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*Taguchi methods, design,*
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# DEVELOPMENT OF SOFTWARE FOR CALCULATION OF BEST CONDITION USING TAGUCHI METHODS AND ITS EVALUATION

Recently Taguchi methods are used to decide optimum processing conditions with narrow dispersion for robust design. On the other hand, innovative development with short-term, low cost, labor and energy saving is also required in the world. In this study, the software for development of a product with optimum condition using Taguchi methods is developed and evaluated. There are two trials in the software using Taguchi methods. First trial investigates rough functions regarding all levers of all control factors, then important control factors and meaningless control factors were sorted with the several comments for the second trial. At that time, maximum, intermediate and minimum values for each lever of each of the control factors should be used for pursuit of all possibilities. In the first trial, the relationship between each level value of each of the control factor and the desired property is also decided by the function, then the optimum combination using each level of each of the control factors were calculated for the second trial by using the function. The second trial is confirmed for the best combination using the estimated optimum level values. For example of an application, the optimum design for the paper craft "airplane" was investigated for evaluating this software in the experiment. It is concluded from the result that: (1) The proposed software was useful for developing with short-term and lower cost, (2) This tool could quickly and exactly decide the optimum design condition and (3) The paper craft "airplane" with most long flying length is manufactured by using the developed software.

## 1. INTRODUCTION

Recently developments with short-term and lower cost are strongly required for the shortening product life cycle. Therefore Taguchi methods [1],[2],[3],[4] are used for deciding optimum process conditions. However these methods are not enough to develop a new product with short time, lower cost, high quality and high accuracy. Particularly the most researches for Taguchi methods are the case study; there isn't a creative research in the quality engineering [5],[6],[7],[8]. However, we are developing several new and original software packages which are "Large profit for production" [9], "God's hand with high precision Taguchi method" [10], "Golden compass for precision profit" [11] and "Inverse

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2010 for investigation of influence" [12]. And now, everyone needs the innovative tool for development with higher speed and lower cost.

Therefore, in this research, the software for innovative tool using Taguchi methods is developed and evaluated. Taguchi methods were used for this innovative tool. The optimum condition is decided by only two trials using the innovative tool. In the first trial, rough functions regarding all levers of all control factors were investigated and calculated. Then important control factors and meaningless control factors were sorted for the second trial. In here, the wide range of each level should be used for inspecting all possibilities. Therefore, maximum, intermediate and minimum values for each lever of each of the control factor should use for pursuit of all possibilities. And when the number of the level increased, the accuracy of the estimation can inevitably improve. In the first trial, relationship between each control factor and the desired property is decided by the function, and the optimum combination of the each level value of the each control factors is calculated for the second trial by using the function.  Then the second trial is performed for confirmation of the best condition using the estimated best level values in the first trial. The developed software was named "Innovation Tool for Tomorrow". The software would like to be used for searching the optimum condition during very short time in the industrial world; such as industry, manufacturing, agriculture, marine products industry, management, finance and so on. At last, the optimum condition regarding a paper craft "airplane" was investigated for evaluating the proposed software in the simple experiment.

## 2. EXPLANATION OF TAGUCHI METHODS

The Taguchi methods [14] are used to decide optimum processing conditions with narrow dispersion for robust design. Therefore the Taguchi methods are explained in this section.

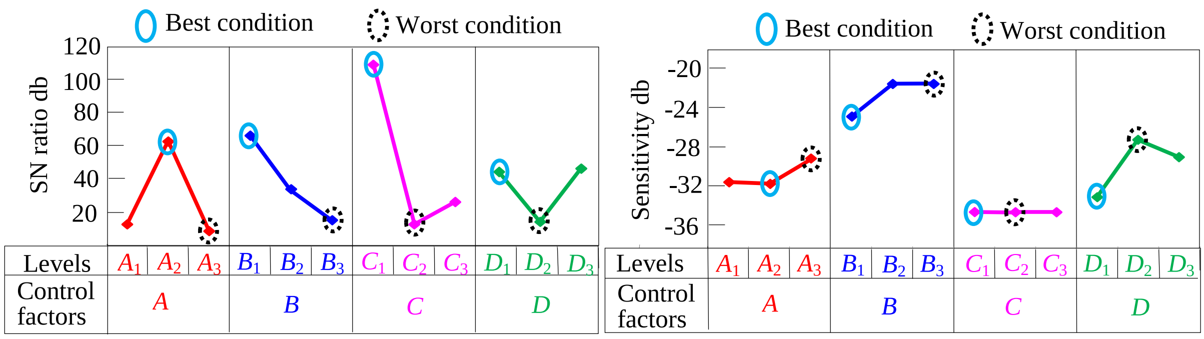
Table 1. Control and noise factors In Taguchi methods

| Control factors | | | | |
|---|---|---|---|---|
| Name | $A$ | $B$ | $C$ | $D$ |
| *Levels* | $A_1$ | $B_1$ | $C_1$ | $D_1$ |
| | $A_2$ | $B_2$ | $C_2$ | $D_2$ |
| | $A_3$ | $B_3$ | $C_3$ | $D_3$ |
| **Noise factors** | | | | |
| Name | $N$ | | | |
| Levels | $N_1$ | $N_2$ | $N_3$ | |

