

Reviewer #1 The article addresses a current topic of great interest in the study of walking robots, analyzing how different constructive factors affect the impact forces of the legs against the ground during the march

Authors Authors appreciate your summary. To clarify the paper's contribution, authors proved that CI, related to the impact, is affected by mechanical structures of the leg of legged robots. For this contribution, first, authors identified the problem that often occur at impacts. Then, authors hypothesized that the impact is affected by mechanical structures of the leg. To prove this hypothesis, authors quantified the impact with CI, and showed that the CI varies on the structures through simulations. At last, authors verified the simulation by experiments. The aforementioned is well shown in the *Abstract* and the last paragraph in the *Introduction*

Reviewer #1 But the article needs substantial changes to be published

Authors Authors appreciate your feedback. Authors are ready to accept the changes.

Reviewer #1 On the one hand, the structure of the article is confusing and infrequent in an applied engineering article. The organization in Introduction, Results, Discussion and Materials and Methods makes reading and understanding difficult. It is considered more appropriate for a correct understanding of work to adapt to the scheme of Abstract, Introduction, Formalization of the problem, Methods and experiments, Results, Discussion and Conclusions. It is noteworthy that the article does not present Conclusions

Authors Authors appreciate your recommendation. According to your recommendation, authors reorganized the paper in the order of *Abstract*, *Introduction*, *Methods*, *Simulations*, *Experiments*, and *Discussions and Conclusions*.

Reviewer #1 On the other hand, sections with mathematical development are lacking in detail, omitting steps that require excessive effort by the reader to understand the argumentation and obtain results. The notation used in some cases and the lack of definition of a considerable part of the variables involved in the expressions does not help either.

Authors Authors appreciate your comment. Authors made great efforts to add and modify the mathematical formulations, terms, and symbols such that the potential readers can understand the methods with more ease. The modifications are highlighted in the *Methods*.

Reviewer #1 Some specific aspects found in the paper are detailed below:

Authors Authors wholeheartedly appreciate your thoughtful consideration.

Reviewer #1 Figure 1: the distance indicated for $r_{1(s)}l_1$ seems not to be correct

Authors Authors appreciate your comment. Unlike $r_{2(s)}$, $r_{1(s)}$ is calculated

using M and m_1 , as described in (22). To avoid the confusion, the COM indicated by $r_{1(s)}$ is colored black with the COMs of M and m_1 colored gray, as shown in Fig. 7(a).

Reviewer #1 Equation (4): Define all the variables and parameters that appear in the equation (R , θ , l_1 , l_2 , ...) This is applicable to all equations. Every term in the equations must be clearly defined in the text. Do not assume that the reader can deduct it

Authors Authors appreciate your comment. All the terms and symbols used in the equation are clearly defined and properly placed, as shown in Line 80-81 and 161-166.

Reviewer #1 Line 117: The angle of the velocity vector appears using a $\angle \dot{\mathbf{x}}$ symbol that must be defined. Not doing so makes reading difficult and slows down.

Authors Authors appreciate your comment. Authors newly defined $\mathbf{v}$, a unit impact direction vector, in the context to separate it from the usage of $\dot{\mathbf{x}}$ which indicates the impact velocity including the direction and magnitude both. Therefore, $\angle \mathbf{v}$ is defined in Line 204-205 with examples for better understanding.

Reviewer #1 Line 122: The Force Plate model used is not indicated (it is not indicated until line 225). It should be indicated here, for consistency with the information on the controllers (lines 129 and 130).

Authors Authors appreciate your comment. The models of the force plate and controllers are properly indicated and placed in Sec. 4.1. *Experimental setup*, modifying the paper's format.

Reviewer #1 Figure 7: What is λ ? Again a term without a previous definition

Authors Authors appreciate your comment. Throughout the initial manuscript, the usage of CIM and CI had been mixed. Therefore, authors clearly defined CIM as Λ and CI as λ , as described in (9) and (10), respectively.

Reviewer #1 Table 2: I do not understand how the value of Average net Force is obtained. Can you explain it?

Authors Authors appreciate your comment. To more clarify the explanation, authors added to the previous explanation "the square root of the sum of squares of the x - and z -forces."

