Judgment Technology to Automate Sensory Inspection

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Abstract

"Sensory inspection" detects normality / abnormality by using human senses. Its weakness is that the criterion is hard to define, but its strength is that it is able to detect a range of abnormalities.

Our company has been researching a way to automate the process of identifying 'abnormal noises' (a kind of sensory inspection) as this is an issue in our inspection process of DVD deck production line. To quantitatively judge "abnormal noises," our past approach has been to pre-judge many 'abnormal patterns' at the initial step, and apply those as inspection tools. The limitation of this approach is that the test only looks for those 'pre-set' patterns.

Now we have developed and implemented new technology to judge "normality" by use of quality engineering MT method on the judgment part of abnormal noise inspection device and by defining patterns of normal products.

1 Introduction

We at Fujitsu Ten have a process of abnormal noise inspection in a production line for in-vehicle DVD decks, in which abnormal noises generated by operations such as disc insertion / ejection are to be checked. However, pass/fail judgment by human senses in the abnormal noise inspection depends on the individual senses, and thus its criteria vary. In this reason, we have been searching the way to automate the process of abnormal noise inspection based on uniform criteria.

In advance of this automation, we developed sound recording technology in noisy environments of production lines and automatic judgment technology, and installed the inspection device to the production line of DVD decks. The judgment technology of this inspection device uses judgment algorithms for detecting items matching to prescribed abnormal patterns. Naturally, this judgment method required the definition of abnormal patterns and complicated criteria since actual products contain various abnormal patterns. Thus, this inspection method was difficult to be used for other models, and the method had some problems of excess detection where a normal product was detected as abnormal due to the complicated criteria.

To solve this problem, we developed new judgment technology with MT method that can judge whether items match normal patterns or not.

2 Problems in Conventional System and Development Objectives

2.1 Problems in Conventional System

Fig. 1 and **Fig. 2** show the outline of the conventional abnormal noise inspection device mentioned above.

The processing flow of this system is as follows; record of the operation noises generated by a test item in a sound-proof box where outside noises are insulated, Extraction of the part for judgment from the recorded data, filter processing / digitization of sound waveforms, check of the result against abnormal patterns, and then pass/fail judgment.

The pass/fail is judged whether the data matches any of the prescribed abnormal patterns of more than a dozen; the data matching none of them is judged as normal and the data matching some of them is judged as abnormal.

However, as mentioned above, the conventional system had problems as follows.

(1) A lot of abnormal patterns were needed in advance of the step to production line. However, it was difficult to define all the abnormal patterns before launching mass production.

(2) The excess detection rate was approx. 2%.

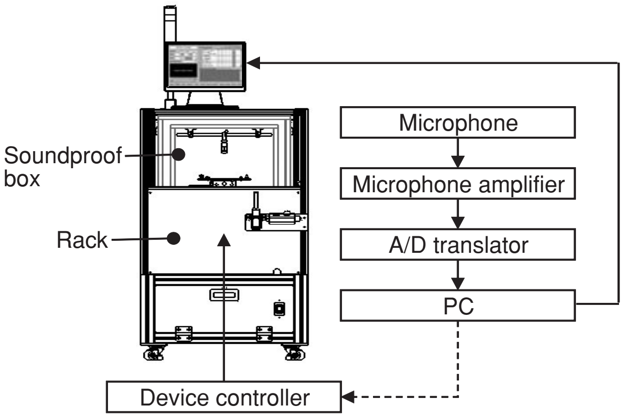

Fig.1 Outline of Conventional System (Hardware)

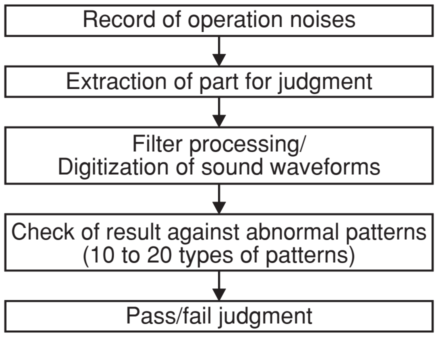

Fig.2 Outline of Conventional System (Inspection flow)

2.2 Development Objectives

We addressed the development of the judgment technology for new abnormal noise inspection to solve the problems of the conventional system. The development objectives are as follows:

(1) Hardware: same level as conventional system

(2) Judgment algorithms:

①Judgment criteria shall be created only with normal products even before launching mass production.