Table 2. Orthogonal array, SN ratio and sensitivity in Taguchi methods

| Trial No. | Control factors | | | | Result with noise factors | | | SN ratio (db) | Sensitivity (db) |
|---|---|---|---|---|---|---|---|---|---|
| | $A$ | $B$ | $C$ | $D$ | $N_1$ | $N_2$ | $N_3$ | | |
| 1 | $A_{1.}$ | $B_{1.}$ | $C_{1.}$ | $D_{1.}$ | 2.7 | 2.6 | 2.4 | 24.5 | 8.2 |
| 2 | $A_1$ | $B_2$ | $C_2$ | $D_2$ | 2.3 | 2.2 | 2.0 | 23.0 | 6.7 |
| 3 | $A_1$ | $B_3$ | $C_3$ | $D_3$ | 2.1 | 1.9 | 2.0 | 26.0 | 6.0 |
| 4 | $A_2$ | $B_1$ | $C_2$ | $D_3$ | 3.3 | 3.1 | 3.0 | 26.2 | 9.9 |
| 5 | $A_2$ | $B_2$ | $C_3$ | $D_1$ | 4.6 | 4.4 | 4.5 | 33.1 | 13.1 |
| 6 | $A_2$ | $B_3$ | $C_1$ | $D_2$ | 3.3 | 3.3 | 3.0 | 25.3 | 10.1 |
| 7 | $A_3$ | $B_1$ | $C_3$ | $D_2$ | 2.1 | 2.3 | 2.4 | 23.4 | 7.1 |
| 8 | $A_3$ | $B_2$ | $C_1$ | $D_3$ | 3.1 | 3.2 | 3.1 | 34.7 | 9.9 |
| 9 | $A_3$ | $B_3$ | $C_2$ | $D_1$ | 4.7 | 5.1 | 4.9 | 27.8 | 13.8 |

Control factors are equal to the design factors. Noise factors were occurred for the error of function on the product (Table 1). Most designer can understand that the final functions of the developed product are strongly influenced for each lever of each of the control factors under several noise factors. All combinations using all levels of all control factors are compressed by an orthogonal table (Table 2). Then the experiment or the CAE (Computer Aided Engineering) analysis with influence of noise factors is performed by the orthogonal array. At last, the average $\mu$ and the standard deviation $\sigma$ regarding all combinations using all levels of all control factors are calculated for the SN ratio (Signal-Noise ratio) and the sensitivity by using the equations (1) and (2).




(a) Effective figure for SN ratio (b) Effective figure for SN Sensitivity

Fig. 1. Relationship between (a) SN ratio and (b) Sensitivity and each level of each of the control factors (In the case, the best condition was supposed at the smallest final function possible for sensitivity)

$$SN\ ratio\ \text{(db)} = 10\ log\ (\mu^2 / \sigma^2) \quad (1)$$

$$Sensitivity\ \text{(db)} = 10\ log\ \mu^2 \quad (2)$$

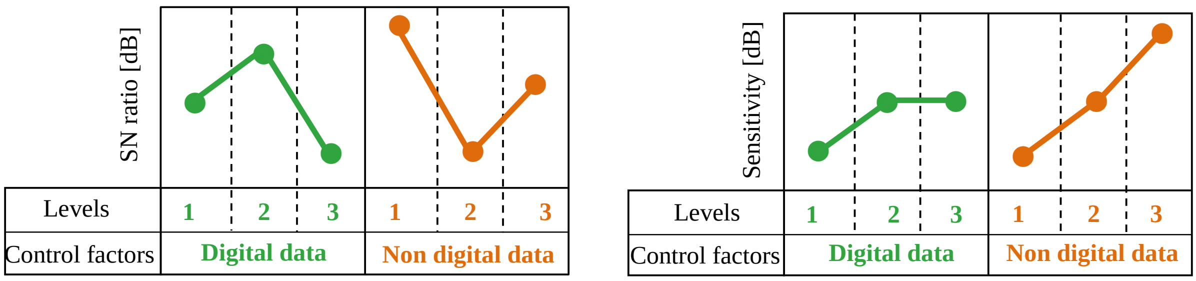
Where $\mu$ *and* $\sigma$ are average and standard deviation of the final function respectively. Then most of users write the effective figure (Fig. 1) of the control factors and earnestly search the optimum level of each of the control factors for large SN ratio. Because when the SN ratio becomes large value, standard deviation of the final function is small value and the level of the control factor brings high robustness for noise factors (See equation (1)). A product using the combination isn't nearly influenced by noise factors. In case of the sensitivity, if the best condition was supposed at the smallest final function possible such as Fig. 1, the optimum level of each of the control factor was selected for small sensitivity. Because when the sensitivity becomes small value, the average of the final function also is small value (See equation (2)). The optimum condition (maximum or minimum?) of sensitivity is dependent on the property of the final function. In original Taguchi methods, the best and worst conditions are finally decided such as Fig. 1.

