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Conceptual Design of a New Stair-Climbing Mobile Platform Using a Hybrid Link Mechanism

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Abstract: High mobility performance is the most important key to mobile robots. In this research, a new indoor stair-climbing mobile platform is proposed on the basis of a hybrid-link mechanism. The hybrid link mechanism combining the passive link with the active mechanism can guarantee well-balanced simplicity as well as adaptability performance in comparison with the previous passive mechanisms. First, a requirement list for a stair-climbing indoor mobile platform is made upon the related researches. Then, a new kinematic model of hybrid link mechanism is suggested by using systematic design methodology. For the optimization of design parameters such as wheel radii and link lengths, the cost function is chosen as the combination of the backward movement and the deviation of path angle during climbing up stairs. Then, the optimization of the kinematic variables for the hybrid link mechanism is carried out via generic algorithm.

Keywords: Mobile platform, Stair climbing, Hybrid link, Optimization

1. INTRODUCTION

Among others, high mobility performance is the most important factor in developing mobile robots. In order to implement 'A robot in every home' paradigm, a novel mobile platform with full mobility in home environment is essential. There are various obstacles in indoor environment such as carpets, steps, furniture etc. In general, stairs are the most difficult obstacle for mobile platforms to overcome. As shown in Fig. 1, a percentage of single-story building is 33%, while the proportion of elevator installed buildings is just 16% in the U.S [1]. Therefore, the stair-climbing ability is essential to indoor mobile platforms.

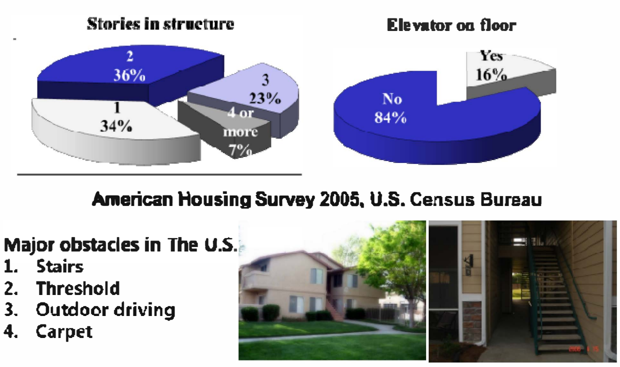

Fig. 1 Housing environment in the U.S [1]

Many mobile-platform mechanisms such as legged, tracked and wheeled mechanisms are suggested to achieve the desired mobility for various purposes. Legged mechanisms have high adaptability to rough terrains, but need numerous actuators and sensors with complex control algorithms [2, 3]. Tracked mechanisms are highly robust to off-road circumstance, but since it has heavy and complicated structure so that unnecessary energy losses and noises are inevitably caused [4, 5]. Wheeled mechanisms are comparatively less complex and highly efficient and furthermore, their obstacle adaptability can be improved by using linkage structure [6-8].

In this research, a new hybrid link mechanism is suggested. The hybrid link mechanism using both active and passive joints can ensure well-balanced simplicity and adaptability compared to the previous passive mechanisms. Optimization combined with active link control strategy will enhance its viability. A detailed requirement list for a stair-climbing indoor mobile platform is created on related researches and regulations. With the requirement list, extracted working principles are listed and then, the active slide joint combined with the passive rotation joint is selected as the locomotive mechanism. To guarantee excellent performance in climbing up various stairs, the optimization of four link lengths and three wheel radii is carried out with the objective function including the effect of backward movement as well as the deviation of path angle.

The rest of this paper is organized as follows. In Section 2, a requirement list for the mobile platform is created based on the previous researches. With the requirements list, conceptual design of hybrid-link mobile platform is performed in Section 3. Finally, the optimization problem is defined and solved through the GA algorithm, and details of the optimization results are shown in Section 4.

2. DEVELOPMENT PREPARATION

2.1 Previous research result

In the previous research, the stair-climbing mobile platform using the rocker-bogie passive link mechanism was proposed, whose design parameters were optimized through the Taguchi method with the aim of making the trajectory of the center of mass (CM) of the mobile platform as straight as possible [9]. Even though its stair-climbing ability was verified through the extensive experiments, several limits of mobile platform are revealed as bellows: 1) Dynamics of mobile platform such as force and torque distribution are not considered in the optimization. 2) Backward movement is observed while climbing stairs, which may cause instability while climbing up stairs. With experience of this previous research, a new hybrid link mechanism is suggested as a clue to these limits of previous stair-climbing mobile platforms.

2.2 Requirements list

Based on the research experience described in section 2.1, other related researches and indoor environment codes, a requirement list for the mobile platform is created in details. Table 1 shows a major requirement list for a stair-climbing indoor mobile platform. This list is employed as a guideline and evaluation index for the mobile platform throughout this research.

