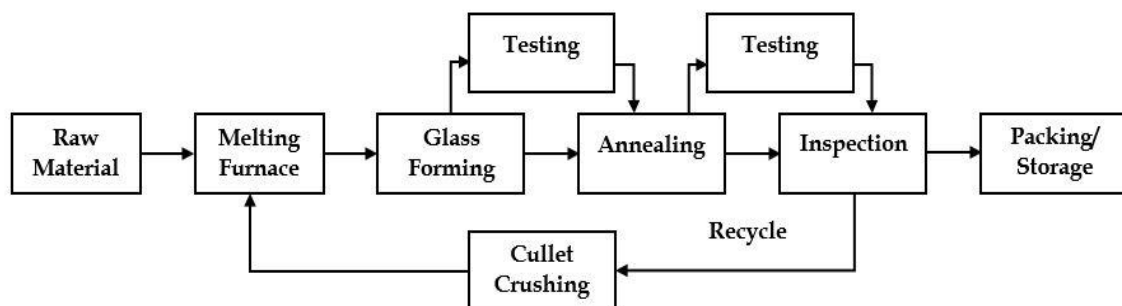


Fig. 2. Glass Container Manufacturing Process

2.2 Types of Glass Container Defects

Defects are named under parts of a container (Anon, 1967).

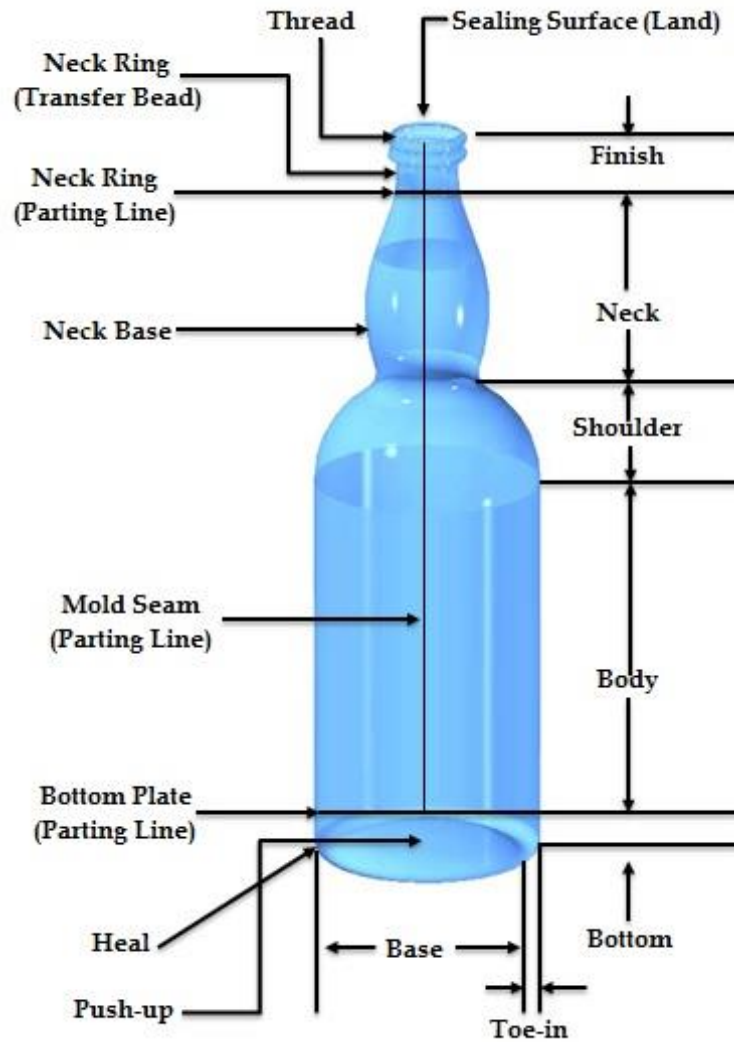


Fig. 3. Parts of a Glass Container

The various types of defects that can be present in the glass are (Anon, 1967): Checks: Consists of miniature and slight crack which does not leakage but it certainly weakness the body wall. Non-glass inclusions: Glass defects due to dirt, adhering to any unsustainable particles or due to enormous oil parks. Marks: Depict the spot or any stray marks in the glass which diminishes the quality of glass. The body of the glass becomes thinner and weaker.

Some of the glass container defects are summarised in the Table 1.

