Psychometric Evaluation with Correlation for Multiple Perceptions

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ABSTRACT

In this paper, we propose a new method for improving detection probabilities of the defect inspection in quality control on the FRP product surface. Our proposed method has improved the detection probabilities by using the joint probabilities of dual attributes with correlation for multiple perceptions. In order to obtain the improving detection probability, three kinds of attributes such as size, aspect ratio, and color density are prepared in experiments. The experiments were performed by the paired comparison under constant stimuli. The result of our experiment qualitatively shows that the improving ratio of detection probabilities for dual attributes:P12, P23, P31 respectively rise approximately 21%, 26% and 24% for the mean in the case of dual attributes experiments. In addition, detection probabilities to be obtained by our method for multiple perceptions such as using dual attributes experiment were improved approximately 28% in comparison with the detection probability of past single attribute. These results showed our method was effective in rising detection probability for multiple perceptions.

Keywords: Human performance, Joint probability, Bivariate normal distribution, Intelligent visual inspection, Detection threshold for attribute of image data

1. INTRODUCTION

In a progress of a current science and technology, it is no exaggeration to say that the steady development of an instrument to measure or observe something about an object serves an important role. In particular there is the progress of a measuring method for a physical hard object of single attribute such as the measure of length, weight, strength in a material, microscope, telescope, illuminometer, thermometer, and other visibility method. On the other hand, the progress of measuring method or evaluation technique in the soft object such as sensor networks[1] for ubiquitous computing, human perception, and decision making for ambient intelligence need to more strengthen the foundation in soft science and technology.

In addition, recently mixed multiple and conjunction measuring methods from a point of view multiple attribute have been hot issue since the progression for multiple attributes has been later than the single attribute measurement. In this study, drawing focus to multiple perceptions in visual inspection system for defects on the product surface, we propose a new method to measure the multiple attributes for soft science and technology.

Recently, several kinds of image processing method have been applying to the automated visual inspection system for defects on the product surface [2,3]. One of the aims of this research is also in the development of the heuristic and simple method that is used in the judgment process in the automated visual inspection system instead of inspector. A sort capacity by human vision is extremely high-performance, therefore such a soft information processing to a sort of images has been regarded unfit on the computer which is good at digital information processing. On the other hand, a visual inspection process has been holding the problem in productivity, since the performance of a precision and a speed will be degraded by fatigue of the inspector. In order to meet these problems, some research works were tried for the standardization of an operation time of visual inspection [4-7], though it is not reached to the place which fixes a good evaluation measure, and research of productivity of the production system which consists of a process including such a human being has left lots of problems unresolved.

In the practical situation of quality control on visual inspection, a panel must decide the judgement of the quality by using one's sensitivities for multiple attributes whether the quality of object is good or not. On the other hand, it is required in the field of automated visual inspection system to measure the characteristics of sensitivities for multiple attributes and to evaluate the detective probability when the multiple attributes were used for the judgement of inspection. In this case, it is an important viewpoint to obtain the skill of the professional sense that has the knowledge or skill. In order to meet these problems, a new trial is proposed for the evaluation of human ability on psychometric function. The standard sample was designed by means of paired comparison and constant stimuli. In order to evaluate the visual sensory properties of panel in the practical inspection task, the psychophysical experiment was performed to obtain the psychometric curves to evaluate the distinction probability of target object under the situation of various combinations of mixed dual attributes. This analysis is to obtain the psychometric curve and to estimate the parameters of detectable probability distribution by the experiment of standard sample for single attribute. It is also examined to estimate the correlation among the attributes of figure and to estimate the detection probabilities when the decision was made under the situation of multiple attributes.

2. PSYCHOMETRIC METHOD AND DEFECT INSPECTION

2. 1. Psychometric curve by single attribute experiment

Psychometric curve, as shown in Figure 1, is a continuous curve which is made from the detection probability as a function of stimulus strength, when the strength of stimulus is continuously varied over a range of values.

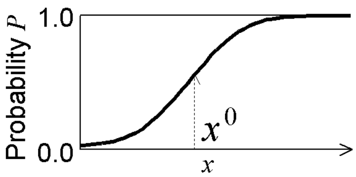


Fig.1 Psychometric curve.