However, you can see very large defect in the Fig. 1 [13]. Everyone couldn't feel a physical image for relationship between each level value and SN ratio or sensitivity in Fig. 1, because the horizontal axis was used for the level number and wasn't used for the each level value in Fig. 1. Therefore everyone couldn't directly decide the optimum level value of each of the control factors by using Fig. 1. This is very large loss in the industrial world; this should be repaired for innovative manufacturing.

## 3. ALGORITHM FOR OPUTIMUM DESIGN USING TAGUCHI METHODS

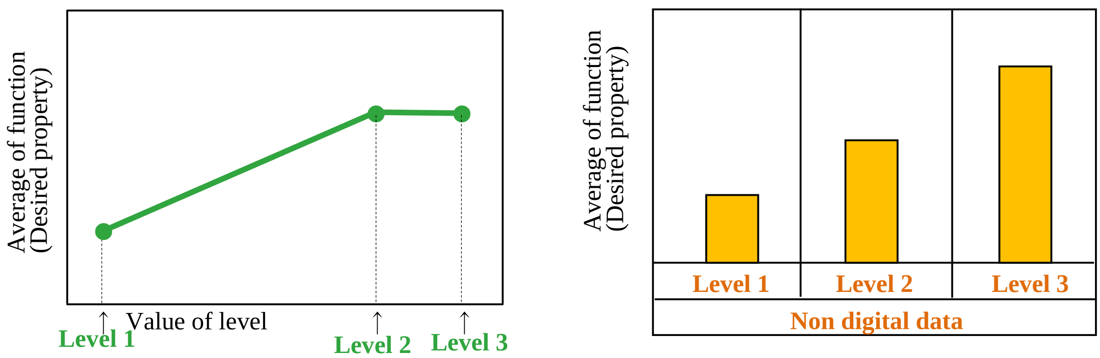
Now, innovative development with short-term, low cost, labour and energy saving is also required in the world. Therefore, in this research, the software using Taguchi methods was developed and evaluated. Algorithm for software using Taguchi methods was shown.

The control factors consist of digital data and non-digital data. When these data are inputted into the software of original Taguchi methods, the results of the effective figures for both SN ratio and sensitivity can calculate such as Fig. 2. In here, after several evaluations were performed by using the effective figures, the trial was completed. Therefore our system starts from here; then Fig. 2 is rewritten to Fig. 3. At that time, each level value of each of the control factors were used for the horizontal axis, and the average value of function (desired property) was used for the vertical axis. In case of the digital data,




(a) SN ratio ( =10$log(\mu^2/\sigma^2)$ ) (b) Sensitivity ( =10 $log\mu^2$)

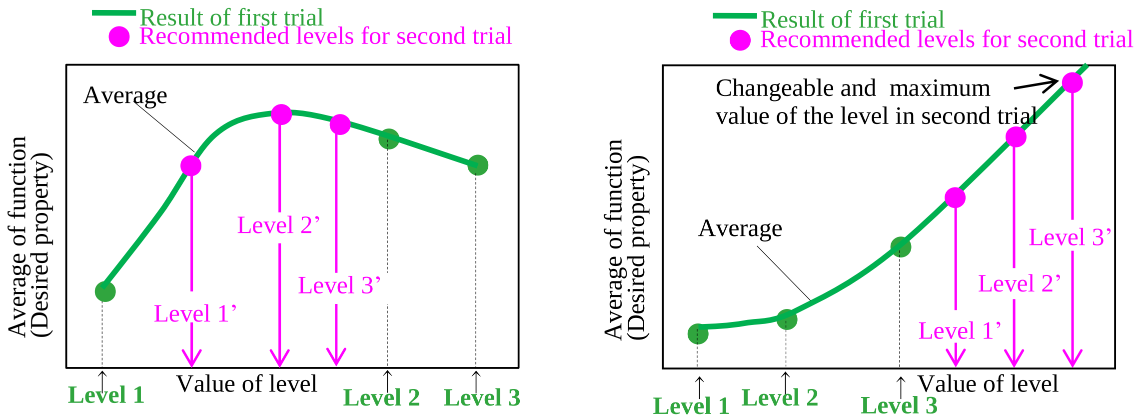
Fig. 2. Effective figures of SN ratio and Sensitivity




(a) In the case of digital data for the control factor (b) In the case of non-digital data for the control factor

Fig. 3. Effective figures of SN ratio and Sensitivity

a line graph is used such as Fig. 3a, and in case of the non-data, a bar graph is used such as Fig. 3b. Everyone can intuitively and visually feel the influences of the control factors by using the Fig. 3, and can grasp for the physical image regarding the influences of the control factors. In case of the line graph, then the curve-fit working is performed by using exponential, linear, logarithmic, polynomial and radical approximations. In here, an operator can intuitively understand the influences of the control factors. And the functions for influence of the each level are decided by this curve-fit working. In case of a bar graph, Fig. 3b could not change to Fig. 4.