Table 1 Glass Container Defects

| Critical Defects | Body Defects | Finish Defects | Neck Defects | Bottom Defects | Shoulder Defects |
|--------------------------|----------------------------|-----------------------|---------------------|-----------------------|-------------------------|
| Freaks | Stringy Glass | Offset | Seam on Neck | Flanged Bottom | Shoulder Check |
| Spikes | Bulged Sides | Off Gauge | Dirty Neck | Wedge Bottom | Sunken Shoulder |
| Checked and Split Finish | Hot or Panel Check | Bulged and Chipped | Bent Neck | Heavy Rocker | Thin Shoulder |
| Crizzeled Finish | Pressure and Letter Checks | Over Pressed | Ling Neck | Baffle Marks | |
| Checks under Finish | Blow Mold Seam | Corkage Check | Hollow Neck | Swung Baffle | |
| Unfilled Finish | Bird Cage | Neck Ring Seam | Pinched Neck | Wedge Bottom | |
| Chocked Neck or Bore | Cold Molds | Bent or Crooked | Danny Neck | Thin Bottom | |
| Bottom Check Thin Ware | Wash Modes | Tear Under Finish | | | |
| Stuck Glass Particles | Sunken Sides | Dirty or Rough | | | |

2.3 Existing Systems

2.3.1 Machine Vision Based Defect Detection

For the inspection of a glass container, image processing is the latest technique used today. By scanning an image of a glass container and compare it with existing image templates in database and then find defective container and reject them (Mohan and Poobal, 2017, Nishu & Agrawal, S., 2011).

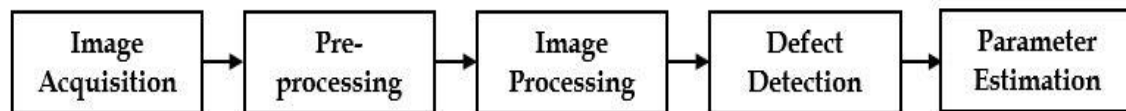


Fig.4. The Architecture of Image Processing Based Crack Detection

The processing difficulty of the crack detection completely depends on the size of the image. Recent digital cameras have the image resolution beyond 10 megapixels. This increase in resolution enables the acquisition of detailed images of concrete surfaces. By using the trendy cameras of commercial purpose, a wide range of a concrete surface can be acquired in a single shot. For inexpensive applications, a wide range image can be used for the practical crack detection (Mohan and Poobal, 2017; Ma *et al*, 2002). This system is expensive and for accurate inspection container is scanned by changing its orientation like

body check, bottom check, finish check etc. But some defects are inspected through manual examination which cannot catch by image processing.

2.3.2 Photo-Electric Crack Detector for Glass Bottles

This system is introduced apparatus for photo-electrically detecting cracks or flaws in the bottoms, necks, or lips of glass bottles while being rotated and traversed in single line through a test path, storing the effect of a signal resulting from the presence of such a defect, and utilizing said stored effect to cause ejection of defective bottles after they pass beyond the test area (Powers, 1971).

2.4 Acoustic Based Systems

According to the direction of this system development is considered the acoustic behavior of a container. There are many systems implemented all over the world based on acoustic characteristics such as acoustic accident detection system, car accident detection and notification, engine fault diagnosis using acoustic signals, leak detection in gas pipeline by acoustic and, detection of diesel engine injector faults, etc. (Atti *et al*, 2007). The following systems developed to detect some other glass container defects.

2.4.1 Plastic Coated Bottle Testing

According to this system it tests plastic coat of the bottle by its sound characteristics and reject those defective. Bottle is struck by an impact mechanism. The sound of impact is detected, and the sound decay characteristics are utilized to determine whether the bottle is solid and acceptable or whether it is cracked or broken and thereby rejected (Hartman, 1975). This system developed to check only coated bottle but can be used to detect empty glass container.

2.4.2 Method and Apparatus for Analyzing the Fill Characteristics of a Packaging Container

This system is considered about filling characteristics defects. It introduced a method for analyzing the internal pressure of a closed container includes inducing vibration in a surface of the container, detecting sound resulting from the vibration; deriving information representing the detecting sound; and predetermining whether this information corresponds to a predetermined spectral frequency condition and a predetermined spectral amplitude condition (Rodriguez, 1998). This idea can be used to detect defects which are developed during the manufacturing of glass container.

3 METHODOLOGY

In this work, a methodology is proposed to detect defective bottles or containers based on its acoustic behaviour. After taking the sound signals of bottles, signal processing and analysis techniques are applied to isolate the differences in frequency responses of non-defective glass containers and defective glass containers.

It is approached through frequency spectrum analysis of non-defective containers and defective containers. Acoustic features are extracted from the recorded soundtracks and compared with the non-defective templates available in the database. Therefore, frequency spectrum is obtained by using Fast Fourier Transformation (FFT) technique and features are extracted using Cross-Correlation and Mel Frequency Cepstrum Coefficients (MFCC) methods to isolate the defective containers from non-defective containers.

Implementation of the system includes a striking device used to excite vibration on the glass container and the sound signal is directed by a microphone sensor and amplified. The amplified signal is then passed through a band-pass filter to obtain a narrow signal envelope as it facilitates the process of comparison of defective signals with non-defective signals. Then the defective container is rejected. The block diagram of the system is given in Fig. 5.

3.1 Cause Vibration

Glass container must vibrate to obtain its sound emission and the vibration strength should be same for whole experiment. Therefore, a tap is given to the center of the body of glass container by a striking device which is designed using a solenoid because the push-pull mechanism of a solenoid can be used to tap the glass container (vibration) and then frequency levels of each container can be obtained.