The psychometric curve fit a continuous function $f(x)$.

$$P = f(x) \tag{1}$$

Equation (1) can be derived from the relationship.

$$P = \Phi(y) = \int_{-\infty}^{y_i} \phi(y)dy, \quad y = \frac{x-\mu_x}{\sigma_x} \tag{2}$$

In Equation (2), $\Phi(\bullet)$ and $\phi(\bullet)$ is cumulative distribution function and probability density function of the standardized normal distribution

$$\phi(y) = \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}} \tag{3}$$

where μ_x and σ_x is a mean and standard deviation of the strength of stimuli x. If the observation probability $\hat{P}_j$ ($j=1,2,\ldots, m$) that is the ratio of the number n_j to the total number of trials N_j, where n_j is the number of the answer by subject when one answer that j-th degree of strength of stimuli x_j is larger than x_0. The observed probability $\hat{P}_j$ at j-th degree of strength of stimuli x_j is obtained by

$$\hat{P}_j = n_j \;/\; Nj \qquad (j=1,2,\ldots,n) \tag{4}$$

The normalized variable $\hat{y}_j$ is defined by the inverse function of $\Phi(\bullet)$ such as:

$$\hat{y}_j = \Phi^{-1}(\hat{P}_j) \tag{5}$$

However, since $\hat{y}_j$ is rewritten by linear relation of stimuli x_j

$$\hat{y}_j = a + bx_j \tag{6}$$

it is noted from Eqs.(4),(5) and (6)

$$\hat{P}_j = \Phi(a + bx_j) \tag{7}$$

Thus the normalized variable obtained from observed probability from sensory test of single attribute can be formulated by the linear function of j-th degree of strength of stimuli x_j of single attribute.

The estimation of this regression coefficient of a and b will be estimated by the following method. Since it can be assumed that the probability that obtain the number n_j to the total number of trials N_j are distributed by the rule of binomial distribution with the mean P_j and variance $P_j(1-P_j)$, the probability that obtain the set of number ($n_1, n_2, \ldots, n_n$) to the total number of trials N_j is given by

$$P(n_1, n_2, \ldots, n_m) = \prod_{j=1}^{m} \frac{N_j!}{n_j!(N_j - n_j)!} P_j^{n_j}(1-P_j)^{N_j - n_j} \tag{8}$$

Therefore, maximum likelihood estimators of a and b are possible to be estimated by partial derivation of the logarithm of likelihood function of Equation (8)

$$L(a,b) = \sum_{j=1}^{l} \log \frac{N_j!}{n_j!(N_j - n_j)!} + \sum_{j=1}^{l} n_j \log P_j + \sum_{j=1}^{l} (N_j - n_j)\log(1-P_j) \tag{9}$$

Thus the ML estimators of a and b can be obtained as the solution of the simultaneous equations such as:

$$\frac{\partial l}{\partial a} = 0 \text{ and } \frac{\partial l}{\partial b} = 0 \tag{10}$$

Since this simultaneous equation cannot be soled analytically because of its non-linearity, it is used to solve Equation (10) by a numerical method such as Newton Raphson Method and so on.

One of the way to obtain the solution of Equation (10) is to iterate the sequential calculation such as

$$\begin{bmatrix} a \\ b \end{bmatrix}_{k+1} = \begin{bmatrix} a \\ b \end{bmatrix}_k + \begin{bmatrix} \frac{\partial^2 l}{\partial a^2} & \frac{\partial^2 l}{\partial a \partial b} \\ \frac{\partial^2 l}{\partial b \partial a} & \frac{\partial^2 l}{\partial b^2} \end{bmatrix}_k^{-1} \begin{bmatrix} \frac{\partial l}{\partial a} \\ \frac{\partial l}{\partial b} \end{bmatrix}_k \qquad (11)$$

until the convergence of a and b. This method of obtaining the ML estimators of a and b is called Probit method[9]. On the other hand, it is possible to use regression analysis x_j and temporary candidate of normalized variable

$$y_{wk_j} = \hat{y}_{wk_j} + \frac{1}{\phi(\hat{y}_{wk_j})}(p - P_{wk_j}) \qquad (12)$$

where $\hat{y}_{wk_j}$ is the normalized variable obtained by Eqs.(8), (9) and (10). The solutions derived by this regression analysis is same as those obtained by Equation (11). An example of this probit analysis is illustrated in Figure 5 where the distinction between initial and probit analyses can be confirmed.

