Optimization of the mechanism from equipment for overcoming obstacles with design of experiments

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Abstract. A data collection considers how the experimental factors, controlled and uncontrolled, fit together into a model that will meet the specific objectives of an experiment and satisfy the practical constraints of resource and time. Customizing any product to improve performance requires a reliable method to measure performance results, in order to accurately assess the effects that design changes have on them. This paper has the purpose to analyse the equipment for overcoming obstacles. A comprehensive approach to model equipment requires performance data related to the design parameters. Slipping, slanting, becoming unstable, sliding, overturning and blocking while climbing steps and stairs are common problems and may cause instability for the user of the equipment. The Taguchi Method is used to optimize several parameters of the proposed mechanism and to ensure the stability through horizontality of the equipment. This method provides an opportunity to reduce the number of required sample size and is implemented by an orthogonal experimental array which enables the effect of multiple parameters to be simultaneously assessed.

1 Literature review

The development of devices that can improve people's quality of life can be a task for engineering researchers. Over the past several years, research of motorized equipment was performed by several scientists who have analysed the types of mechanisms to access obstacles. There are many studies conducted in areas related to climbing equipment. These include crawler type, leg type, hybrid type and wheeled type. Ghani and others [1] investigated an equipment used indoor, evaluating different mechanisms for accessing stairs: track, legs and wheeled combined system, analysing various forces and couples acting. Quaglia [2] analysed aspects of developing equipment for climbing stairs, which can move in structured and unstructured environments that can go over obstacles and can go down or up the stairs. The device consists of a frame, seat and a linkage mechanism. The framework consists of a chassis built with two motorized units, support for two electric motors, two wheels and a battery. The seat has a tubular structure consisting of a frame and

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a pivoting wheel. Linkage mechanism is responsible for the relative movement between the frame and the seat during operation. To climb the stairs, it is necessary to move the seat back, then refocus and finally, to raise swivel wheel. The mechanism is driven by a motor connected to a lead screw mechanism. When the seat reaches the desired position, the engine is off and needs no additional energy to maintain position.

Lawn [3] identified the developments of the mechanisms of mobility support, while studying the importance of the wheels. A proposed mechanism is based on the use of four wheels, the rear wheels are driven independently and the front wheels are free wheels. The influence of external factors such as cost, weight, aesthetics, range of operation, safety, operational efficiency or comfort were evaluated by overview of recent advances in mobility assistive devices available for curbs or stairs.

Yoneda [4] proposed a deformable track considering the most fundamental track based problem that of the high pressure exerted on the stair edges. The tracked vehicle can easily climb stairs by using two active arms in front. One arm is basically used to put in contact the crawlers with the first step and to assist the vehicle motion, while the other arm adjusts the payload position, changing the posture of the carrier in order to maintain a constant posture.

Yun et al. [5] have developed transmuting track equipment which has a dynamic track tension characteristic. They have used fuzzy logic control as an optimal estimation algorithm to estimate the proportion of various factors that affect the track tension. Frame of the equipment consists of fixed shelf, seat and track transmutation mechanism in which the main factors affecting tension are determined by fuzzy decision [5].

A hybrid solution combines the high effectiveness of wheel locomotion on flat ground with the performance of a track on stairs. The advantages of tracks are the stability and regularity of the trajectory during stair-climbing. The disadvantage is represented by the dimensions and weight involved in the use of a motorized track. This solution is one of the most effective, and it is used in most commercial stair-climbing devices. Equipment with pure leg locomotion has a high climbing capability, but it requires a complex structure for both the actuation and the control systems. The stability could be a critical aspect, and the seat oscillates due to leg movement during both stair-climbing and flat ground motion, thus causing an uncomfortable sensation for the user.

The stair climbing IBOT include 4 active wheels and 2 front small casters. Only the two rear wheels make contact with the ground using the front casters to provide free wheeled steering. Dual wheel cluster type stair climbing equipment uses two pairs of wheel clusters, the rear of which for drive and the front as freewheeling casters. The stair climbing motion is forward down the stairs and back up the stairs. The front cluster rotates passively during stair-negotiation. Scalevo device is a hybrid between a wheelchair and a Segway device. It is equipped with a track platform that rises and helps in moving across the stairs, managing to climb or to descend without the intervention of the user or others. The rotary technology is used in Scalevo design, thus the device can rotate on the spot and can change direction easily.