(a) Inside estimation b) Outside estimation

Fig. 4. Recommendation of the levels for second trial using the results of the first trial

The optimum level value of each of the control factors for the second trial was decided by using the results in the first trial. The method for selection of the optimum level values of two control factors are shown in Fig. 4. In the explanation, it supposes that the larger function is desired by everyone. The curve of Fig. 4a has a mountain shape, there is the optimum level value of the control factor in the region of the first trial. Therefore new level 2' is decided on the top of the mountain, new level 1' is middle between the old level 1 and the new level 2', and new level 3' is middle between the new level 2'and the old level 2. Level 1', level 2' and level 3' are the new levels for the second trail. The curve of Fig. 4b has a shape of graph rising to the right, there is the optimum level value of the control factor in the right outside region of the first trial. Therefore new level 3' is decided to the practicable large value, new level 1' and new level 2' divide into three regions between the new level 3'and the old level 3. The operator of the software can also select the standard deviation for the vertical axis, at that time, the operator can estimate stability for the noise factors. Everyone can feel regarding the physical image and phenomenon in Fig. 4, because the horizontal axis in Fig. 4 is using the each level value. Therefore everyone can directly decide the optimum level value of each of the control factors by using physical image and Fig. 4. This is very large benefit in the industrial world, this would become the innovative tool for development with higher speed and lower cost. As both organic and inorganic materials or both proper noun and digital value were used for control factors, this software would like to use for searching the optimum condition during very short time in the industrial world; such as industry, manufacturing, agriculture, marine products industry, management, finance and so on.

# 4. OPTIMUM DESIGN FOR PAPER CRAFT "AIRPLANE" USING TAGUCHI METHODS

At last, the optimum design for a paper craft "airplane" was performed for evaluation of the proposed software. Of course, this software can use in the industrial world; such as industry, manufacturing, agriculture, marine products industry, management, finance and so on. Therefore, in here, this experiment is simple trial for only one example.

How to make the paper craft "airplane" and sizes are shown in Fig. 5. A paper with half size of A4 was used. There are three kinds of thickness of the papers. Paper weight is the parameter A. These levels are 68.1 $g/m^2$, 72.9 $g/m^2$ and 127.5 $g/m^2$. The sheet of the paper was folded as the procedure. Parameters B and C have influence for weight balance. Parameter C and D have the influence for shear resistance of wind.

Photographs of the paper craft "airplane" were shown in Fig. 6. The control factors of each parameter are also shown in the figure. Ditch with V-shape in the center and the vertical fins on the end of the wings have shear resistance of wind. Therefore the airplane would like to fly in a straight line. And the area of the wings has the influence of air resistance in vertical direction.

