IROS 2018 with RA-L

Title: Soft Wearable Augment Walking Suit with Pneumatic Gel Muscles and Stance Phase Detection System to Assist Gait

RA-L Submission ID: 18-0260

Summary of Changes:

Firstly, we would like to thank esteemed reviewers, associate editor and editors for their valuable comments and feedback. We have done our best to address all the comments and suggestion from reviewers and editors to improve the quality of our manuscript.

In brief, we have included essential references to state-of-art wearable walking assist suits which were missing earlier, differentiated the contribution of this manuscript compared to our previous publication. Improved the results and discussion section by experimenting additional two subjects and perform statistical analysis on normalized average sEMG data. We have also revised out manuscript thoroughly for written English and reviewed it from native English speaker.

Along with the updated manuscript, we also submit,

1. This answer sheet with answers to all the questions and comments from reviewers.
2. Manuscript with text highlighted referring to changes made for the reviewer's comments. An id is assigned to each question and answer for identification. Along with the highlighted with yellow color, and question id is mentioned in the callout next to highlighted portion to identify a respective change in the manuscript. (We uploaded this manuscript file to the multimedia materials folder as a zip file.)
3. A supplementary video to demonstrate our work. Minor corrections are made in the video as compared to the previously uploaded video.

Dear Reviewer, 1

Firstly, Authors show gratitude for the valuable comments based on which we have significantly revised the paper.

(R1-1) The significance of this paper is explained as being to overcome the gap that existing wearable lower limb support devices fail to simultaneously fulfill the criteria of a "wearable, lightweight, portable, easy to use and muscle fatigue reducing" device. This is supported by the examples of the HAL, Wearable agri robot, Walking Assist Device, Roboknee and Malcolm et al.'s pneumatic exoskeleton. However, there are additional assistive devices that should be considered in the literature review due to their relevancy to the gap and key contribution of this paper

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(A1-1) In then introduction section we have included discussion about the additional lower limb assistive device for gait support.

(R1-2) The gap and Contribution of the paper, you should emphasise that you have shown muscle activity reduction during gait of the suit in the worn compared to the unworn state (instead of the worn but "off" state).

(A1-2) We have addressed this point in results and discussion section where we compare the reduction in muscle activity when not wearing AWS and wearing AWS with two levels of assistive air pressure.

(R1-3) Some improvements can be made to make the paper easier to understand. This includes minor language corrections and making sure the text in the figures is not too small.

(A1-3) We have addressed this point by correcting the English language and proofreading the paper with native English speaker and making text in figures larger and easy to read.

Dear Reviewer, 2

Firstly, Authors show gratitude for the valuable comments based on which we have significantly revised the paper.

(R2-1) The presentation of the paper should be improved with a thorough revision of the writing

(A2-1) We have revised the paper for language correction and also conducted proofreading with native English speaker.

(R2-2) The introduction should be improved in several aspects. The authors mix different kind of exoskeletons in the state-of-the-art. I would suggest to focus on walking assistive exoskeletons. Industrial exoskeletons are usually not focused on walking, so the inclusion of them is a bit confusing. A better organization of the introduction would help to follow the reasoning.

(A2-2) We understand the concern raised here about the referred state of art exoskeletons. The exoskeletons were referred to discuss the requirement of wearable assistive suits but at the same we also realized we did not referred several state of art wearable walking assist suits. We have address this by organizing the introduction section with the help additional and relevant wearable walking assist suits.

(R2-3) Evaluating the system with only 5 subjects is probably not enough to demonstrate statistically the effectiveness of the system. However, at least there is some good indication of it.

(A2-3) We conducted experiment with two additional subjects. For quantitative analysis sEMG data for all subjects is normalized with the percentage of max voluntary contraction (%MVC) and then averaged to compare reduction in the muscle activity when not wearing AWS and wearing AWS with two levels of assistive air pressure.

(R2-4) Did the authors consider the use of more than one pressure sensor? Using also a pressure sensor on the front of the foot, would allow to detect also the toe-off. It could be possible to use IMUs to measure the motion and use it in the control.

