

Prototype of passive sit-stand exoskeleton for prolonged standing tasks

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ABSTRACT – In manufacturing industry, many tasks require workers to perform in standing position, for examples, milling and welding processes. These manufacturing processes are nearly impossible to perform in seated position using a conventional chair. The aim of this study was to fabricate a medium fidelity prototype of passive sit-stand exoskeleton. Survey on user requirements, Quality Function Deployment and Pugh method were applied to develop the prototype. A medium fidelity prototype of passive sit-stand exoskeleton was fabricated and tested at few manufacturing tasks. This study found that the developed sit-stand exoskeleton prototype allowed user to alternate sitting and standing positions, walking and support body weight.

1. INTRODUCTION

Standing is a flexible working position and has large degree of freedom to handle heavy products, pushing and pulling excessive loads. However, continuous standing in a long period is not only cause discomfort and muscle fatigue but can even cause back pain [1-2]. In a worst scenario, the effects of prolonged standing may result in performance decrement in the industry such as low productivity and efficiency. The aim of this study was to fabricate a medium fidelity prototype of passive sit-stand exoskeleton. This wearable exoskeleton prototype allows user to walk together with the sitting support without obstructing the workspace. Furthermore, it supports body weight and provides sitting and standing positions to the user.

2. METHODOLOGY

The development of the passive sit-stand exoskeleton started with a questionnaire survey to identify the users' requirements. There were 31 industrial workers (90.3% male, 9.7% female aged 25 to 40 years old) participated in the survey. All the respondents exposed to prolonged standing at their workplaces. Relevant users' anthropometry was measured to determine dimensions of the exoskeleton. The Quality Function Deployment was utilized as a tool to translate users' requirements into technical specifications. Few initial sketch and conceptual designs (Figure 1) were generated based on the user requirements survey. The Pugh Method was applied to choose a best design from the four conceptual designs.

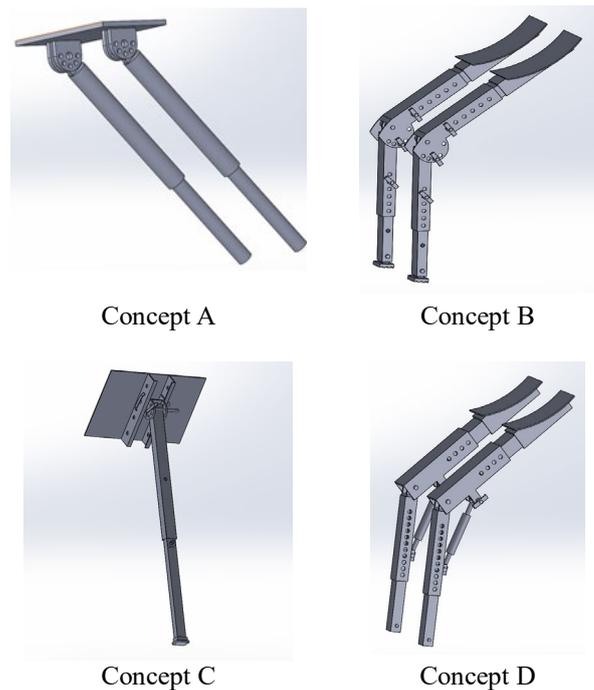


Figure 1 Initial sketch of four conceptual designs

Based on the Pugh Method, a final concept was identified. Figure 2 and Table 1 show the exoskeleton's parts and functions. Additionally, a body grip belt was used for attaching the exoskeleton to user's body (Figure 5).