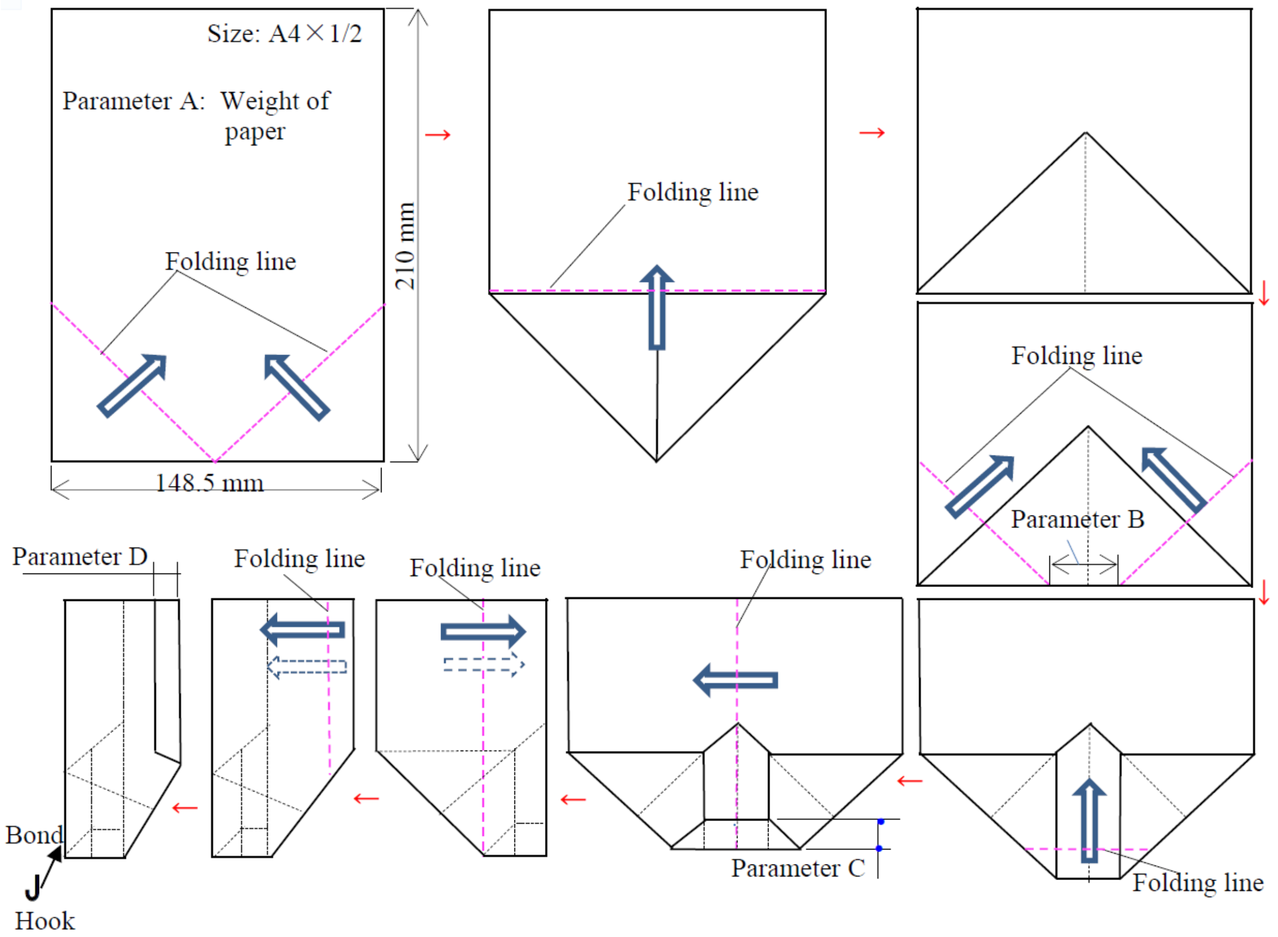
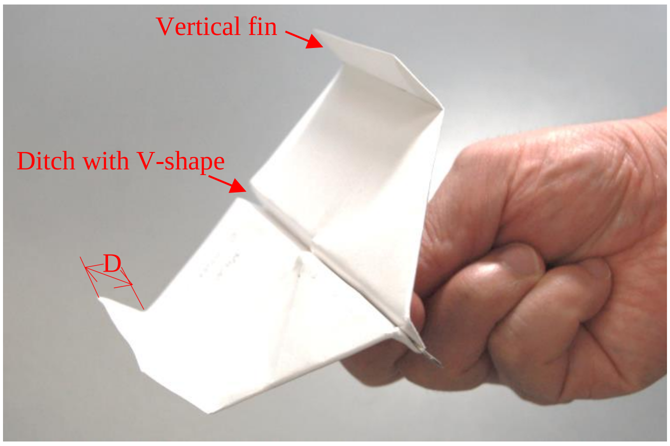



Fig. 5. Procedure for making the paper craft "airplane"




Parameter A : Paper weight
Parameter B : Aperture of tip
Parameter C : Foldout of tip
Parameter D : Height of fin

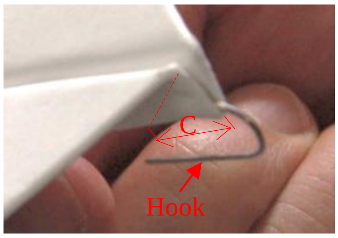



Fig. 6. Photograph of the paper craft "airplane"