3.2 Amplifier

The signal outcome of a glass container due to the vibration is detected by a microphone sensor which is situated on top of the bottle lip and amplified it to obtain a larger signal as it facilitates the work of signal processing. The frequency response lied between 5.5 kHz - 7.5 kHz. Common-Emitter Amplifier is designed as amplifier circuitry using 2N3904 NPN transistor.

3.3 Bandpass Filter

The frequency spectrums of glass containers obtained using MATLAB and it is lied between 5.5 kHz and 7.5 Hz. Therefore, wide band pass filter is designed as the filter circuitry.

3.4 Decision Making Unit

Spectrums of each signal must analyze to identify differences of sound signals of glass containers. Therefore, decision making unit involves two feature extraction methods which are used in signal processing. The two methods are Mel Frequency Cepstrum Coefficients (MFCC) and Cross-Correlation which is implemented in MATLAB environment. Features extracted for all non-defective sound samples in the database and for a given glass container. Extracted features are matched using a mathematical function called Euclidian Distance to make the final decision whether a given glass container is defective or not.

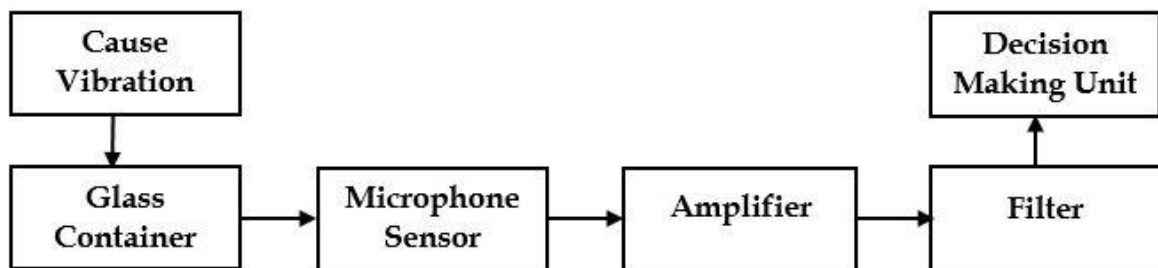


Fig.5. Block Diagram of the System

4 THEORY

4.1 Fast Fourier Transformation (FFT)

Frequency spectrum of sound signals are obtained by applying the mathematical process of Fast Fourier Transformation (FFT) which converts the amplitude data into frequency data. For any given time-window of a sound recording, FFT calculates the frequency components of the signal and their relative amplitudes produce a frequency spectrum (French, 1983).

4.2 Feature Extraction

A database contained 10 sound samples of non-defective containers and decision is made by comparing each spectrum of sound samples in database with a given sound sample of a glass container. Fig. 6 shows signals of two non-defective sound sample and Fig. 7 shows a signal of a defective sound sample.