2. 2. Approximation evaluation for detection probability of dual attribute experiments

The probability obtained by psychometric curve or by Equation (1) means the probability that one can feel the strength of stimuli of target object larger than specified strength of stimuli such as threshold x^0 in Figure 1. Therefore, this probability is also calculated by Equation (2) as a probability that one can judge that the strength of stimuli of the target sample for paired comparison is larger than that of standard sample as shown in Figure 3. From this discussion, now suppose that this probability is defined by

$$P_i = P(E_i) \qquad (13)$$

where $P(\bullet)$ is an occurrence probability of probability event $\bullet$. E_i means the probability event that a panel judges that the strength of the stimuli of the target sample is less than that of the threshold x_i^0 such as a standard sample for i-th attribute among multiple attributes to express the characteristic of interest.
On the other hand, now suppose that the detection probability P under the situation of multiple attributes are defined by

$$P = P(E_1 \cup E_2 \cdots \cup E_n) \qquad (14)$$

In this condition, the confidence interval of detection probability P under multiple attributes can be estimated with upper and lower probability bounds P_L and P_U such as $P_L \le P \le P_U$ by the equations [8].

$$P_L = P_1 + (P_2 - P_{12}) + \sum_{k=3}^{n} \max\left\{ P_k - \sum_{l=1}^{k-1} P_{lk} \, , 0 \right\} \, ,$$
$$P_U = P_1 + \sum_{k=2}^{k_n} \min\{P_k - P_{lk}\}, \; for \;\; l \in \{1,2,\cdots,k-1\} \qquad (15)$$

where $P_1 \ge P_2 \ge \cdots \ge P_n$. In the equation, P_{lk} is the joint probability of the events E_l and E_k

$$P_{lk} = P(E_l \cap E_k) \qquad (16)$$

that can be calculated by the integral

$$P_{kl} = \Phi(y_k, y_l) = \int_{-\infty}^{y_k}\int_{-\infty}^{y_l} \phi(y_k, y_l; \rho_{kl}) dy_k dy_l \qquad (17)$$

where $\phi(y_k, y_l; \rho_{kl})$ is the density function of bivariate standard normal distribution.

$$\phi(y_k, y_l; \rho_{kl}) = \frac{1}{2\pi\sqrt{1-\rho_{kl}^2}} \exp\left\{ -\frac{1}{2(1-\rho_{kl}^2)} \left(y_k^2 - 2\rho_{kl} y_k y_l + y_l^2 \right) \right\} \qquad (18)$$

where

$$y_k = \frac{x_k - \mu_k}{\sigma_k}, \quad y_l = \frac{x_l - \mu_l}{\sigma_l}, \quad y_k^0 = \frac{x_k^0 - \mu_k}{\sigma_k}, \quad y_l^0 = \frac{x_l^0 - \mu_l}{\sigma_l},$$

$$\mu_k = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x_k \phi(x_k, x_l) dx_k dx_l \, ,$$

$$\mu_l = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x_l \phi(x_k, x_l) dx_k dx_l \, ,$$

$$\sigma_k^2 = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (x_k - \mu_k)^2 \phi(x_k, x_l) dx_k dx_l \, ,$$

$$\sigma_l^2 = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (x_l - \mu_l)^2 \phi(x_k, x_l) dx_k dx_l \, ,$$

$$\rho_{kl} = \frac{\sigma_{kl}}{\sigma_k \cdot \sigma_l} \qquad (19)$$

2.3. Detection probability of dual attribute experiments for discrete quantity

Correlation coefficient in multi attribute experiment is obtained by Equation (19) in a theoretical sense. In the experiment, detection probabilities to calculate correlation coefficient are discretely obtained by actual measurement, hence the calculation of discrete quantity is prepared as follows. Detection probabilities p_{ij} ($i = 1,2, \ldots, n$, $j = 1,2, \ldots, m$) are obtained discrete probabilities $p_{g_{ij}}$($i = 1,2, \ldots, n-1$, $j = 1,2, \ldots, m-1$) for each discrete zone of combination i variable and j variable.

$$p_{g_{ij}} = \max\left(p_{ij} - p_{i+1,j} - p_{i,j+1} + p_{i+1,j+1}, \, 0\right) \qquad (20)$$

where $g_{ki}=(x_{k,i}+x_{k,i+1})/2$, $g_{lj}=(x_{l,j}+x_{l,j+1})/2$. Discrete probabilities $p_{g_{ij}}$($i = 1,2, \ldots, n-1$, $j = 1,2, \ldots, m-1$) is normalized and used gravity point.