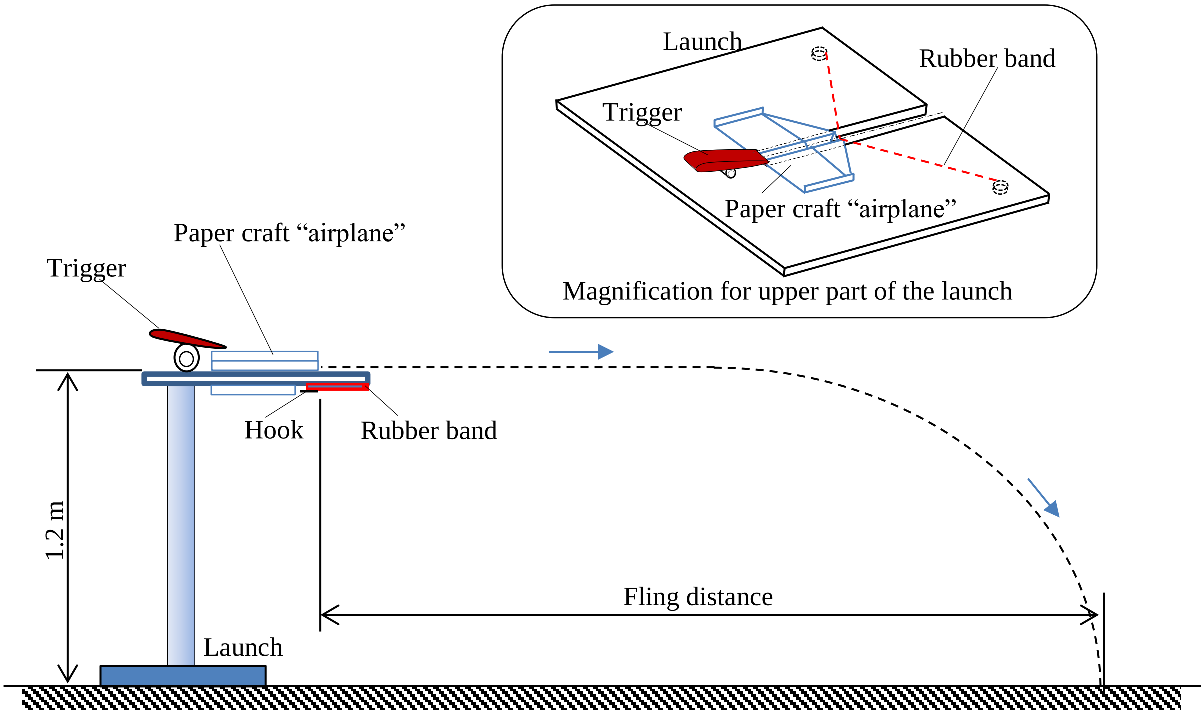



Fig. 7. Explanation for experimental set-up

Table 3. Control and noise factors for first design regarding the paper craft "airplane" using Taguchi methods

| Control factors | | | | | Noise factor |
|---|---|---|---|---|---|
| Name of factors | Parameter A Paper weight [g/m$^2$] | Parameter B Aperture of tip [mm] | Parameter C Foldout of tip [mm] | Parameter D Height of fin [mm] | Number of experiments: 9 |
| | first design | first design | first design | first design | |
| Level 1 | 68.1 | 5 | 5 | 5 | |
| Level 2 | 72.9 | 10 | 10 | 10 | |
| Level 3 | 127.5 | 15 | 15 | 15 | |

Experimental set-up was shown in Fig. 7. For the paper craft “airplane”, everyone will desire long fling distance. Therefore the fling distance of paper craft “airplane” is used for the final function in the proposed software. The paper craft “airplane” was loaded on the launch pad with 1.2 m, its hook was pulled by the rubber band and its body was locked by the trigger. When the trigger was removed, the airplane takes off in front and flying distance was measured. The control and noise factors for first trial are shown in Table 3. Design values in Fig. 5 were used for four control factors; the parameter A is the paper weight, the parameter B is the aperture of the tip, the parameter C is the foldout of the tip and the parameter D is the height of the fin. The noise factor is number of experiments. Influences of the changes of the wind speed and the direction of the wind were included for the noise factor of 9 times experiments. Then, the optimum design for paper craft “airplane” were proposed software was used for planning of the optimum design.

The results of the first trial are shown in Fig. 8. There are the results of the first trial (Blue line) and the estimated best value for the each parameter in Fig. 7. We can directly decide the best level value for each of the control factors by using physical image and sense in Fig. 8. Shapes of graphs in (a), (c) and (d) are mountain shape. Therefore, there is the each best level value in middle region which are on the each top of the each mountain shape. As (b) was graphs rising to the left, therefore the most left value 0.0 was selected for