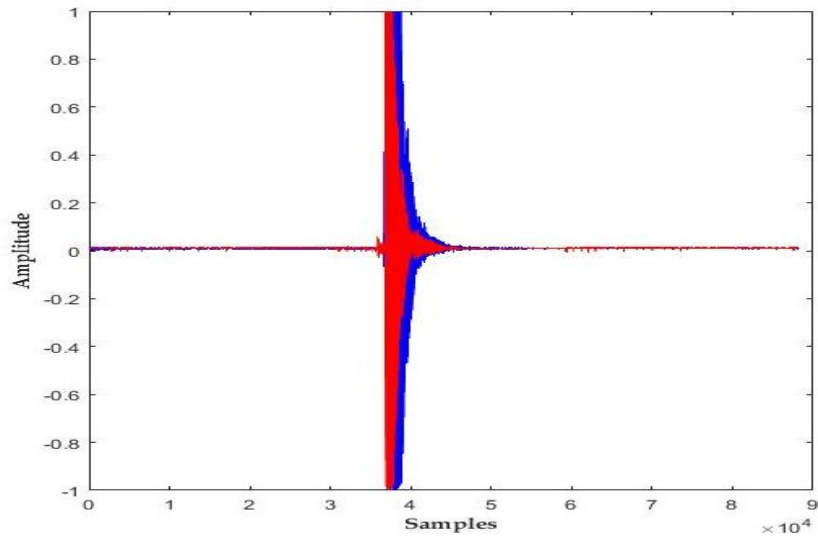


Fig. 6. Sound Samples of two Non-Defective Glass Containers

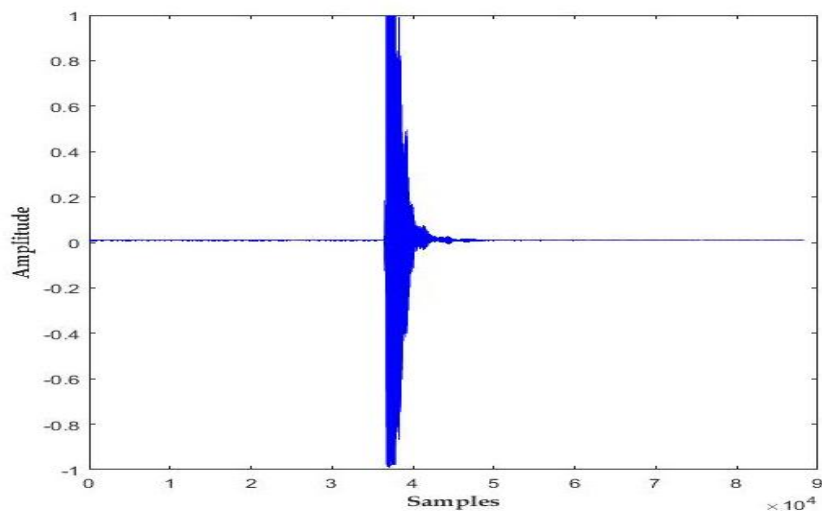


Fig. 7. Sound Sample of a Defective Glass Container

To analyse and identify differences between glass containers, spectrums are obtained of each signal and processed in MATLAB environment using two audio feature extraction methods called Cross-correlation and Mel Frequency Cepstrum Coefficients (MFCC) (MathWorks Inc, 2004). Fig. 8 and Fig. 9 represent spectrums of two non-defective glass containers and a spectrum of a defective glass container respectively.

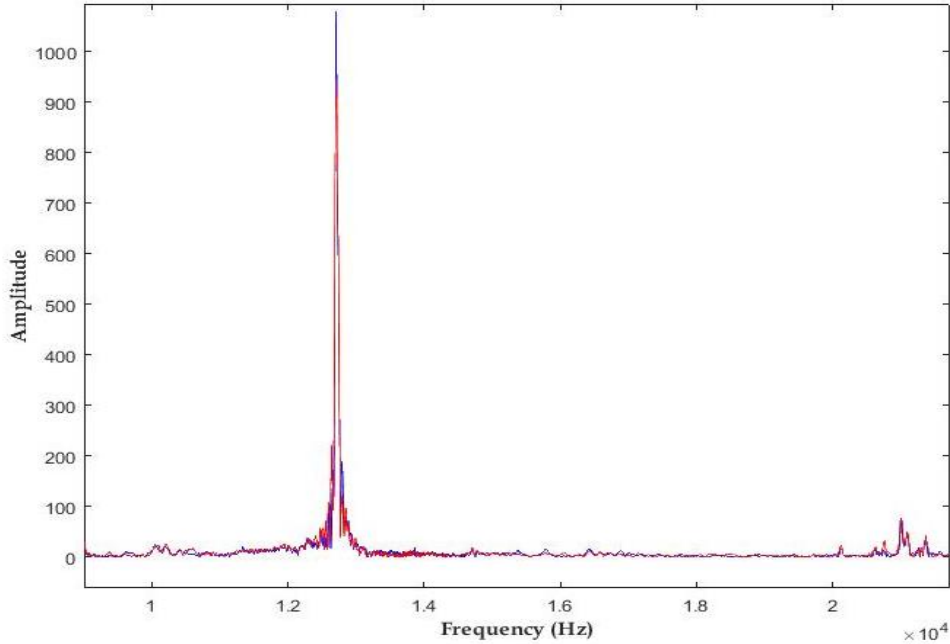


Fig. 8. Spectrums of two Non-Defective Glass Containers

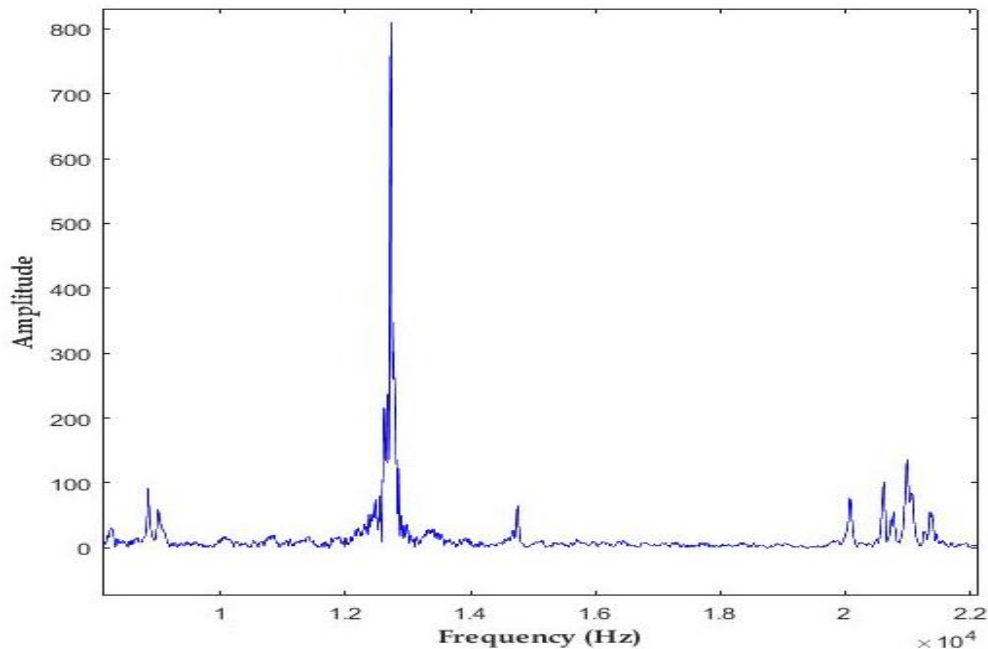


Fig. 9. Spectrum of a Defective Glass Container

In feature extraction, each audio signal segment into a relevant small number of parameters or features which describes each segment in such a characteristic way that other similar segments can be grouped together by comparing their features.