The parameters μ_k, μ_l, σ_k^2, σ_l^2, $\sigma_{k\,l}$ are calculated using the following equation.

$$\mu_k \doteqdot \sum_{i=1}^{n-1}\sum_{j=1}^{m-1} g_{ki}\, p_{g_{ij}} \qquad \mu_l \doteqdot \sum_{i=1}^{n-1}\sum_{j=1}^{m-1} g_{lj}\, p_{g_{ij}}$$

$$\sigma_k^2 \doteqdot \sum_{i=1}^{n-1}\sum_{j=1}^{m-1} (g_{ki}-\mu_k)^2\, p_{g_{ij}} \qquad \sigma_l^2 \doteqdot \sum_{i=1}^{n-1}\sum_{j=1}^{m-1} (g_{lj}-\mu_l)^2\, p_{g_{ij}}$$

$$\sigma_{kl} \doteqdot \sum_{i=1}^{n-1}\sum_{j=1}^{m-1} (g_{ki}-\mu_k)(g_{lj}-\mu_l)\, p_{g_{ij}} \qquad (21)$$

That is approximately obtained from discrete quantity.

3. EXPERIMENT

3. 1. Experimental material: inspection data

An attention has been paid on three kinds of attributes such as the size, aspect ratio and color density of object in the sampling image data. These selected attributes are considered from the practical visual inspection image data of FRP product as shown in the left photo in Figure 2. In the visual inspection, there are many candidates detected from the image data. These candidates are called "object" for judgement whether the quality of object is poor not. For the purpose of this judgement, three kinds of attributes such as the size, aspect ratio and color density of object are selected as the typical qualities that mean geometric characters of the defect or flaw in the surface of FRP product. The size is the first attribute of the object for the judgement that is quantified by area or maximum length of the object. The aspect ratio is the second attribute of the object that is defined by the ratio of the shortest radius to the longest radius. The color density is the third attribute of the object that is quantified by 8bit digits from 0 to 255. Table 1 is mean and standard deviation of three attributes by image processing.

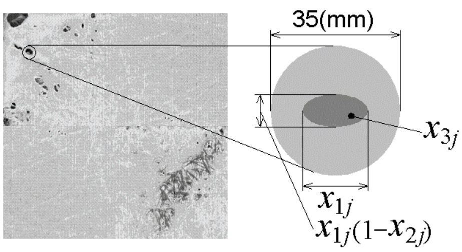


Fig.2 Inspection image data and parameters of sample.

For the sensory test, the strength of these attributes must be formulated as the strength of stimuli in order to obtain the psychometric function that is used to evaluate the relation between the detection probability and stimulus threshold for each attribute in the experiment. Some standard samples of objects are captured from the practical inspection image data of FRP panel in Figure 2.

The properties of the three attributes are investigated statistically. Thus the strength of stimuli x_{1j}, x_1^0 of size as the first attribute is quantified as

$$x_1^0 = \sqrt{\frac{4S}{\pi\mu_R}}, \quad S = 15\,\mu_A \qquad (22)$$

$$x_{1j} = \sqrt{\frac{4S_j}{\pi\mu_R}}, \quad S_j = 15\{\mu_A + \sigma_A h_A (j-3.5)\} \qquad (23)$$

where μ_A, σ_A, μ_R are the mean and the standard deviation of size, and the mean of aspect ratio respectively. The constant value of 15 in Eqs. (22) and (23) is a scale factor and The h_A is a coefficient for normalization and j is from 1 to 7. Target sample stimuli are 7 levels. Standard sample stimulus is set the centre of the target sample stimuli. In a similar way, the strength of stimuli for the second and third attributes are