②The excess detection rate shall be kept at 1% or less under the state with no outflow of an abnormal product. (The rate here is the half or less of the excess detection rate occurred in the conventional system)

To carry out the development objective; "Judgment criteria shall be created only with normal products," new algorithms different from the conventional ones for pattern matching against abnormal patterns are required for judging whether normal products or not. So, we developed new judgment technology using MT method for carrying out the development objective mentioned above.

3 Abnormal Noise Inspection Technology with MT Method

3.1 Outline

MT method is a method for pattern recognition where the concept of Mahalanobis distance was taken into quality engineering system, which was developed in 1980 to 1990 by Dr. Genichi Taghchi; inventor of quality engineering. The MT means Mahalanobis Taguchi. Now the method with various aspects added is called MT system. The MT system is used practically or going for practical use in the following fields.

- **Classification (handwritten character recognition, sound recognition, image recognition)**
- **Prediction (profit prediction, earthquake prediction, strength prediction)**
- **Diagnosis (disease diagnosis, fire alarm, inspection for industrial use, malfunction diagnosis)**

The following phrase in famous novel "Anna Karenina" will be a help to understand the MT method.

"Happy families are all alike; each unhappy family is unhappy in its own way."

Looking at the abnormal noise inspection in a manner of this phrase, "Normal sound waveforms are all alike in features; each abnormal sound waveform is abnormal in its own way."

This MT method, using the definition obtained from the data collections only of normal products (hereinafter referred to as "unit space"), which is easy to be defined due to their uniformity, judges all the waveforms far from the definition as abnormal.

Fig. 3 shows the concept of "Mahalanobis distance" used as a unit indicating near or far from the unit space. In MT method, when the calculated Mahalanobis distance is short, the waveform is judged as normal since it is near the unit space, on the other hands, when the distance is long, the waveform is judged as abnormal since it is far from the unit space. Mahalanobis is the name of Indian statistician who introduced this concept.

The Mahalanobis distance is defined as follows;

$$\text{Mahalanobis distance} = k X^t R^{-1} X \ (k\text{: constant}) \cdots \quad (1)$$

X: Multidimensional vector that is a set of physical quantities (hereinafter referred to as feature value) distinguishable between normal and abnormal (X^t: transposed matrix)

R: Correlation matrix calculated from unit space (R^{-1}: inverse matrix)

In this MT method, through the normalization of data mentioned below, the Mahalanobis distance of a normal product becomes nearer 1; on the contrary, the distance of an abnormal product becomes larger than dozens. Using this nature, we can digitize the qualitative judgment criteria that have depended on human hearing sense.

The characteristics of this MT method are as follows;

(1) Single numerical value (Mahalanobis distance) can elicit the qualitative judgment of pass/fail.

(2) This method, which does not extract abnormal-specific patterns, can detect unknown abnormal patterns that might appear in the future.

To make a judgment of pass/fail in the abnormal noise inspection with this method,

- **creation of unit space and formula (1)**
- **set of threshold value for Mahalanobis distance calculated through formula (1)**

are required.

The concrete procedure for calculating Mahalanobis distance is as follows;

①Collect sound waveforms (unit space data) of normal products and extract plural feature values (generally approx. 200 values) suitable for pass/fail judgment. (Table 1)
(e.g. level, waveform area, etc.)

②Calculate m (average value) and σ (standard deviation) for each feature value.

③Normalize data set of each feature value so as to make m=0 and σ=1.

④Obtain correlation matrix R of the normalized data.