4.2.1 Cross-Correlation

Correlation function gives similarity study between signals (Atti *et al*, 2007).

4.2.2 Mel-Frequency Cepstrum Coefficients (MFCC)

MFCC are coefficients that represent audio. They are derived from a type of cepstral representation of the audio clip (a "spectrum-of-a-spectrum"). The difference between the cepstrum and the Mel-frequency cepstrum is that in the MFC, the frequency bands are positioned logarithmically (on the Mel scale) which approximates the human auditory system's response more closely than the linearly spaced frequency bands obtained directly from the FFT (Fast Fourier Transformation) or DCT (Discrete Cosine Transform). This can allow for better data processing (Bala *et al*, 2010). Fig. 6 explains the process of MFCC test.

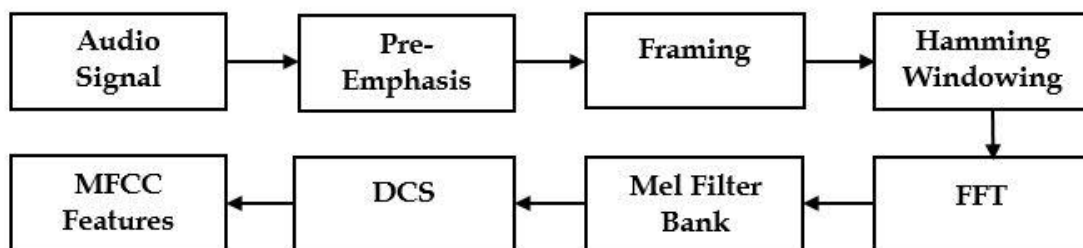


Fig. 10. Flow Diagram of MFCC Process

Pre-emphasis filter is used to balance the frequency spectrum by amplifying high frequencies (Bala *et al*, 2010). It is difficult to do Fourier transformation across the signal because frequencies in a signal change over time. To avoid this, frequencies in a signal are kept stationary over a very short period which is called "frame" and do Fourier transform over this frame (Bala *et al*, 2010). Then each frame is multiplied with hamming window. Fast Fourier Transform (FFT) is applied to each frame which transforms signal to frequency domain. Thus, the spectrum for each frame is obtained. It still contains lot of information not required for feature matching stage. The feature matching algorithm cannot discern the difference between two closely spaced frequencies (Hasan *at al*, 2004). Therefore, take clumps of spectral bins and sum them up to get an idea of how much energy exists in various frequency regions. This can be performed by multiplying each frame with Triangular MEL Filter banks (Hasan *at al*, 2004).

The result of the conversion is called Mel Frequency Cepstrum Coefficient. The set of coefficients is called acoustic vectors. Therefore, each input utterance is transformed into a sequence of acoustic vectors.

4.3 Feature Matching

4.3.1 Euclidean Distance

The comparison process involves the use of a Euclidean distance to evaluate the result of MFCC test. The Euclidean distance measures the percentage of dissimilar bits out of the number of comparisons made (Black, 2004). Ideally, when input a sound wave of a non-defective glass container, nearly its entire features match and when input a sound wave of

a defective- glass container, which does not fully match, and the system will reject the defective container.

4.3.2 FAR and FRR

The final matching decision is taken based on matching score and acceptance rates. The performance of the system is evaluated using two parameters called False Acceptance Rate (FAR) and False Reject Rate (FRR) (Hasan *et al* 2004).

FAR is calculated as $[FP / (TN + FP)] * 100 \%$

FRR is calculated as $[FN / (TP + FN)] * 100 \%$

Where,

FP is the False Positive i.e. incorrectly identified.

TP is the True Positive i.e. correctly identified.

TN is the True Negative i.e. correctly rejected.

FN is the False Negative i.e. incorrectly rejected.

5 COMPARISON

The evaluation in this work is done using 125ml Alpha (A) bottle which is shown in the Fig. 11.



Fig. 2. 125ml Alpha (A) Bottle

Frequency spectrums of sound signals of containers lie between 5.5 kHz and 7.5 kHz. According to the observations, spectrums of non-defective containers quite similar while defective containers give different spectrums.

In Fig. 12, spectrums of 10 sound samples non-defective glass containers represent in blue colour and red colour represents a spectrum of a defective glass container.