Table 1 Statistics by image processing

	area size (mm^2)	aspect ratio	color density
mean	μ_A = 5.855	μ_R = 0.361	μ_V = 0.547
S.D.	σ_A = 19.113	σ_R = 0.197	σ_V = 0.422

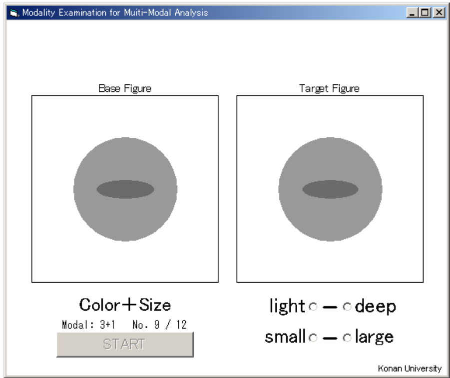


Fig. 3 Samples for sensory evaluation experiment.

Table 2 Stimuli strength of standard and target samples.

i	x_i^0	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}
1	17.50	16.05	16.63	17.20	17.80	18.38	18.95	19.53
2	0.639	0.611	0.622	0.633	0.644	0.655	0.666	0.677
3	0.547	0.517	0.529	0.541	0.553	0.565	0.577	0.589

obtained as follows. The strength of stimuli x_{2j}, x_2^0 of shape of object as the second attribute is defined by

$$x_{2j}=(1-\mu_R)+\sigma_R h_R(j-3.5),\quad x_2^0=(1-\mu_R) \qquad (24)$$

where constant number σ_R is the standard deviation of aspect ratio. In this case, the original data of aspect ratio is calculated by $1-\mu_R$ from the standard samples. Finally, the strength of stimuli x_{3j}, x_3^0 of the color density of object as the third attribute is quantified as

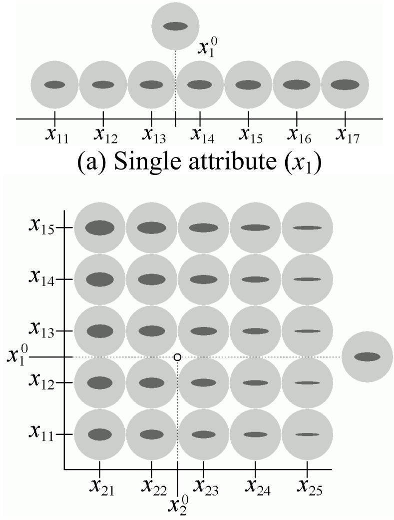
$$x_{3j}=\mu_V+\sigma_V h_V(j-3.5),\quad x_3^0=\mu_V \qquad (25)$$

where μ_V, σ_V are respectively the mean and the standard deviation of the color density of object as shown in Table 1. The values of coefficients h_A, h_R, and h_V are decided by the previous experiments, and are 0.053, 0.055, and 0.028 respectively. In this way, the strength of stimuli x_{ij}, x_i^0 (i=1,2,3, j=1,2,…,7) were set for the paired comparison, then they were presented as shown in Figure 3. In this case, the original data of color density of the object is obtained by capturing from inspection data as 8bit digits from 0 to 255. As the color density, grey scale of that density is defined by Equation (25) is used as the third attribute, since it is well known that the degree of grey scale density is applicable rather than true color scale to judge whether the quality of object is poor or not. From the above definitions of the strength of stimulus of the attributes, it may be possible to evaluate the psychometric curve that means psychometric function of detection probability to strength of stimuli. It is well known that this curve can be obtained by the experiment of the method of constant stimuli. Table 2 shows the value of stimulus strength of standard sample x_{1j}, x_{2j} and x_{3j} and target samples x_1^0, x_2^0 and x_3^0.

In this paper, the paired comparison method is used to evaluate the psychometric curve for the mentioned attributes as shown in Figure 5. The attribute of standard sample in paired comparison is designated by the right side figure in Figure 2 where an object with heavy density is a sample object with the strength of stimulus of size, aspect ratio and color density. The degrees of these attributes of object can be created by the specified strength of stimuli of attributes and stimulus thresholds such as x_1, x_2 and x_3 as shown in Figure 4.