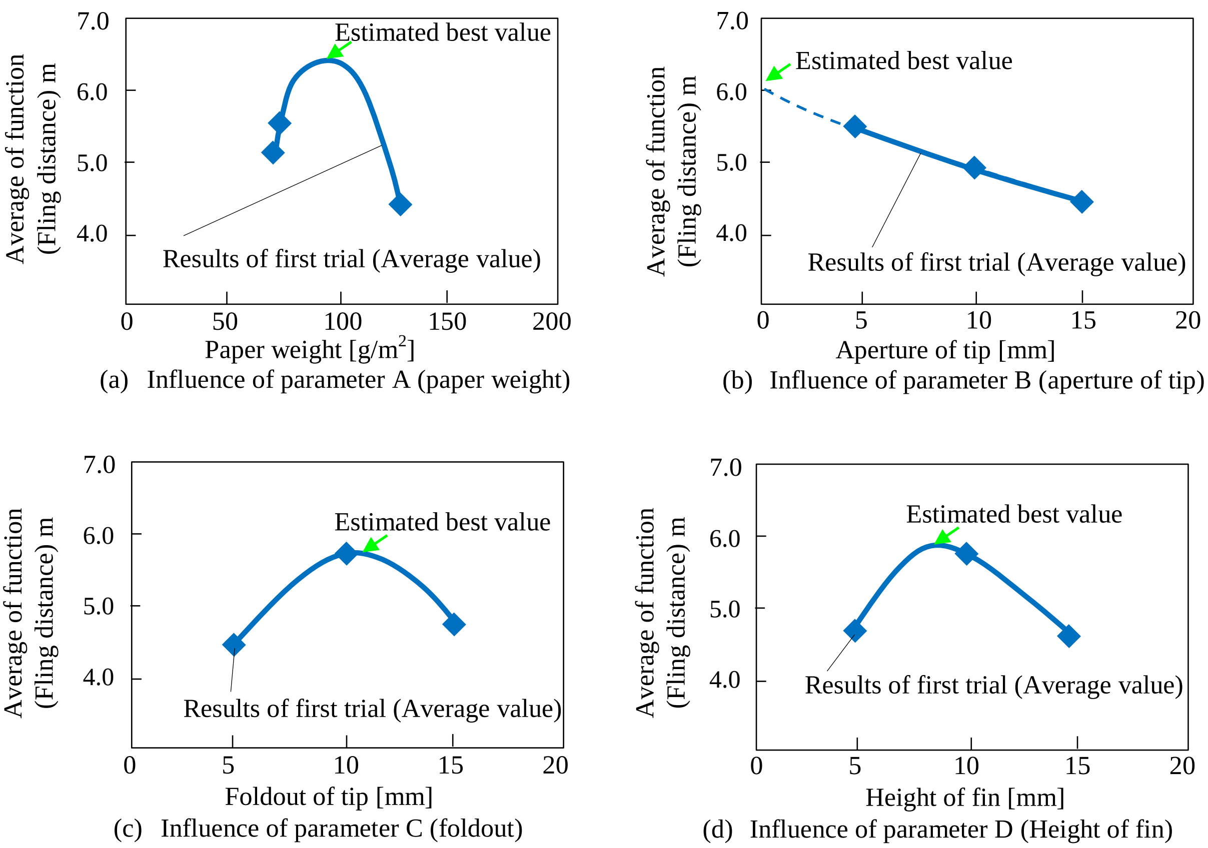


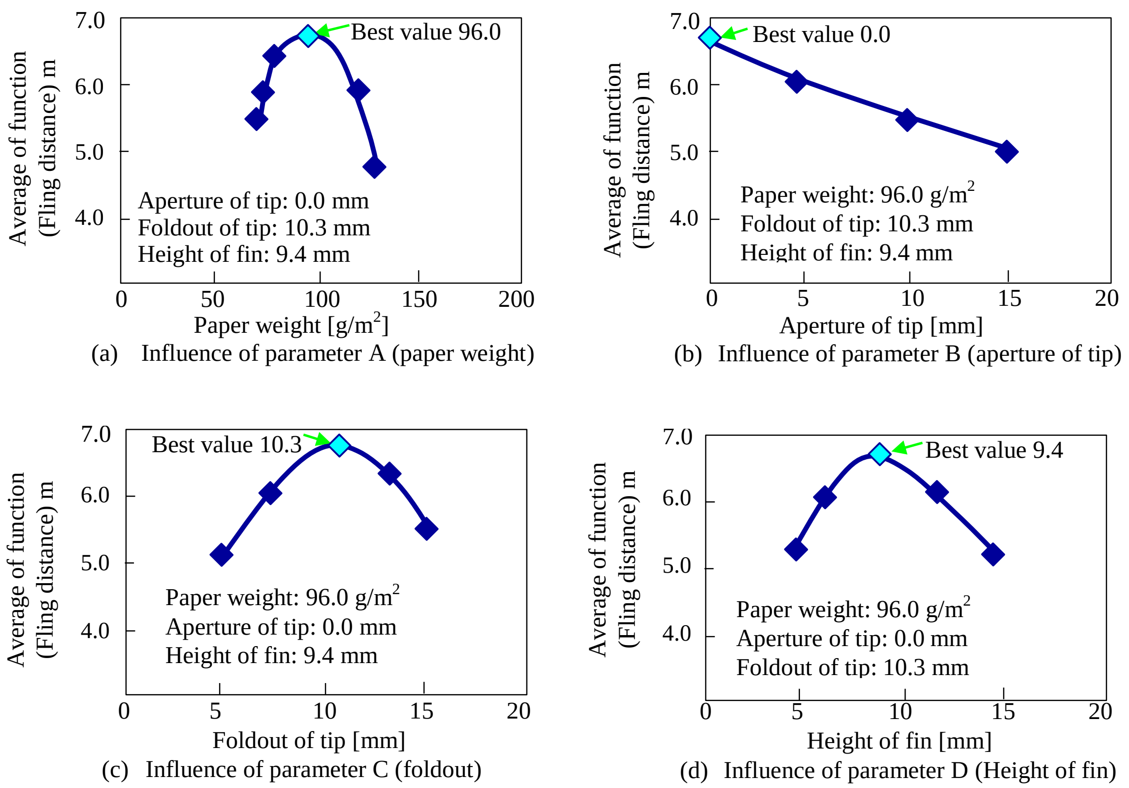

Fig. 8. The result (**Blue line**) of first design regarding the paper craft “airplane” and the estimated best value for the optimum design using its

the best level value regarding (b). If you used 6 levels for a control factor, you get the physical figure with higher accuracy.

The estimated best level values are shown in Table 4. Paper weight (Parameter A), Aperture of tip (Parameter B), Foldout of tip (Parameter C) and Height of fin (Parameter D) are 96 g/m$^2$, 0.0 mm, 10.3 mm, 9.4 mm, respectively. If you need more little value or more large value for the new level of each of the control factors in the second trial, you should change the experimental set-up or the equipment. And the new invest in plant and equipment will succeed. Because the proof of the results in the second trial is certainly given from the results of the first trial in Fig. 8.

Table 4. Estimated best values regarding the paper craft "airplane" using Taguchi methods
(The cell with light blue is optimum condition which decided was after 1$^{nd}$ design)

| Name of factors | Control factors | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Parameter A Paper weight [g/m$^2$] | | Parameter B Aperture of tip [mm] | | Parameter C Foldout of tip [mm] | | Parameter D Height of fin [mm] | |
| | first design | Estimated best vale | first design | Estimated best vale | first design | Estimated best vale | first design | Estimated best vale |
| Level 1 | 68.1 | | 5 | | 5 | | 5 | |
| Level 2 | 72.9 | 96.0 | 10 | 0.0 | 10 | 10.3 | 10 | 9.4 |
| Level 3 | 127.5 | | 15 | | 15 | | 15 | |



(a) Influence of parameter A (paper weight)
(b) Influence of parameter B (aperture of tip)
(c) Influence of parameter C (foldout)
(d) Influence of parameter D (Height of fin)

Fig. 9. Experimental results (**Dark blue line**) of evaluation and the estimated best values using first results

Then the estimated best values regarding the paper craft “airplane” using the results of first trial are evaluated in several experiments. The results of the evaluations are shown in Fig. 9. In Fig. 9a, the only paper weight (Parameter A) was changed. In Fig. 9b, the only aperture of tip (Parameter B) was changed. In Fig. 9c, an only foldout of tip (Parameter C) was changed. In Fig. 9d, the only height of the fin (Parameter D) was changed. At those times, the other parameters were used the each best value. Each experimental number is 9 times. Off course influences of the changes of the wind speed