Morales et al. [6] designed a hybrid two decoupled equipment mechanisms in each axle, one to negotiate steps and the other to position the axle with regard to the device in order to accommodate the overall slope. Kinematic model was utilized to improve the trajectory planning.

2 Modelling of the mechanism

One of the most important features of the design of equipment for overcoming obstacles is its ability to surmount physical obstructions that may occur (e.g. threshold, stairs). The basic requirements for a product of this type are: to enable to move along various kinds of

surfaces (e.g. uneven surface, sand, snow); to have a small size; to enable the movement up and down the stairs.

A shape of the proposed mechanism is presented in Figure 1. The mechanism consists of: a drive wheel R_1 , two power driven wheels R_2 and R_3 articulated through two arms. Parallelogram mechanism is placed in the centre and is operated by Link2 through a lever. System stability is achieved by wheel R_3 and Link1.

Fig. 1. Diagram of the mechanism.

The mechanism of the equipment presented in this paper should be able to overcome obstacles in a comfortable and safe way, and it must be stable during climbing operation. The way to overcome the obstacles for the type of scale chosen, in three steps is shown in Figure 2.

Fig.2. Steps for overcoming obstacles.

One type of stair (300mm X 190mm) is selected to determine a robust optimal solution. The result will show the variation of the horizontal position of the platform support. The kinematic model of the mechanism shown in Figure 3, is built and it is simulated in Matlab.

Fig.3.Analysis of the mechanism

A kinematic analysis of a connection is used to assess its performance keeping the design goal and to ensure that the mechanism has no flaws. A complicated structure will determine unnecessary energy losses [7]. Models and references to prior experimental work have identified important design parameters of similar devices, for ensuring the horizontal and vertical seat position. The seat connects with the mechanism in points C and D, and the wheel driven R_2 in H point. Changing the position of lever FG is transmitted to the mechanism ACDE through the arm BG. The angle α_2 is the angle made by FH link with the horizontal. The range of the angle α_2 was $\pm 30^\circ$, this variation being determined by the height of the staircase taken into consideration.

3 Optimization procedure

Experimental design can be used to reduce design costs by speeding up the design process, reducing late engineering design changes, and reducing product material and labour

complexity. Designed of Experiments are a powerful tool to achieve manufacturing cost savings by minimizing process variation and reducing rework and the need for inspection [8].

Taguchi method shows the importance of studying the response variation using the signal to noise (SN) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied [8]. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. In this study, four dimensions of the link (l_1, l_2, l_3, l_4) have been considered with their range as design parameters shown in Table 1 and were improved using the optimization procedure.

Table 1. Input parameters and their levels.

Levels	l_1 [mm]	l_2 [mm]	l_3 [mm]	l_4 [mm]
1	100	200	250	150
2	125	250	300	200
3	150	300	350	250

The parameters for design of experiment, based on Taguchi’s L9 Orthogonal Array design have been selected as shown in Table 2.

Table 2. Design of Experiment Using L9 Orthogonal Array.

Exp. No.	l_1 [mm]	l_2 [mm]	l_3 [mm]	l_4 [mm]
1.	1	1	1	1
2.	1	2	2	2
3.	1	3	3	3
4.	2	1	2	3
5.	2	2	3	1
6.	2	3	1	2
7.	3	1	3	2
8.	3	2	1	3
9.	3	3	2	1

4 Results and discussions

The objective function was the minimizing of the inclination angle. To determine the effect each variable has on the output, the SN ratio needs to be calculated for each experiment conducted. The parameter $\bar{y}_i$ is the mean value of the performance characteristic for a given experimentand the parameter s_i is the variance and is given as:

$$\bar{y}_i = \frac{1}{N_i} \sum_{u=1}^{N_i} y_{i,u}$$

(1)

$$s_i^2 = \frac{1}{N_i - 1} \sum_{u=1}^{N_i} (y_{i,u} - \bar{y}_i)^2$$

(2)

where: i = experiment number; u = trial number ; N_i = number of trials.