Table 1 Major requirements list for developing stair-climbing indoor mobile platform [10-12]

List	*Requirements*
Geometrical shape	Width x Depth x Height < 600 mm x 600 mm x 450 mm
Force	Body weight: 20 kg Payload: 10 kg
Circumstance condition	- Step depth > 254 mm, Step height < 196 mm, Step width > 914 mm (From International Residential Code) - Install landing (depth > 1200 mm) if the height of steps more than 2m (Housing construction standards regulations #16) - 600mm < (Step depth) + 2 × (Step height) < 660 (ISO 14122-3:2001)
Motion	On a plane surface : Faster than 0.8m/s (2/3 of walking speed) Stair climbing speed: 0.2 m/s

3. CONCEPTUAL DESIGN OF HYBRID LINK MOBILE PLATFORM

3.1 Working principle

In this section, a systematic design process is carried out using the engineering design methodology [13] to develop a new mobile platform adopting a hybrid link mechanism. Design problem is defined on the basis of the requirement list consisting of five functions essential to a stair-climbing mobile platform. Table 2 shows the extracted working principle for the five functions of the mobile platform and several working principles are selected for each function. Basically, a mechanism to control body angle is required to stabilize its main body combined with payloads. A suitable suspension and actuation mechanisms for front and rear wheels are also required to guarantee mobile stability and adaptability while climbing stairs. Design candidates for a new mechanism are obtained by tactfully combining these working principles.

Table 2 Extracted working principle list

	1	2	3	4	5	6	7
Body Angle Control	Fixed	Rotating	Linear				
Front Suspension Mechanism	Fixed	Rocker	Bogie	Parallel	Fork	Up/Down	Lifter
Rear Suspension Mechanism	Fixed	Rocker	Bogie	Parallel	Fork	Up/Down	Lifter
Front Actuation	None	Linear	Rotation	Slide			
Rear Actuation	None	Linear	Rotation	Slide			

3.2 Design candidate selection

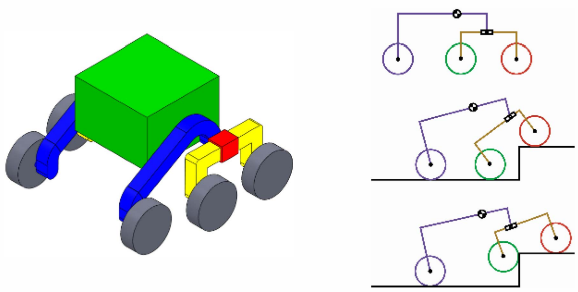

Fig. 2 Final conceptual design

Fig. 2 depicts concept design and kinematic shape of the final design. In this conceptual design, active slide actuator is combined with passive revolute joint so that the front bogie link can move in forward/backward directions to achieve a desired posture on any size of stair. Therefore, this hybrid link mechanism can overcome the limit of general passive linkage mechanisms by adding simple active link. Also, the active slide link mechanism helps avoiding undesired situations like backward movement of mobile platform so that energy efficiency of mobile platform is highly improved and design requirements or limit of the mobile platform such as size, weight and required motor torque can be mitigated. Also, it is quite important how to move along the slide while climbing stairs, the detailed shape and movement stratagem of the slide can be a challenging issue.

4. KINEMATIC OPTIMIZATION

4.1 Definition of optimization problem

To guarantee excellent performance in climbing up various stairs, an optimization for kinematic design parameters of the mechanism is carried out. As shown in Fig. 3, four link lengths and three wheel radii are selected as the design variables. Three types of stairs shown in Fig. 4 are selected as environmental conditions based on the building construction code in the U.S [10].

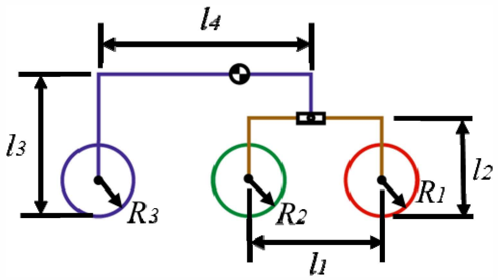

Fig. 3 Kinematic variables of the mobile platform

Objective function is set to minimize 1) backward movement trajectory as well as 2) deviation of CM trajectory slope for three shapes of stairs. Backward movement of a mobile platform may cause undesired discontinuity in path angle resulting in instability while climbing up stairs. On the other hand, the slope of CM trajectory is highly related with energy consumption and required torque [14] so that minimizing the deviation of path angle can improve the energy efficiency as well as the maximum torque requirement.

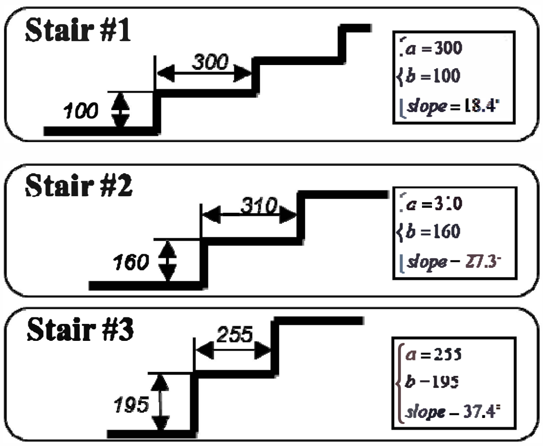

Fig. 4 Three shapes of the selected stair dimensions

4.2 Optimization result

By using the genetic algorithm, optimized design parameters are obtained. Fig. 5 shows the process and generations results of the optimization via the genetic algorithm. Best, worst and mean scores of each generation are displayed, and the lowest score of the final generation is selected as the optimized point.