3. 2. Experimental method

The target sample is located in the centre on background figure that is within a circle with light density as shown in Figure 3. The degree of visual field is about 1 degree from fixation point for target figure and 2 degree for background circle. The paired comparison method is used for standard sample where the allocation of constant and target figures are located on left and right



(b) Dual attributes (x_2 and x_3)

Fig. 4 Examples of degree of stimuli

side respectively in the standard sample as shown in Figure 3.

The strength of the visual stimulus is divided into several categories that are dependent on the strength of stimulus. One of the example on the strength of stimulus of attributes such as size and aspect ratio is shown in Figure 4 (a) and (b). It is seen that there are two kinds of standard samples for single and dual attributes.

The answer of subject is performed as a selection from two kinds of candidates, for examples:
1. The size of target sample is larger than that of standard sample.
2. The size of target sample is smaller than that of standard figure.
A subject must answer two kinds of questions simultaneously for the single and dual attributes.

In the single attribute experiment, as shown in Figure 4 (a), 7 levels of stimulus are tested trials N_j=30 (j=1,2,⋯,7) per strength of stimulus. Actual measurement probabilities p_j are obtained by the experiment of paired comparison which are obtained reaction number n_j under constant stimuli such as:

$$p_j = P(x_{ij} > x_i^0) \quad (i=1,2,3, j=1,2,\cdots,7)$$

hence, $1-p_j$ is equivalent to $P(x_{ij} < x_i^0)$ in a similar way.

In the dual attribute experiment, as shown in Figure 4 (b), 25 levels (5 times 5 levels for each variable) of stimulus are tested trials N_{kl} = 15 (k,l=1,2,⋯,5) per strength of stimulus. Actual measurement probabilities p_{kl} such as $x_{ik} > x_{ij}^0$ and $x_{jl} > x_{ij}^0$ (i,j =1,2,3, $i \neq j$) are obtained by

$$p_{kl} = P\{(x_{ik}>x_{ij}^0)\cap(x_{jl}>x_{ij}^0)\}+ P\{(x_{ik}>x_{ij}^0)\cap(x_{jl}<x_{ij}^0)\}/2+P\{(x_{ik}<x_{ij}^0)\cap(x_{jl}>x_{ij}^0)\}/2.$$

Hence, $1-p_{kl}$ is proper for $P\{(x_{ik}<x_{ij}^0)\cap(x_{jl}<x_{ij}^0)\}$ and the same probabilities 1/2 are supposed $P\{(x_{ik}>x_{ij}^0)\cap(x_{jl}<x_{ij}^0)\}$ and $P\{(x_{ik}<x_{ij}^0)\cap(x_{jl}>x_{ij}^0)\}$ in balance.

In the experiment, 13 persons from 20 to 28 years old were selected as subjects who have regular class load vehicle licenses with normal vision or corrected normal vision. The size, aspect ratio and color density are selected as the attributes of target sample which strengths of stimuli are represented by the variables x_1, x_2 and x_3.

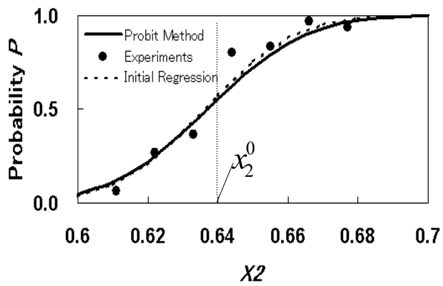


Fig. 5 Psychometric curves (Subject A)

4. EXPERIMENT RESULTS AND DISCUSSION

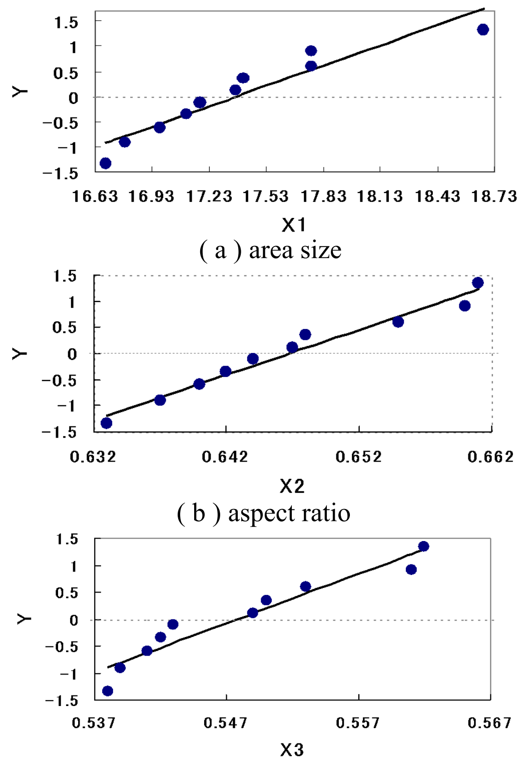
4. 1. Experimental results in the single attribute experiment