⑤Substitute the value of the calculated inverse matrix of correlation matrix R into the formula (1).

⑥Obtain sound data targeted for judgment, extract feature values and calculate Mahalanobis distance through the formula (1).

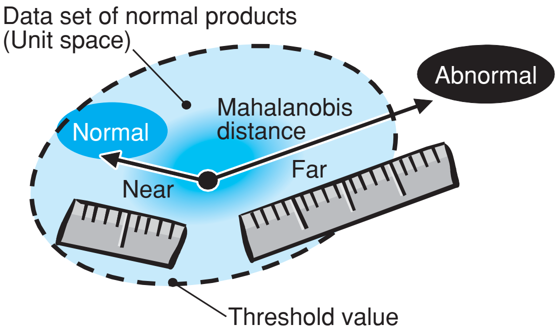

Fig.3 Concept of Mahalanobis Distance

3.2 Procedure for MT Method for Abnormal Noise Inspection

When conducting actually the abnormal noise inspection, first, obtain the value of R-1 of the formula (1) by following offline the procedure ① to ⑤ mentioned in Section 3.1. Then, set the threshold value for the Mahalanobis distance (hereinafter referred to as MD value). When there is no abnormal pattern available for verification, set the threshold value around at 5 or less. This is because the average of MD values of unit space tends to be 1. When there are some abnormal patterns, set the threshold value at the one between the MD values of normal patterns and abnormal patterns.

Calculate the MD value by following the procedure ⑥ at the production line and compare the value to the threshold value. When the value is bigger than the threshold value, judge the item as abnormal. When the value is smaller, judge the item as normal. The accuracy of the pass/fail judgment depends on the accuracy of formula (1) to obtain the MD values. The accuracy of the formula (1) depends on the accuracy of the unit space, since it is created based on a unit space. Further, the judgment accuracy depends on the feature values and the set of normal products, since the unit space is created based on the feature values indicated in **Table 1** and the set of normal products. Here, the feature values used for the abnormal noise inspection are the values digitized from sound waveform features.

Table 1 Data of Normal Samples (Examples)

	Feature value 1	Feature value 2	…	Feature value N
Sample A	0.15	0.32		0.55
Sample B	0.11	0.41		0.43
Sample C	0.13	0.35		0.44
:	:	:		:
Sample N	0.11	0.42		0.45

3.3 Algorithms to Digitize Sound Waveforms

Since the judgment accuracy of abnormal noise inspection depends on the feature values of sound waveforms as mentioned above, the sound waveforms must be digitized accurately. As for the digitized waveform values, looking at time-axis waveforms, abnormities in frequency component such as "piercing noise" can not be detected. Looking at frequency waveforms, the abnormities in time component such as rattle noise can not be detected.

To respond to this problem, both of the information of sound waveforms in time domain and frequency domain must be digitized. Thus, we decided to use feature values in a matrix containing both of the information of time domain and frequency domain, which are obtained through the algorithms in Fig 4. by dividing sound waveforms into three areas (low-pitch, middle-pitch and high-pitch sounds) and digitizing time-axis waveforms of each area.

3.4 Unit Space Creation

Using the algorithms for digitization mentioned in Section 3.3, we created the unit space. Even normal noises generated at operating DVD decks vary. Thus, the judgment accuracy depends on which data are extracted from a large amount of data for the creation of unit space. This time, the engineer in charge of deck development, who has set criteria to judge abnormal noises before, selected approx. 300 sound waveforms judged as normal, and created the unit space by using the algorithms in **Fig. 4**.