and the direction of the wind were included in 9 times experiments. Averages of the flying distance of the paper craft “airplane” with the best values were larger than those of one with other conditions. The proposed software could estimate the best condition for the paper craft “airplane”. And an average of flying distance of the paper craft “airplane” with optimum condition was improved to 6.88 m. Fling distance 6.88 m which was searched by the proposed software was the largest value in the all experiments. Therefore the proposed software effective for design and development in the industrial world.

The developed software “Innovation Tool for tomorrow” is very useful for searching the optimum condition of the paper craft “airplane” during very short time. We think that this software is used other territories; such as industry, manufacturing, agriculture, marine products industry, management, finance and so on. Because everyone can search the optimum condition by using physical image and phenomenon such as Fig. 8. Therefore, everyone can directly decide the optimum level value of each of the control factor.

However, if once the method is attempted to be applied to case of practical industrial use, it could not compete with conventional procedures which have been adopted. Therefore, in the near future, we would like to investigate for the practical industrial use by using the software.

## 6. CONCLUSION

In this research, the software for innovative tool using Taguchi methods is developed and evaluated. The software was improved regarding the effective figures of SN ratio and sensitivity for expressing physical image and phenomenon. Then experiments using the paper craft “airplane” were performed for evaluation of the software.

It is concluded from the result that;

(1) Innovative tool using the Taguchi methods was developed for the design and development with short-term and lower cost.
(2) The proposed software could quickly and exactly decide the optimum condition. The paper craft “airplane” with optimum condition using the developed software has very long fling distance (6.88 m). This development is finished in the only twice trials.
(3) The developed software can indicate the physical image and phenomenon for searching the optimum condition regarding the paper craft “airplane” in the figure. The operator could search the optimum condition during very short working time.
(4) The developed software is very useful for innovation in the industrial world.

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