Fig. 6 and Table 3 shows optimized shape and design parameters of the mobile platform. C.M. trajectories of the three types of stairs are shown in Fig. 7. In every shape of stairs, the repetitive trends of CM trajectories can be observed while climbing up the stairs.

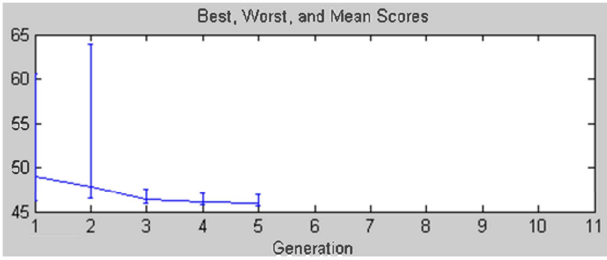

Fig. 5 Optimization process and result using the genetic algorithm

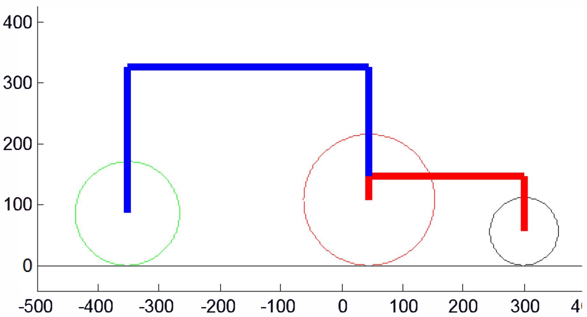

Fig. 6 Optimized shape of the mobile platform

Table 3 Optimized design parameters

R_1	R_2	R_3	l_1	l_2	l_3	l_4
56	108	86	255	147	327	398

5. CONCLUSION

In this research, a new hybrid link mechanism for a stair-climbing indoor mobile platform is proposed and optimized its kinematic design variables. Based on the previous development experience and other related researches and regulations, detailed requirement list is made to obtain an extracted working principle list and its combination results as design candidates. Final conceptual design is selected among those combination results, which use a hybrid-link mechanism combining active slide link with passive revolute joint. To ensure excellent performance, the optimization is carried out by using the genetic algorithm for three wheel radii and four link lengths. The hybrid mechanism proposed in this research will be used as the basis of building a new stair-climbing mobile platform prototype. By using this prototype, a noble control algorithm and strategy for climbing stairs will be designed and tested.

6. ACKNOWLEDGEMENT

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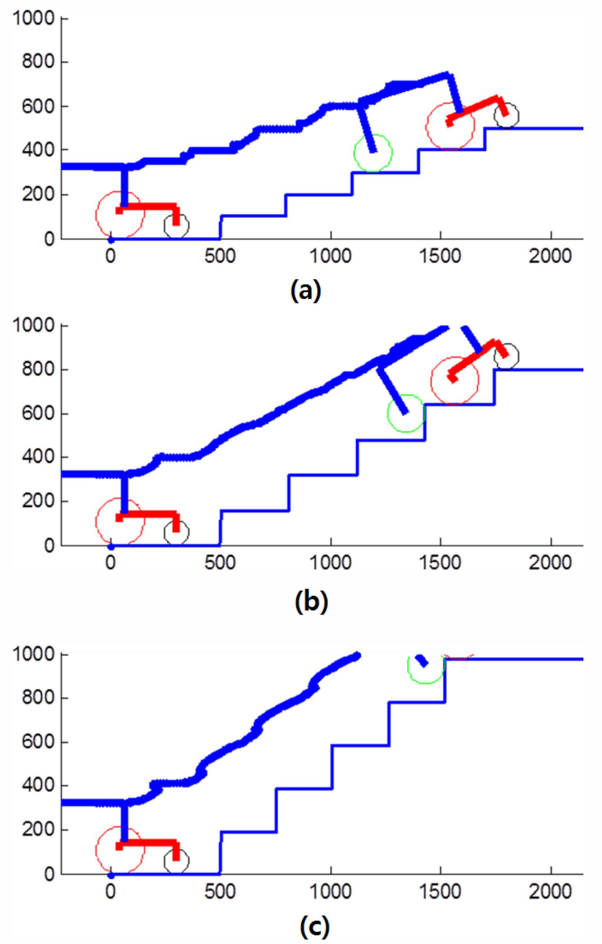

Fig .7 CM trajectories of the optimized mobile platform for three types of stairs (a) 300mm X 100mm, (b) 310mm X 160mm, (c) 255mm X 195mm

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