Reviewer #1 Table 2: What are the differences between the values given to the Relative CI and those obtained from F / B ? For example, for case (3) $F / B = 0.25 * 0.22 = 1,136$, while 1.11 appears in the table.

Authors Authors appreciate your comment. Thanks to your comment, authors found errors in numbers and figures. Along with Fig. 16, TABLE 2 was corrected with an additional row of "Simulated rCI" to directly compare it with

the experimental rCI, which is visualized in Fig. 16. The new term of “rCI” is defined in Line 242 and the *Abbreviations*.

Reviewer #1 Line 172: Again two expressions are used without explaining their meaning: $\dot{\mathbf{x}}_F$ and $\dot{\mathbf{x}}_D$

Authors Authors appreciate your comment. Authors corrected them as $\mathbf{v}_H$ and $\mathbf{v}_D$ with the supplements in Line 178-179.

Reviewer #1 Figure 11: It is NOT indicated that it is Λ

Authors Authors appreciate your comment. Authors corrected Fig. 11 in Sec. *Flexion direction*, and defined Λ in (19).

Reviewer #1 Section 4.1.2 and 4.2.2: They must be rewritten clarifying all developments. The lack of details in the deductions makes the reading complicated and confusing. The notation used does not facilitate it.

Authors Authors appreciate your comment. Authors suppose that the confusion came from the usage of undefined terms and the unintended error in the equation. Thus, authors supplemented the lack in order to help you clearly understand all the developments by defining the necessary notations and correcting the error.

Reviewer #1 For example: (7): appears $\mathbf{H}$ and H (without indicating that it is this second)

Authors Authors appreciate your comment. The explanation was added following the equation.

Reviewer #1 (8): $\mathbf{I}$ is “Impulse” or the Identity matrix?

Authors Authors appreciate your comment. The explanation was added following the equation.

Reviewer #1 Line after (8): (l circumflex) $\hat{l} = \begin{bmatrix} 0 & -l \end{bmatrix}$ should not be transposed $\begin{bmatrix} 0 & -l \end{bmatrix}^\top$?

Authors Authors appreciate your comment. The equation was corrected.

Reviewer #1 (11): H should not be the inverse? $\Lambda^{-1} = \mathbf{J}\mathbf{H}^{-1}\mathbf{J}^\top$ (as in (21))

Authors Authors appreciate your comment. The equation was corrected.

Reviewer #1 (13): It must be explained how the expression is deduced

Authors Authors appreciate your comment. Authors added the descriptions about the terms used in the equation in order to help you understand in the process of developing the equation.

Reviewer #1 4.2.3 Since the experiment is performed without any control (“dropped 10 times repeatedly from about 0.5m”; “dropping it with an angle

of about 30”), how is it possible to validate the results? It is surprising that the experiment with an angle of approximately 30 degrees has less standard-deviation than the vertical drop, when this (perpendicular to the ground) is more repetitive.

Authors Authors appreciate your sharp observation. Authors conducted the same experiment with a linkage this time to confirm the repeatability. Please note that authors increased the number of experiments from 10 to 20. As shown in Fig. 6, the case of dropping it with an angle showed the less impact force on average, which corresponds to the simulation, but with the variance similar to that of the other case this time. Authors believe that it is important for the averages to take the same trend as before, not the variances. Authors also believe that, since CI will be thoroughly verified with an articulated rigid body in the *Experiments*, this preliminary experiment is enough to show the possibility that the two cases with a single rigid body can be different as expected in (9), and thus arrange it in the early part of *Methods* which moves on to the articulated rigid body later. Authors attached a video about the preliminary experiments for reference.

Reviewer #2 In this paper, leg mechanisms are developed to effectively mitigate the impact due to the consistent collisions with the ground and discussed what is a good measure for impact mitigation and additional consideration of leg mechanisms.

Authors Authors appreciate your summary. To clarify the paper’s contribution, authors proved that CI, related to the impact, is affected by mechanical structures of the leg of legged robots. For this contribution, first, authors identified the problem that often occur at impacts. Then, authors hypothesized that the impact is affected by mechanical structures of the leg. To prove this hypothesis, authors quantified the impact with CI, and showed that the CI varies on the structures through simulations. At last, authors verified the simulation by experiments. The aforementioned is well shown in the *Abstract* and the last paragraph in the *Introduction*

Reviewer #2 After the correction of the problems below, this paper could be considered for publication.