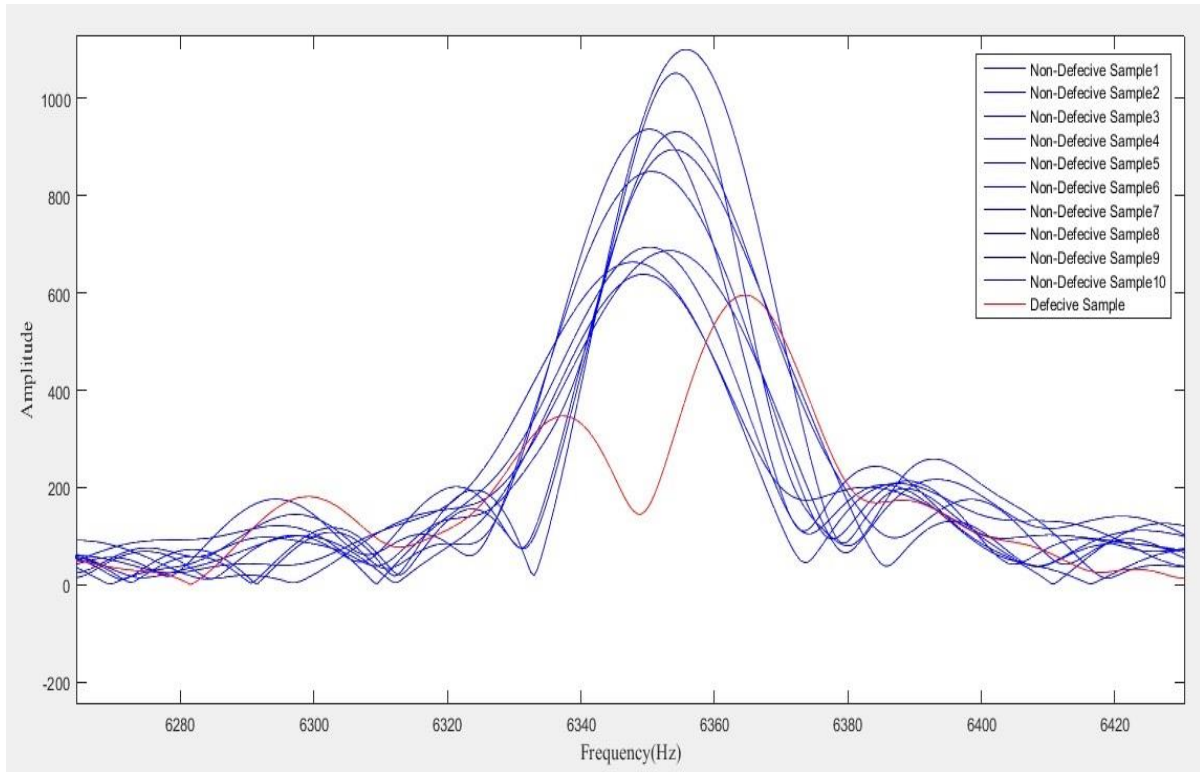


Fig. 12. Comparison of Frequency Spectrums of Non-Defective Glass Containers vs Defective Glass Containers

Each test used for feature extraction and matching gives a vector table. After doing several tests each vector table evaluated to find a value that can predict a threshold level which can use to direct the comparison process. The database is created including 10 audio samples of non-defective glass containers which were recorded for 2 seconds. For the real time testing, audio signal recording time for a given glass container is stationary to 2 seconds. In the testing process, test file is overlapped with the template files in the database and their features are compared. The analysis concludes whether the container is damage-free or otherwise.

6 RESULTS

6.1 Cross-Correlation Test

According to the evaluation of the vector tables received for cross-correlation test a threshold value is identified as 600. Therefore, in the design it checks whether the maximum values obtained in the vector tables during the cross-correlation test, exceeds the threshold value.

If a processed audio wave for a given glass container exceeds the threshold value, then it gives the result as the container is not defective. If that value lies below the threshold value, the container is identified as a defective one. Following Table 2 shows the results for three tests which are applied cross-correlation test.

Table 2 Results for Cross-correlation Test

| Database | Defective Container1 | Defective Container2 | Non-Defective Container |
|-----------|----------------------|----------------------|-------------------------|
| Sample 01 | 447.120 | 367.913 | 1147.097 |
| Sample 02 | 434.258 | 366.530 | 1030.859 |
| Sample 03 | 535.043 | 351.768 | 511.014 |
| Sample 04 | 357.698 | 321.715 | 712.359 |
| Sample 05 | 511.716 | 376.805 | 1142.853 |
| Sample 06 | 375.490 | 342.189 | 767.511 |
| Sample 07 | 434.338 | 372.178 | 1016.184 |
| Sample 08 | 442.189 | 340.933 | 891.427 |
| Sample 09 | 490.659 | 399.687 | 969.486 |
| Sample 10 | 458.603 | 372.689 | 1016.389 |