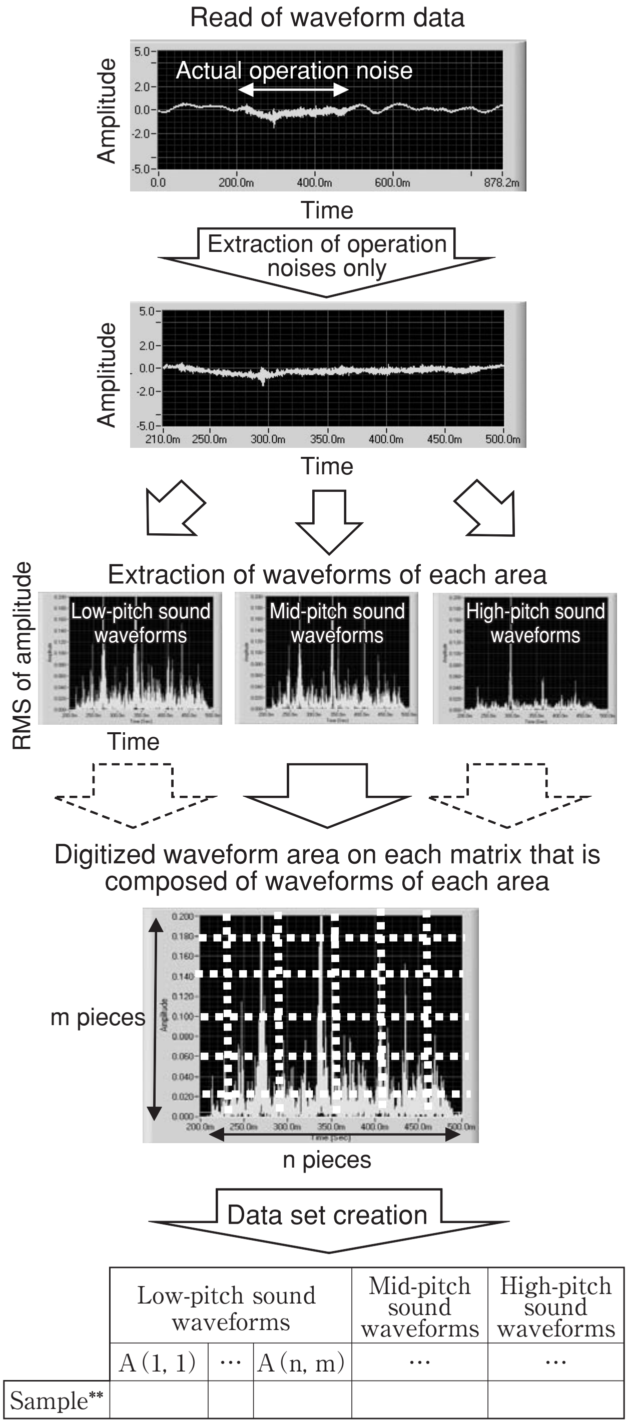

Fig.4 Algorithms to Digitize Sound Waveform

3.5 Judgment as Normal or Abnormal Products by Use of MD Values

We verified the effectiveness of judgment with the products already judged as normal or abnormal by use of the algorithms for digitization mentioned in Section 3.3 and the unit space created in Section 3.4. Here, the minimum value within the MD values of abnormal product set was used as the threshold value. In the verification result of excess detection to normal product set, with taking 1000 samples (N) including abnormal products, the excess detection rate was 1.5% as shown in **Fig. 5**.

The result indicated the prospect of the excess detection rate lower than the system used at that time regardless of unsuccessful result to the development objectives; target excess detection rate was set at 1% or less. So, we decided to have a trial on the actual production line.

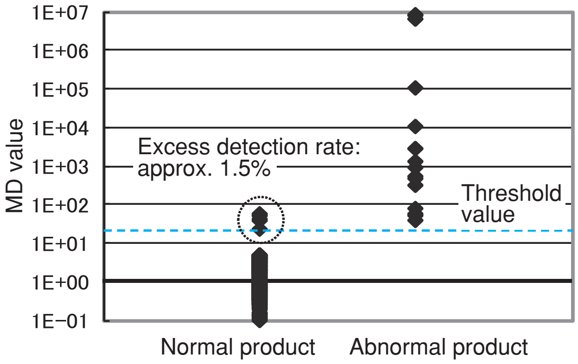

Fig.5 Accuracy in Judging Normal/Abnormal Products by Use of MD (Mahalanobis Distance)

3.6 Software Development for Offline and for Production Line

For the actual operation on a production line, new software adaptable to the following points is required.