(A2-4) The authors are aware and did considered the use of more than one pressure sensor. Since in the current design of AWS the FSR sensor can detect transition in gait phases we decided to keep the configuration simple and therefore, we have not added additional pressure sensor. However, we are considering use of additional pressure sensor and IMU for further enhancement of our suit to detect and support additional gait functions and muscle activation for controlling dynamic assistive force.

(R2-5) Maybe the authors could report also the weight of the system.

(A2-5) We added the wait of AWS in section II-C.

(R2-6) Also subjective opinions from the users would be interesting, to know more about comfort and wearability. This will give more importance to the soft aspect of the system.

(A2-6) We did not conducted survey for usability or soft aspect of the system. But we recorded subjects oral feedback during experiment, we have discussed this feedback at the end of discussion section.

(R2-7) Table I has too many information. Maybe it could help to use some colors to indicate the more significant values.

(A2-7) As it was point out 5 subjects are not enough for statistical analysis we conducted evaluation experiment with two more subjects and performed statistical analysis on normalized averaged sEMG data. Previously Table I is now Table II with the results of statistical analysis conducted on normalized data. The table is has less data and easy to understand.

(R2-8) <u>**I have also a few minor comments:**</u>

- **Several acronyms are not properly defined (PAM, AWS, etc);**
- **The figure captions should be more explanatory, in particular figures 1, 2, 3, 4, 5, 6, 7, 8 and 9;**
- **The figures should be referenced using always the same format, for example "Fig.";**
- **Equation (2) has two ";" between the polynomial and the R value.**
- **Figures 2 and 4 use different units for the pressure. Please, use the same one for clarity;**
- **Figure 5 is difficult to understand. I would suggest to use a more standard gate figure;**
- **Table I should have the caption on the top and not at the bottom**

(A2-8) We authors made the respective changes as mentioned by reviewer above in the updated manuscript. We tried to make all the figures captions more explanatory and informative. Figure reference are corrected. A standard gait cycle is used to explain biomechanics of gait cycle in Fig. 5. All tables have caption on top.

Dear Reviewer, 3

Firstly, authors show gratitude for the valuable comments based on which we have significantly revised the paper.

(R3-1) The authors do not clearly mention where the walking suit assists during walking (i.e. the swing phase which is clear from the accompanying video.).

(A3-1) This concern is address by improving Figure 5 to incorporate standard gate cycle and highlighting assist region. We also added detailed description on the region of assist with respect to gait cycle in the Section II-C.

(R3-2) Contributions of this work as compared to previous literature should be clearly specified in the introduction.

(A3-2) In the introduction section we have added description and drawback of our previous research and how we improved those shortcomings in the current research.

(R3-3) Prior literature on soft assistive devices for similar applications are not cited

(A3-3) In the updated manuscript we added missing essential references matching soft wearable assistive devices previously developed.

(R3-4) The design of the walking suit is not presented.

(A3-4) In Section II-C we now discussed the design of AWS using gait identification system more clearly.

(R3-5) Fig. 10: The data from the left and right FSR for all participants looks very similar. Please verify this. This figure is also not cited in the text.

(A3-5) It is the mistake on our part, we have updated the graph with correct data and added missing citation in the text with discussion.

(R3-6) The results are not explained clearly. More clarification is required in the discussion section pertaining to the percentage reduction in muscle activity.

(A3-6) The results are discussed clearly by using average %MVC for all subjects after conducting experiments with two more subjects. The percentage reduction in the muscle activity is also discussed in the discussion section with the help of Table III describing % reduction.

(R3-7) Standard deviation for the data in Fig. 4 is not provided.

(A3-7) We added standard deviation for the data in the graph. We did not add it earlier

because the force generated by the PGM shows less deviation for the given condition i.e. stretched vs unstretched.

(R3-8) Acronyms must be defined in the test prior to using them ex: AWS, TA etc.

(A3-8) We made sure all the acronyms are defined before they are used.

(R3-9) Thorough grammatical revision and proofreading is required.

(A3-9) The updated manuscript is revised for English language and proofreading is done with native language speaker.