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IMPACT ANALYSIS OF EXPLORATION ROVERS

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ABSTRACT

Exploration rovers are likely to experience impact during their operation in non-structured environments. An excessive impact force can result in damage of the rover and the equipment that it carries, so it is desirable to keep the value of such loads small. Reconfiguration of the rover suspension can be used to reduce the risk of maneuvers where impact is expected, e.g. obstacle negotiation.

The evaluation of contact forces during impact requires the use of continuous force-based methods. Such models, however, are subject to parameter uncertainty and it is difficult to generalize them for their use with different systems undergoing impact. In this work, we apply an alternative performance measure for rovers. This is based on the part of the pre-impact kinetic energy of the rover, which is associated with the characteristic direction of impact, e.g. normal direction.

The use of this performance measure is illustrated with the comparison of different impact scenarios of rovers. Results show that the measure can accurately represent the effect of changes in rover parameters and configuration on the intensity of impact. This approach can help to select adequate vehicle parameters for rover design and operation.

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KINETIC ENERGY AS PERFORMANCE INDICATOR

The part of the kinetic energy of a mechanical system associated with its subspace of constrained motion (SCM), T_c, can be used as an indicator of the maximum normal force developed during an impact [1]. Let us consider that the motion of a system can be described with an $n \times 1$ array of generalized velocities $\mathbf{v}$, subject to a set of m kinematic constraints $\mathbf{Av} = \mathbf{0}$, with $\mathbf{A}$ an $m \times n$ matrix. The set of generalized velocities $\mathbf{v}$ can be decomposed into components associated with the SCM and its orthogonal complement, the subspace of admissible motion (SCA), as

$$\mathbf{v} = \mathbf{v}_c + \mathbf{v}_a = \mathbf{P}_c\mathbf{v} + \mathbf{P}_a\mathbf{v} \tag{1}$$

where $\mathbf{P}_c$ and $\mathbf{P}_a$ are the projection matrices onto the SCM and the SAM, respectively. This decomposition allows for obtaining the kinetic energy associated with the SCM as

$$T_c = \frac{1}{2}\mathbf{v}_c^{\mathrm{T}}\mathbf{M}\mathbf{v}_c \tag{2}$$

where $\mathbf{M}$ is the $n \times n$ system mass matrix. The expression of the projection matrix $\mathbf{P}_c$ is given by [2]

$$\mathbf{P_c} = \mathbf{M}^{-1}\mathbf{A}^{\mathrm{T}}\left(\mathbf{A}\mathbf{M}^{-1}\mathbf{A}^{\mathrm{T}}\right)^{-1}\mathbf{A} \tag{3}$$

If we assume a perfectly elastic contact, all the kinetic energy associated with the SCM will be transformed into elastic potential energy at the end of the compression phase of the impact. Therefore, the value of T_c at the moment at which the impact begins, T_c^-, can be used to characterize the maximum value of the normal force during the impact. This kinetic energy can be referred to as the effective kinetic energy.

SIMULATIONS AND RESULTS

A 2-D model of a rover (Fig. 1) was used to demonstrate the relationship between the effective kinetic energy and the maximum impact force.

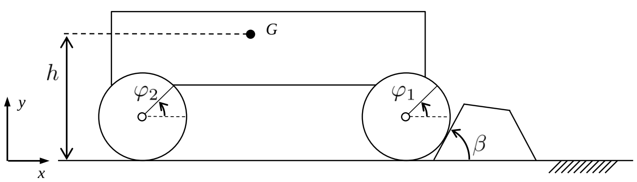

FIGURE 1. A 2-D MODEL OF A ROVER UNDERGOING AN IMPACT WITH AN OBSTACLE

Simulations of the impact of the rover with an obstacle were carried out for different impact angles β and heights of the centre of mass (COM) of the vehicle with respect to the ground h. The effective kinetic energy was computed at the instant just before contact was established, and the maximum impact force was determined during the impact interval using the non linear spring-damper model proposed by Hunt and Crossley [3]

$$f_n = -k\delta^{3/2}\left[1 + \frac{3\left(1-e_{eff}\right)}{2}\frac{\dot{\delta}}{v_i}\right] \tag{4}$$

where f_n is the normal force at the contact interface, δ is the indentation of contacting bodies, e_{eff} is the coefficient of restitution, and v_i is the initial penetration velocity.

In both cases, results show that the effect of modifying the impact configuration on the impact force f_n can be captured using the effective kinetic energy T_c^-. This supports the validity of such an indicator in the estimation of the intensity of impact. The analysis can be carried out without the need for detailed information about the nature of the bodies involved in the impact. The information obtained with this indicator can be useful in the design and operation of rovers.

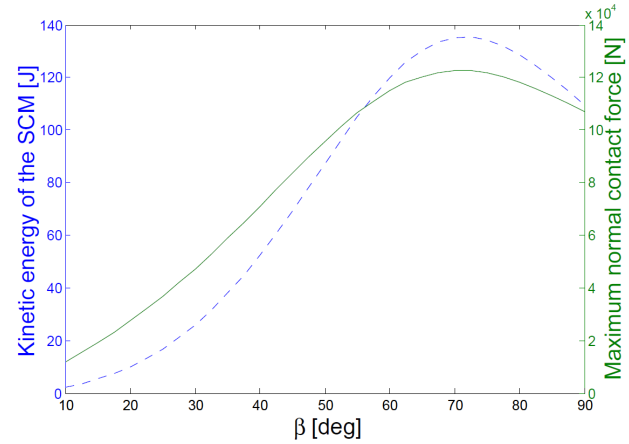

FIGURE 2. COMPARISON OF MAXIMUM IMPACT FORCE (f_n) AND EFFECTIVE KINETIC ENERGY (T_c^-) FOR DIFFERENT VALUES OF THE IMPACT ANGLE β

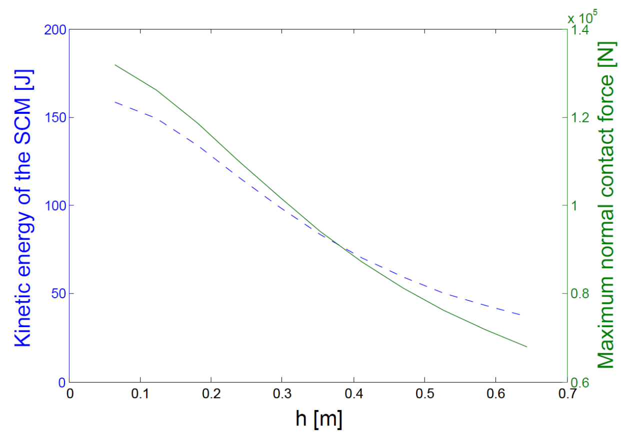

FIGURE 3. COMPARISON OF MAXIMUM IMPACT FORCE (f_n) AND EFFECTIVE KINETIC ENERGY (T_c^-) FOR DIFFERENT HEIGHTS OF THE ROVER COM h

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