At offline;
- **creation of unit space**
- **set of threshold values for MD values**

At production line;
- **digitization of sound waveforms**
- **calculation of MD values**
- **judgment by MD values**

However, the development of software exclusive for the production line requires a large amount of man-hours, because the software will be used as other than judgment (e.g. I/O control). We decided to develop the software exclusive for offline and the judgment software for the production line that can be incorporated as a part of FUJITSU TEN's standard inspection sequence. **(Fig. 6** and **Fig. 7)**

[Software exclusive for offline]

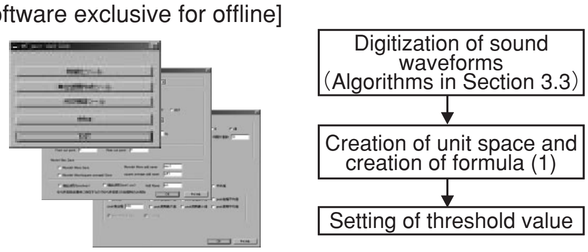

Fig.6 Software Exclusive for Offline Use

[Software exclusive for production line]

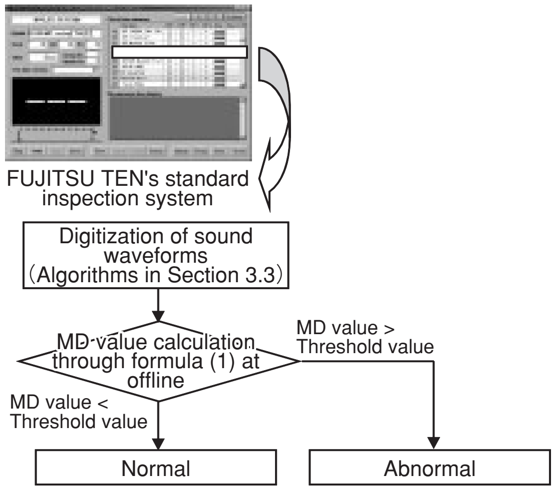

Fig.7 Software Exclusive for Production Line

3.7 Application Result to Production Line

The application of the software developed in Section 3.6 to the production line resulted in approx. 5% of excess detection rate that was far above the rate verified in Section 3.5. **(Fig. 8)**

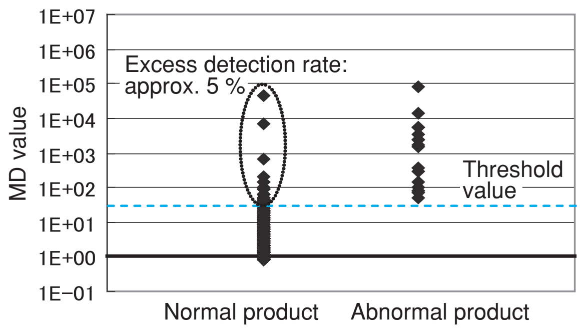

Fig.8 Excess Detection Rate When Applying Software on Production Line

The MT method judges all the items other than normal products as abnormal by its nature. Thus, the normal products with the features different from the ones of samples used for the unit space are judged as abnormal due to their large MD values. The operation noises slightly vary due to the various lots of component parts or installation state. The occurred excess detections were caused because the detection was too sensitive to ignore the variance. To solve this problem, adjustment is needed to reduce the excess detections. There are three adjustment methods in MT-method judgment as follows;

①Review of threshold value for MD values

It is simply to shift the threshold value for MD values. However, it is not a realistic way as seen in **Fig. 9**, because shifting the threshold value for MD values may result in the occurrence of outflow of abnormal products.