Authors Authors appreciate your positive feedback.

Reviewer #2 There are some recent developments in the field of robotics using machine learning algorithms to guarantee controllability and durability. I suggest the author add some sentences of literature review to make the introduction section more adequate. For example: @article{li2018enhanced, title=An enhanced teaching interface for a robot using DMP and GMR, author=Li, Chunxu and Yang, Chenguang and Ju, Zhaojie and Annamalai, Andy SK, journal=International journal of intelligent robotics and applications, volume=2, number=1, pages=110–121, year=2018, publisher=Springer

Authors Authors appreciate your suggestion. Authors thoroughly reviewed the suggested paper, but the paper focuses on the controllability and durability of the robot about the repeated tasks rather than those about the repeated collisions or impacts. Therefore, please understand that authors couldn't adopt the paper as a reference.

Reviewer #2 The paper is well written, but the contributions or novelties of this work are not clear. The paper reads like a technical report. For a journal paper, new methods or experimental results must be included.

Authors Authors understand your concern. To begin with, the paper's format was reorganized in the order of *Abstract*, *Introduction*, *Methods*, *Simulations*, *Experiments*, and *Discussions and Conclusions*. Authors proposed the method of comparing CIs, related to the impact, from various mechanical structures in the *Methods*, and verified by simulations and experiments that CI is affected by the structures in the *Simulations* and *Experiments*.

Reviewer #2 The whole structure of the paper looks unclear, the authors should better organize.

Authors Authors appreciate your comment. Accordingly, authors reorganized the paper in the order of *Abstract*, *Introduction*, *Methods*, *Simulations*, *Experiments*, and *Discussions and Conclusions*.

Reviewer #2 The strategy remains complex to implement with many parameters. A discussion on the adjustment of these parameters should be presented in the document.

Authors Authors understand your concern. The strategy is to compare CIEs by mechanical structure as described later in the *Methods*. The results, along with the short discussion, are shown in Fig. 8, 9, and 10 throughout the *Simulations*.

Reviewer #2 There are some minor typo errors, please check carefully.

Authors Authors appreciate your comment. Authors confirmed and corrected the typos.

Reviewer #3 This paper investigate how to mitigate the impact force, the actuator configuration, segment ratio, total length, and flexion direction and contact inertia (CI) defined at the tip of the leg is derived and utilized to analyze the leg mechanisms in terms of impact mitigation.

Authors Authors appreciate your summary. To clarify the paper's contribution, authors proved that CI, related to the impact, is affected by mechanical structures of the leg of legged robots. For this contribution, first, authors identified the problem that often occur at impacts. Then, authors hypothesized that the impact is affected by mechanical structures of the leg. To prove this hypothesis, authors quantified the impact with CI, and showed that the CI varies on the structures through simulations. At last, authors verified the simulation by experiments. The aforementioned is well shown in the *Abstract* and the last

paragraph in the *Introduction*

Reviewer #3 Some of the suggestions

Could you do some simulation to simulate what is the contact inertia and impact force in different mass, length, flexion direction, and segment ratio configuration.

Authors Authors appreciate your comment. Reorganizing the paper's format, authors added the *Simulations*, though not the dynamic simulations. Authors believe that CI is shown to be dominant in the impact force through the impact dynamics in the *Methods*, and that simply computing CI without dynamic simulations is enough to verify by experiments in the *Experiments* that the simulated rCI and the experimental rCI match as described in TABLE 2. 3 **Reviewer #3** I think it will let the reader to understand how to chose those configuration as they design a leg. It will be better to have a table to review your developed leg and other legs you mention in the introduction. In the table, you can compare those parameter you discuss in this papers. It will be let us understand what are the state-of-art legs and what is their configuration of leg. It seems like reducing the CI can mitigate the impact force. But how to reduce the CI ? Could you summary how to reduce CI in detail.

Authors Authors appreciate your comment. To avoid the confusion, authors reorganized and refined the manuscript. The study has been done to prove the hypothesis that CI is affected by mechanical structure. Therefore, the paper focuses on the fact that the CI varies on the structure, not the structure to reduce the CI at most. Authors believe that the CI can be used to follow up on leg design for mitigating the impact, as discussed in the second paragraph of the *Discussions and Conclusions*.