The observations for the inclination angle of the platform support are shown in Table 3. Three trials were performed for each experiment, and the informations below were collected.

The SN ratio measures how the response varies relative to the nominal or target value under different noise conditions. The Nominal is Best SN ratio is useful for analysing or

Table 3. Experimental data.

Exp. No.	l ₁ [mm]	l ₂ [mm]	l ₃ [mm]	l ₄ [mm]	Trial 1	Trial 2	Trial 3	Mean	Standard deviation
1.	100	200	250	150	5.75	5.66	5.70	5.70	0.045
2.	100	250	300	200	6.49	6.43	6.46	6.46	0.031
3.	100	300	350	250	8.28	8.19	8.18	8.21	0.055
4.	125	200	300	250	6.18	6.15	6.09	6.14	0.045
5.	125	250	350	150	7.65	7.57	7.61	7.61	0.041
6.	125	300	250	200	8.30	8.29	8.25	8.28	0.026
7.	150	200	350	200	6.26	6.24	6.19	6.23	0.036
8.	150	250	250	250	6.61	6.56	6.55	6.57	0.032
9.	150	300	300	150	7.40	7.34	7.35	7.36	0.032

identifying scaling factors, which are factors in which the mean and standard deviation vary proportionally. For Taguchi dynamic designs, it is used one SN ratio which is closely related to the Nominal is Best SN ratio for static designs [8].

$$SN_i = 10 * \log \frac{\overline{y_i^2}}{s_i^2}$$

(3)

Below is shown the response table, where is calculated an average SN value for each factor.

Table 4. Experimental Observations and S/N Ratio for the inclination angle.

Exp. No.	l ₁ [mm]	l ₂ [mm]	l ₃ [mm]	l ₄ [mm]	S/Ni
1.	100	200	250	150	42.04
2.	100	250	300	200	46.66
3.	100	300	350	250	43.47
4.	125	200	300	250	42.54
5.	125	250	350	150	45.58
6.	125	300	250	200	49.90
7.	150	200	350	200	44.75
8.	150	250	250	250	46.21
9.	150	300	300	150	47.19

Compute the SN ratio for each experiment for the target value case, was created a response table and a response chart, and were determine with Matlab Software the parameters that have the highest and lowest effect.

Table 5. Ranking of parameters Response Table for Signal to Noise Ratios.

Level	l ₁ [A]	l ₂ [B]	l ₃ [C]	l ₄ [D]
1	44.05	43.11	46.05	44.94
2	46.01	46.15	45.47	47.11
3	46.05	46.86	44.60	44.08
Delta	2.00	3.75	1.45	3.03
Rank	3	1	4	2

The effect of factors is then calculated by determining the range: Δ₂ = Max – Min = 46.86 - 43.11 = 3.75 and Δ₃ = Max – Min = 46.05 - 44.60 = 1.45. Therefore, link with length l₂ has the largest effect on the mechanism stability and link with length l₄ has the smallest effect. From the experimental data we got better values for angle inclination at minimum dimensions of the links. Optimum parameters resulted from Taguchi analysis is: l₁ = 100 mm, l₂ = 200 mm, l₃ = 350 mm, l₄ = 250 mm.

Fig.4.Response chart for Signal to Noise Ratios.

Conclusions

This paper has presented application of Taguchi method to determine the optimal dimensions for the components of a mechanism. The concept of SN ratio is used to determine the effect and influence of the dimensions links on output measure represented by the angle of the mobile platform. Matlab software is used for analysis the response graphs of average values and SN ratios. From the analysis results that l_2 and l_4 played a more important role on output measure than other dimensions. The model is useful for selecting the optimal values for the lengths of the elements considered in the study. On understanding the effect of each parameter, decisions can be made for getting a reliable and compact product, with reduced weight, small dimensions and low cost. Experiments at the optimum set of dimensions for inclination angle will be carried out in further research. For this purpose, the mechanism will be practically made and will be tested under field conditions to verify the results obtained by simulation. Future work can be done by including more parameters as the angles that the mechanism elements must be able to negotiate if other types of obstacles occurred in terms of ensuring the stability.

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