②Review of feature values

It is to analyze the feature values of the product judged as abnormal regardless of normal one due to excess detection, and to reset its feature values. However, the change in feature values requires recreation and re-verification of the unit space from the start because the existing unit space will be no longer available. This leads to a large amount of man-hours to be required. While this method is effective when the feature values were not examined thoroughly, this method, when the feature values were examined thoroughly, is not realistic due to the difficulty in adjusting the feature values.

③Review of unit space

It is to add newly the pattern judged as abnormal regardless of normal pattern due to excess detection, as a normal one into the existing unit space. Thereafter, the normal products with the same pattern can be judged as normal due to their small MD values.

In this examination, the feature values were examined thoroughly and a lot of abnormal sample data were collected. Thus, we concluded the method ③ above was realistic. We tried to add newly the normal product data judged as abnormal due to excess detection into the existing unit space. However, by adding the unchecked excess detection samples into the unit space, the pass/fail judgment did not work properly due to the MD values of real abnormal products lowered (as in **Fig. 9**).

To solve this problem, we reviewed the unit space based on the algorithms shown in **Fig. 10** and **Fig. 11** and the judgment improved as in **Fig. 12**.

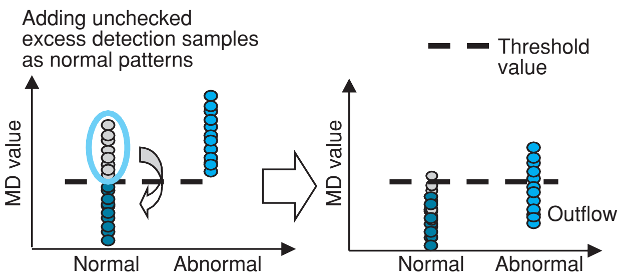

Fig.9 Result When Adding Unchecked Excess Detection Samples

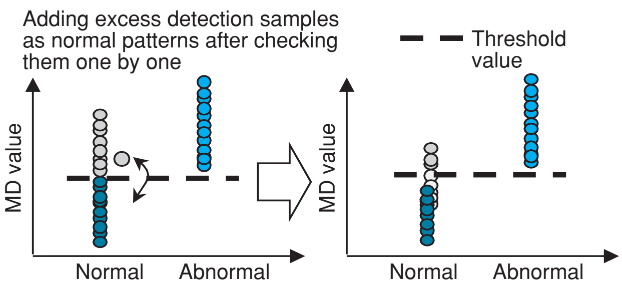

Fig.10 Result When Adding Checked Excess Detection Samples

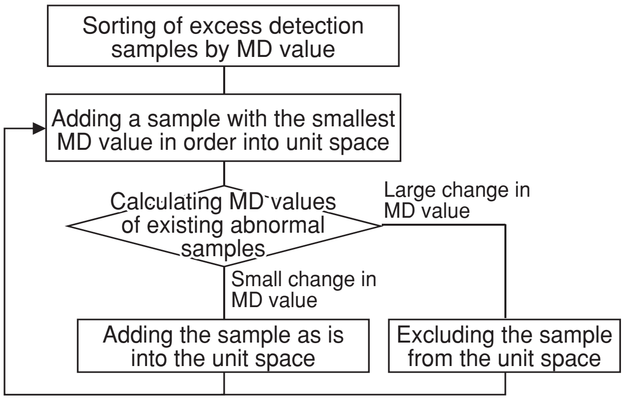

Fig.11 Algorithms to Add Excess Detection Samples into Unit Space

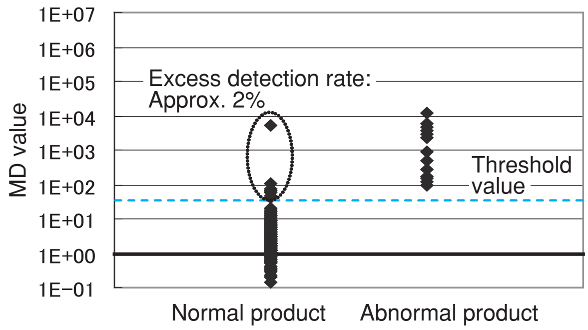

Fig.12 Excess Detection after Reviewing Unit Space

3.8 Further Reduction of Excess Detection

As in **Fig. 12**, we succeeded in finding the method to reduce the excess detection rate down to approx. 2%, but still not at 1% or less of our target rate. The main factors blocking the successful reduction of excess detection is the existence of sound waveforms shown in **Fig. 13**, **Fig. 14** and **Fig. 15**. The sound waveforms in **Fig. 13** and **Fig. 14** indicate clicking noises in a specific range (e.g. faint noises generated when the bend of a FPC changes) and the waveforms in **Fig. 15** indicates rattle noises of low level. The sound waveforms in **Fig. 13** and **Fig. 14** are to be judged as normal because they indicate the operation noises generated in normal operation with no problem by hearing. However, the sound waveforms in **Fig. 15** are to be judged as abnormal because they indicate abnormal sounds.