As an example of psychometric curve, Figure 5 illustrates the psychometric curve of a subject derived from the data measured by paired comparison test for single attribute of x_1. As can be seen Figure 5, a monotonically increasing function is derived from the ML estimation in the case of all experimental conditions.

Distributions of differences on characteristic of x_1, x_2 and x_3 among 10 subjects are shown in Figure 6. This distribution of PSE can be obtained by method of mean rank in due small order of PSE. From Figure 6, it is known that the mean values of PSE of x_1, x_2 and x_3 are 17.37, 0.647 and 0.548 respectively. Mean values of PSE become close the standard stimuli of x_1^0, x_2^0 and x_3^0. In addition, on the other hand, the coefficients of variation are 0.043, 0.018 and 0.020. Distributions of PSE indicate normality as can be seen to become near straight lines on the plane by normalized variable Y and strength of stimuli x_i.

4. 2. Experimental results in the multi attribute experiment

From the result in experiments, the probabilities for dual and multiple attributes are larger than that of single attribute as shown in Figure 7. This tendency is same in all experimental conditions. Increasing amount of detection probability, however, is not same in different ways with the variation of correlation coefficient. In fact, the variation is seen from the correlation coefficient ρ_{12} , ρ_{23} and ρ_{31} for combinations of attributes x_1 , x_2 and x_3 in Table 3. In addition, mean values of correlation coefficient ρ_{12} , ρ_{23} and ρ_{31} are 0.21, –0.081 and 0.066 respectively. On the other hand, Table 4 shows improving ratio of detection probabilities for dual attributes: P12, P23, P31 respectively rise approximately 21%, 26% and 24% for mean in the case of dual attribute experiments. That is to say improving ratio of detection probabilities have a pronounced tendency to depend correlation coefficient. In addition, the improving ratio PL which is obtained by the approximation formula for the multiple attributes rises approximately 28% in comparison with the detection probability of past single attribute.



(a) area size

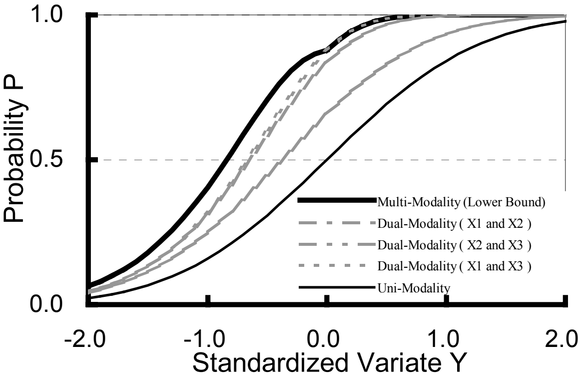
(b) aspect ratio

(c) color density

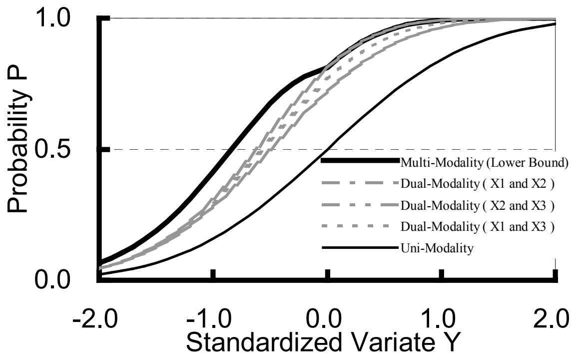
Fig. 6 Sample distribution of PSE for each attribute