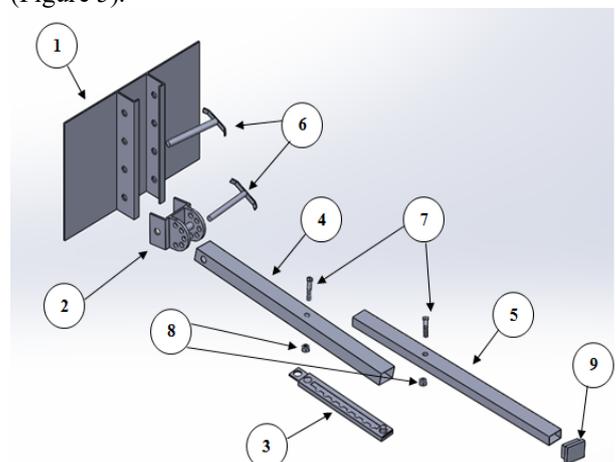


Figure 2 Parts details of passive sit-stand exoskeleton

Table 1 Part name and function

Part no	Part name	Function
1	Seat pan	Support the buttock
2	Sliding bracket	Adjust the seating angle
3	Cam lock	Lock the seat height
4	Upper support	Support for seating
5	Lower support	Support for seating
6	Lock pin	Lock the seating angle
7/8	Bolts and nuts	Joint & tighten the supports
9	Support grip	Friction to avoid slip

3. RESULTS AND DISCUSSION

3.1 User requirements

Results of the survey found that 14 respondents (45%) experienced low back pain due to performing jobs in prolonged standing. Remarkably, 27 respondents (87.1%) agreed to apply passive sit-stand exoskeleton to alternate standing and sitting positions throughout their working hours. As tabulated in Table 2, more than 90% respondents required a passive sit-stand exoskeleton which has design criteria: ‘stability’, ‘movement flexibility’, ‘ease of use’, ‘lightweight’, ‘adjustability’, and ‘portability’.

Table 2 User requirements on exoskeleton design

No.	Design criteria	Requirements (%)
1	Stability	96.8
2	Movement flexibility	96.8
3	Ease of use	93.6
4	Lightweight	93.5
5	Adjustable and portable	93.5
6	Comfort and low cost	80.7
7	Appearance/ aesthetic	71.0

3.2 Stability analysis

Application of stability and body balance principles in the exoskeleton design is obligatory to ensure users are secure when standing and walking [3]. Upper body weight (530 N or 54 kg) was applied to the free body diagram in Figure 3. Summation of moment was calculated at support grip (point O) to study stability of the exoskeleton. To calculate a maximum moment, the support grip was positioned at farthest point, 0.3 m measured horizontally from the downward vertical force of 530 N. The moment at this position is 159 N.m, and the exoskeleton tends to turn clockwise rotation. However, this rotation is stabilized by the reaction force from the feet ($2R_f$) of 265 N.

3.3 Mechanical stress analysis

Based on the finite element analysis, the maximum von Mises stress of 33.41 MPa was found at

the sliding part under the seat pan as shown in Figure 4. This resulted the safety factor of 2.8 with regards to the yield strength of aluminum material.

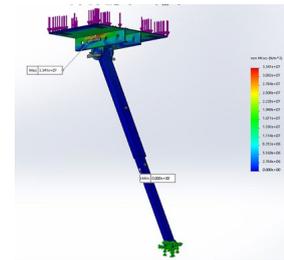
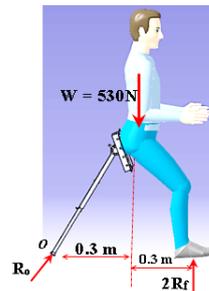


Figure 3 Free body diagram Figure 4 Stress analysis

3.4 Prototype and application

Based on user requirements, a medium fidelity prototype of passive sit-stand exoskeleton was fabricated and tested at few workplaces (Figure 5). This wearable exoskeleton prototype allows user to walk together with the sitting support without obstructing the workspace. The length of exoskeleton can be adjusted to suit the user’s height. Moreover, seating angle can be positioned to 0°, 30° and 45°.



Fitting Turning Milling
Figure 5 Application of prototype at workplaces

4. SUMMARY

The prototype of passive sit-stand exoskeleton was fabricated and tested in manufacturing tasks such as fitting, turning and milling operations. During these operations, the exoskeleton allows user to alternate sit-stand positions and walking.

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REFERENCES

- [1] Lee, J. Y., Baker, R., Coenen, P., and Straker, L. Use of a footrest to reduce low back discomfort development due to prolonged standing. *Applied Ergonomics*, pp. 218-224, 2018.
- [2] Rahman, I. A., Mohamad, N., Rohani, J. M., and Zein, R. M. The impact of work rest scheduling for prolonged standing activity. *Industrial Health*. pp. 1-8, 2018.
- [3] Egoyan and Moistsrapishvili (2013). Equilibrium and stability of the upright human body. *The General Science Journal*, pp. 1-10, 2013.