Since the peak of the sound waveform in **Fig. 13** is generated at unfixed timing, even after the waveform is added into the unit space, another peak of the sound waveform as in **Fig. 14** leads to excess detection again. It is difficult to distinguish the waveforms as in **Fig. 15** from the levels of the operation noises generated by a normal product near a boundary as in **Fig. 16**.

However, the conventional judgment technology to detect abnormal patterns can detect specific patterns. So, the sound waveforms as in **Fig. 13**, **Fig. 14** and **Fig. 15** are to be judged not by MT method by the conventional technology; setting specially the patterns in **Fig. 13** and **Fig. 14** as normal and patterns in **Fig. 15** as abnormal. **(Fig. 17** and **Table 2)**

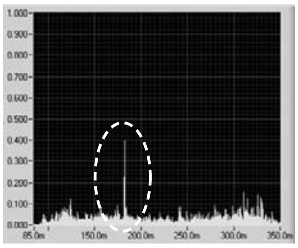

Fig.13 Sound Waveform 1 Having Clicking Noise of No-problem

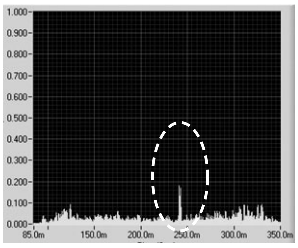

Fig.14 Sound Waveform 2 Having Clicking Noise of No-problem

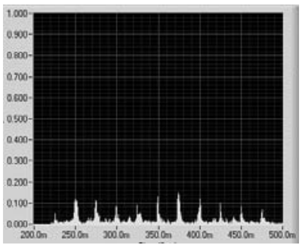

Fig.15 Rattle Noise of Low Level

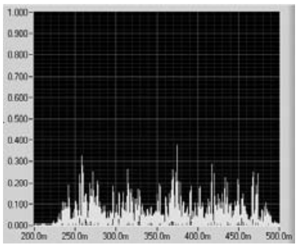

Fig.16 Operation Noise of Normal Product Close to Boundary

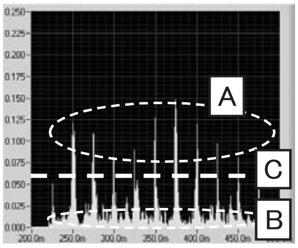

Fig.17 Application of Conventional Judgment Technology

By the conventional judgment technology,

- **Level rate between A and B**
- **No. of excess times over level C**
- **whole level**

are used for waveform pattern detection.

Table 2 Judgment of Fig.13 to Fig.16 by Conventional Technology

	Level rate	No. of excess time	Whole level	Judgment
Sound waveform in Fig.13	Large	Small	Low	OK
Sound waveform in Fig.14	Large	Small	Low	OK
Sound waveform in Fig.15	Large	Large	Low	NG
Sound waveform in Fig.16	Small	Small	High	OK

4 Judgment Technology to Automate Sensory Inspection

4.1 Judgment Technology to Automate Sensory Inspection

As mentioned in the development and verification result mentioned in Section 3 above, for aiming at the achievement of the development objectives, using only algorithms in **Fig. 6** and **Fig. 7** is not enough to reduce the excess detection. The method combining the algorithms indicated in **Fig. 11** and the conventional judgment technology is effective. We concluded the effective judgment technology to automate the sensory inspection is as follows; at the introduction step, use the algorithms indicated in **Fig. 6** and **Fig. 7** because of no abnormal patterns, next at the irregular normal patterns detected as excess detection or abnormal patterns occurred, optimize the unit space, and then, change the judgment to the one using the conventional judgment technology.

