Comparison of Capture Point estimation with human foot placement: Applicability and Limitations

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Introduction

For bipeds like humans, taking a step to recover its balance is fundamental. The question that arises is the location where the biped should step. Pratt et al. [1] developed an algorithm to estimate the so-called *Capture Point*, a point on ground where a robot can step in order to bring itself to a complete stop. The objective of the current work is to test the applicability of the algorithm for the prediction of step location in humans under perturbed state.

Method

Healthy volunteers were subjected to a platform translation lasting 400ms and large enough to induce compensatory step(s) [2]. 8 volunteers participated in a first series of experiments where a large space was provided for the subjects in front of them to take several steps. Among them, 4 participated in a 2nd series, where the space was limited to about 800 mm (the average stepping distance observed in the 1st series). Ground reaction force and kinematics were recorded, body segments inertial parameters were estimated using regression tables and the experimental whole body center of mass (CoM) position and velocity were computed.

The capture point algorithm [1] considers a linear inverted pendulum model to calculate a unique capture point corresponding to the *instantaneous* state of the robot (i.e. CoM position and velocity). In addition a flywheel centered at the CoM is used to represent the upper-body rotational inertia characteristics. It enlarges the capture point to a *Capture Region*. The model assumes the *instantaneous* foot placement at the capture point/region with no time-delay.

The capture point was estimated at two key instants (the step initiation and impact of the foot on ground) using the CoM data from the experiments. The size of the capture region was calculated assuming Bang-Bang torque profile [1], using the estimated upper body inertia of the subject, a maximum torque value of 300Nm [3], and a maximum hip flexion ankle of 90°.

Results

Typical size of the capture region was found to be in vicinity of 10cm. The gap between the actual foot placement and the capture region at impact was large for the 1st series (11.4±5.8cm). However, in the 2nd series, subjects stepped *on* or *near* to the capture region. One subject intersected the base of support with the capture region (but not the capture point) and recovered absolutely in one step. Subjects who stepped close to the capture region (within 5cm), but not exactly on it, had to take another small step to retain balance. A large shift of capture region (50-75cm) was observed during the delay between step initiation and its impact on ground.

Discussion and Future work

The size of capture region is small as compared to the step length and length of base of support (foot). However, 2nd series results, showing that one subject could recover without stepping on the capture point (but on the capture region), underlined the importance of upper-body inertia in balance recovery process. Moreover, as evident from the 1st series' results, if the subjects are not bound to recover in one step, they step far from the capture region and take several steps to recover. This indicates the existence of some other criterion during stepping decisions such as energetic costs etc. Furthermore, the shift of the capture region during the time delay between step initiation and its impact on ground is significant. Considering this time-delay is thus required if one wants to accurately predict the stepping location. Ongoing work is intended to improve this estimation by considering the above-mentioned aspects.

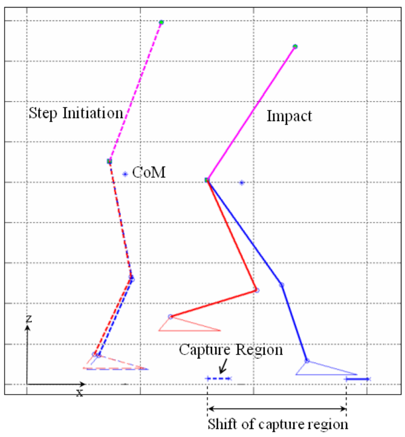

Figure 1: Two key states of the stepping process: step initiation and impact, an example of 2nd series

References

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