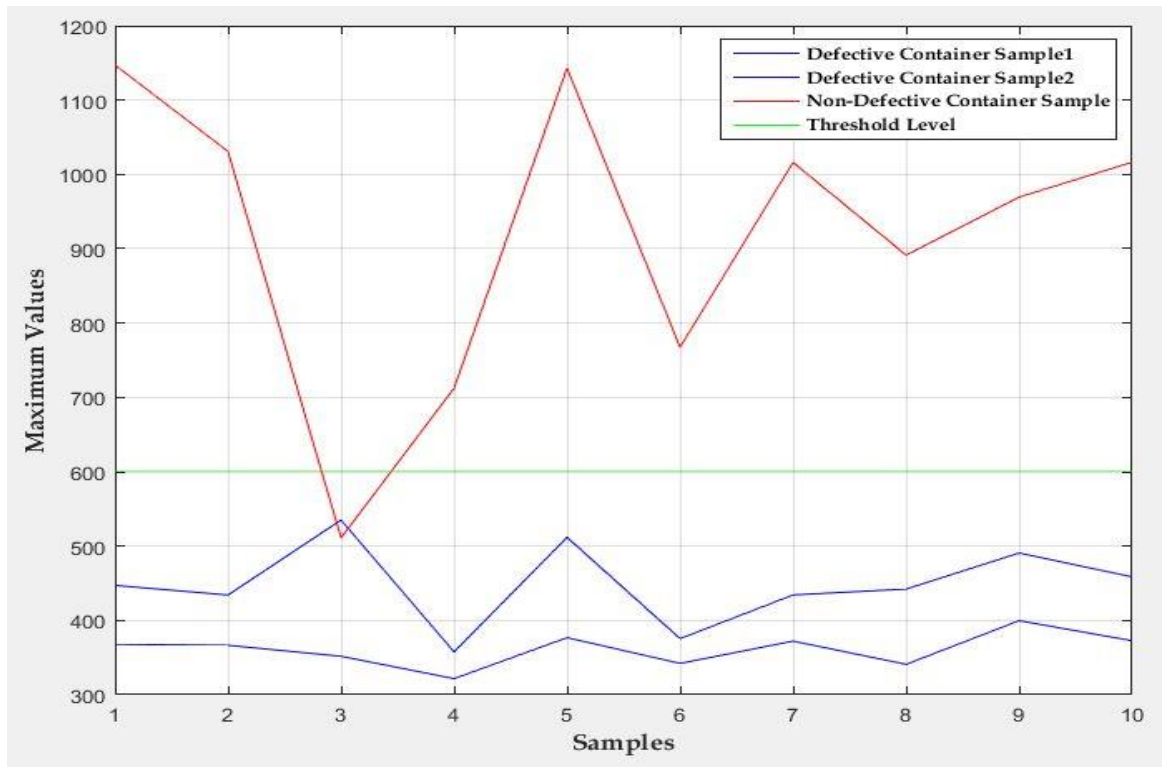


Fig. 13. Cross-correlation Result of Three Tests

Green line in the Fig. 13 represents the threshold level which is concluded for the prediction of container status. The result of a test which is lie below the threshold value (i.e. 600), is identified as a defective container.

6.2 MFCC Test

In the MFCC test it calculates 13 MFCC coefficients of each audio sample. To apply MFCC method following parameters should be defined according to the type of the container.

Table 3 Parameter Values for MFCC Test

| Parameter | Value |
|--|---------|
| Analysis Frame Duration | 25ms |
| Analysis Frame Shift | 10ms |
| Pre-emphasis Coefficient | 0.97 |
| Centre Frequency of Lowest Mel-filter | 5000Hz |
| Centre Frequency of Highest Mel-filter | 7000Hz |
| No. of Mel bands | 40 |
| Sampling Frequency | 44100Hz |
| No. of Cepstral Coefficients | 13 |

Euclidean distance between test audio sample and samples in database is calculated to direct the comparison process. It gives distance vectors of 13x13 matrixes for each comparison. The 13th column of each distance vector gives the variation for distances. Therefore, each vector table evaluated to obtain a threshold value. According to the evaluation of vector tables a threshold value is identified as 860. This is the maximum possible distance value for a non-defective container can acquire. Following Table 4 and Fig. 15 shows the test results of three tests with same glass containers used for cross correlation test given above.

Table 4 Results for MFCC Test

| Database | Defective Container1 | Defective Contaner2 | Non-Defective Container |
|-----------|----------------------|---------------------|-------------------------|
| Sample 01 | 829.202 | 822.740 | 909.947 |
| Sample 02 | 838.892 | 831.818 | 918.037 |
| Sample 03 | 815.817 | 810.244 | 889.153 |
| Sample 04 | 835.219 | 828.556 | 912.36 |
| Sample 05 | 848.772 | 842.516 | 926.526 |
| Sample 06 | 815.817 | 810.244 | 889.153 |
| Sample 07 | 846.629 | 840.071 | 925.312 |
| Sample 08 | 829.137 | 822.744 | 904.835 |
| Sample 09 | 832.081 | 825.059 | 913.496 |
| Sample 10 | 842.095 | 835.531 | 922.505 |