Fig. 18 shows the actually-available judgment algorithms, which is the improvement result of **Fig. 6** and **Fig. 7**.

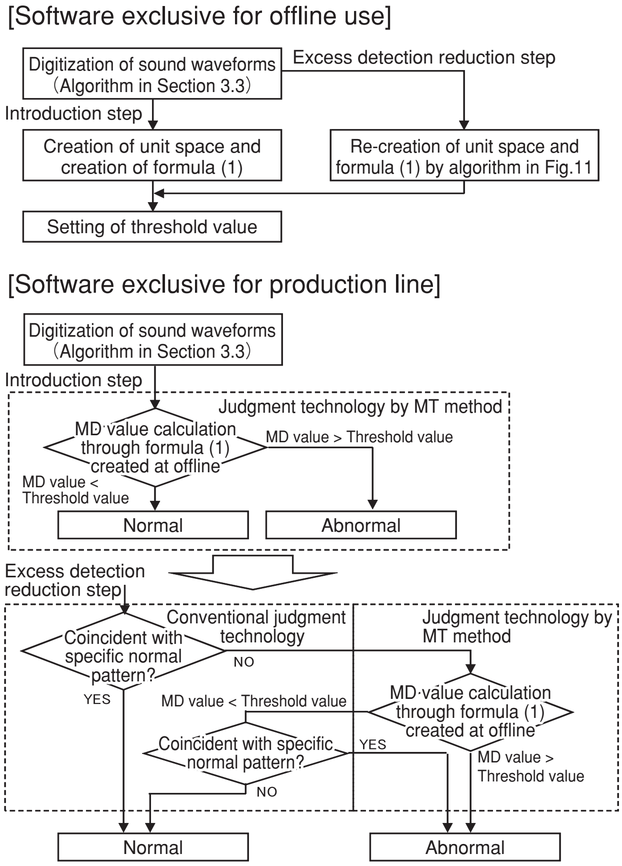

Fig.18 Judgment Technology to Automate Sensory Inspection

4.2 Application Result and Future Objectives

(1) Application result

Table 3 shows the application result of judgment technology indicated in **Fig. 18**.

Table 3 Application Result

Development objectives	Conventional judgment technology	Judgment technology by MT method	Combination of conventional method + MT method
Creation of criteria only with normal products	NG	Best	OK [1]
No outflow of abnormal products	OK	OK	OK
1% or less of excess detection	Approx. 2%	Approx. 2%	1% or less [1]

(2) Future objectives

We confirmed the quality engineering MT method is effective for sensory inspection through the use of the MT method for abnormal sound inspection. This method is also available for other sensory inspections when the features of inspection targets can be digitized accurately.

On the contrary, MT method requires much data of unit space rather than a lot of feature values based on the mathematical restrictions. In other words, a lot of normal samples are required prior to the introduction. We will look for another method using judgment criteria requiring fewer normal samples.

5 Conclusion

This paper introduced a new judgment technology to automate sensory inspection with an application example of abnormal noise inspection processing.

Lastly we would like to express our sincere thanks to all concerned in this development.

Reference

"Ohanashi MT system (Quality engineering method to expand prediction/guess possibility)"
Published by Japanese Standards Association, 2005

＊(1) While the judgment criteria can be created only with normal products at the introduction step, the judgment flow must be changed to the one shown in Fig.18 at the mass-production step in order to satisfy the prescribed excess detection rate at 1% or less.

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