4. 3. Discussions

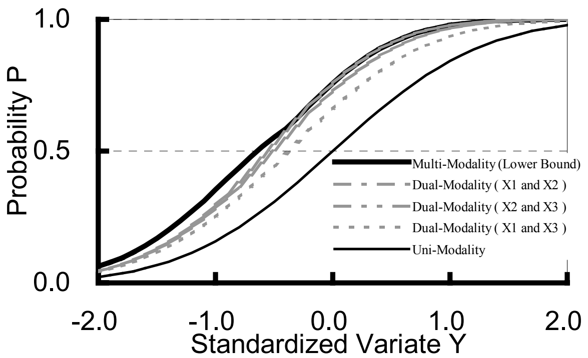
Apparently, we success the growth of detection probability on the dual attribute experiment more than on the single attribute experiment as shown in results.



(a) Subject C



(b) Subjects G



(c) Subject Y

Fig. 7 Example of psychometric curves for multiple perceptions

Mean values of PSE are close the standard stimuli. Distributions of PSE tend indicate normality as can be seen to become near straight lines on the plane by normalized variable Y and strength of stimuli x_i from single attribute experiment. These results suggest that standard stimulus is near the threshold on the detection probability, therefore, target stimulus of setting range is good to obtain psychometric curve.

The detection probabilities for dual and multiple attributes are larger than that of single attribute. This result was expected to follow the theory of proposing our method in section 2.2. It is similar to the improving ratio of detection probabilities depend on correlation coefficient for dual attributes.

A perceptual decision with multiple attributes information possesses qualitatively higher reliability than the perceptual decision with single attribute information in traditional qualitative. In this study it has no small significance that quantitative evaluation, the improving ratio of detection probability or the correlation coefficient based on experimental results, gives a cogent explanation to traditional qualitative property of a perceptual decision with multiple attributes. In addition, it is also similar to be shown quantitatively the improving ratio of detection probabilities depend on correlation coefficient for dual attributes.

Table 3 Correlation of coefficient

Subject	ρ_{12}	ρ_{23}	ρ_{31}
A	-0.406	-0.426	0.397
B	0.072	0.173	0.1
C	0.545	-0.522	-0.718
D	0.423	-0.042	0.528
E	0.532	-0.249	-0.315
F	0.573	-0.18	0
G	0.177	-0.373	-0.104
H	0.342	0.224	-0.272
I	0.528	0.548	0.048
J	-0.1	0.031	-0.02
K	-0.038	-0.095	0.329
L	-0.062	-0.09	0.346
M	0.144	-0.05	0.539
mean	0.21	-0.081	0.066

Table 4 Improving ratio of detection probability

Subject	P12 (%)	P23 (%)	P31 (%)	PL (%)
A	31.65	32.01	18.5	32.15
B	23.85	22.23	23.41	23.85
C	15.83	33.74	37.76	37.76
D	18.06	25.67	16.14	25.67
E	16.07	29.01	30.11	30.11
F	15.29	27.88	25	27.88
G	22.17	31.08	26.65	31.08
H	19.45	21.41	29.38	29.38
I	16.14	15.78	24.23	24.23
J	26.59	24.51	25.32	26.59
K	25.61	26.51	19.66	26.51
L	25.98	26.43	19.38	26.43
M	22.7	25.8	15.94	25.8
mean	21.49	26.31	23.96	28.27

5. CONCLUSION

In this study, drawing focus to multiple perceptions evoked multiple attribute stimulus, we proposed a new method for improving detection probability of the defect inspection. We compared the detection probability of single attribute and multiple attributes. The result of our experiment qualitatively showed that the improving ratio of detection probabilities for dual attributes: P12, P23, P31 respectively rose approximately 21%, 26% and 24% for mean in the case of dual attribute experiments. In addition, the improving ratio of multiple attributes rose approximately 28% in comparison with the detection probability of past single attribute. This result showed effective in rising detection probability for multiple perceptions. In addition, the result experimentally showed that improving rate of detection probability depended on various value of correlation coefficient. The diverse correlation coefficient suggests that the detailed standard can be set for the inspection. In other words, we conclude that our method of psychometric evaluation for multiple perceptions is useful for improving detection probability of the defect inspection in quality control on the FRP product surface. In the future we plan to decrease the trial number for dual attribute experiment.

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