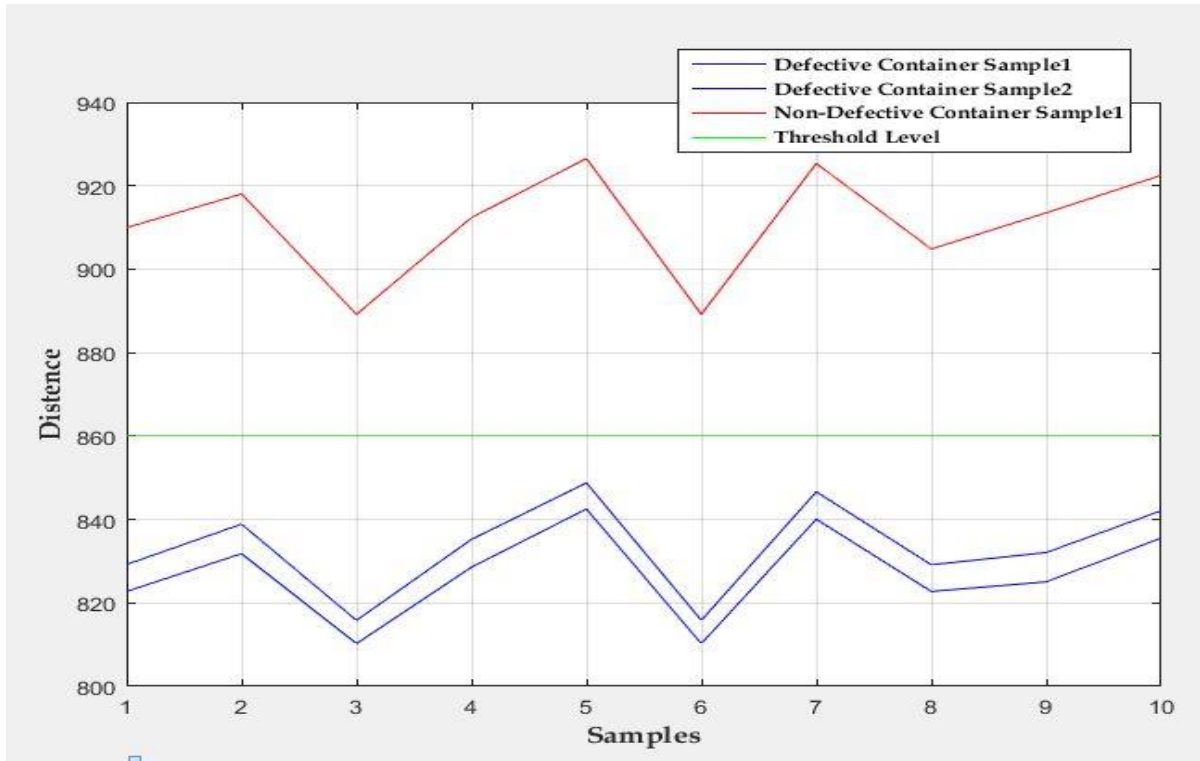


Fig. 14. MFCC Result for three Tests

In the Fig. 14 the threshold level represents by the green line (i.e. 860). If the maximum value of a distance vector exceeds the threshold value, the test sample is identified as defective container.

6.3 FAR and FRR

The final prediction is done by comparing both test results and obtained the FAR is around 10%, and FRR is around 18%. The FAR and FRR test results of 60 tests are given in the Table 5.

Table 5 Test Results of FAR and FRR

| Test | FAR % | FRR % |
|---------|-------|-------|
| 1 - 10 | 9 | 16 |
| 11 - 20 | 7 | 18 |
| 21 - 30 | 10 | 16 |
| 31 - 40 | 6 | 15 |
| 41 - 50 | 11 | 11 |
| 51 - 60 | 8 | 18 |

7 CONCLUSIONS

This investigation is approached through frequency spectrum analysis of non-defective glass containers and defective glass containers. By vibrating a glass container its' sound outcome is recorded to extract acoustic features which is then compared with non-defective sound templates available in the database. Therefore, frequency spectrum is obtained by using Fast Fourier Transform (FFT) technique and features are extracted using Cross-Correlation and Mel Frequency Cepstrum Coefficients (MFCC) methods to isolate the defective containers from non-defective containers. The comparison process involves the use of a Euclidean distance which measures the percentage of dissimilar bits out of the number of comparisons made. The final prediction is done by comparing both test results and obtained the FAR is around 10%, and FRR is around 18%. We expect that the extracted features can uniquely represent the status of the container.

Recently, machine vision based (image processing) defect detection systems are most popular in the industry. But we have identified advantages and disadvantages of those systems by comparing them with this proposed system.

Table 6 Comparison with Existing Systems

| Feature | Existing Systems | Proposed System |
|---|------------------|-----------------|
| Cost | High | Low |
| Portability | Low | High |
| Set-up Area | High | Medium |
| Maintenance | High | Low |
| Reliability | Medium | Medium |
| Operating | High | Medium |
| Accuracy (False Acceptance Rate - FAR) | Low | Medium |
| Accuracy (False Rejection Rate - FRR) | Medium | Medium |

This work is concluded through strong defects such as chocked bore, offset seal, wavy body, dented body, etc. For further arrangements we hope to develop this methodology to detect all kind of defects.

ACKNOWLEDGEMENT

Authors wish to extend their gratitude to Piramal Glass PLC Company for their kind support given to successfully carry out this research.

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