Dysturbance: DYnamic and STatic pUsheR to Benchmark bAlaNCE

Simone Monteleone[1], Francesca Negrello[2], Giorgio Grioli[2], Manuel G. Catalano[2], Manolo Garabini[1], and Antonio Bicchi[1,2]

***Abstract*—Legged robots could impact on a wide range of applications in real environments, thanks to their enhanced dexterity and flexibility. However, accidental collisions with the environment, or contacts with humans or other robots may lead to robot instability, or even to a fall, preventing the accomplishment of the task. The robots capability to resist and recover from disturbances is a topic extensively studied in research. However, to assess performance, researchers still rely on qualitative methods, that lack of repeatability.**

In this work, we propose a new methodology and a framework to quantitative characterize the resilience of legged robots when subjected to external perturbations. The major contributions are the proposal of a new concept for benchmarking robots stability, and the design of a structure capable to execute, on different systems, repeatable tests. Furthermore, we are contributing to develop a testing facility accessible by other research institutions.

***Index Terms*—Benchmarking, Humanoids, Legged Locomotion**

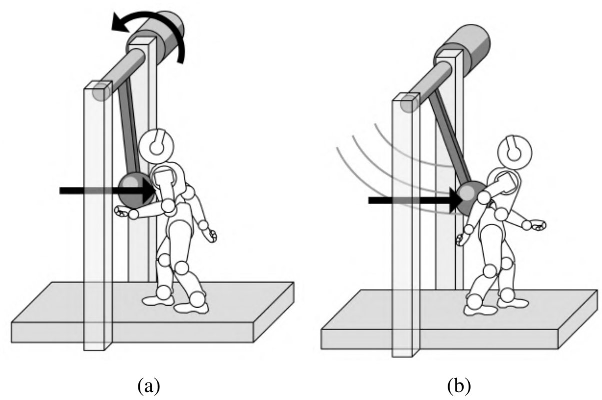

Fig. 1: Dysturbance Conceptual Design. Examples of different loads. a) Quasi-static tests, executed through an actuated pendulum, and b) impulsive tests, executing by a fast swing of the pendulum.

I. Introduction

The resilience of robotic systems is defined in literature as the capability to recover from sudden changes or perturbations so that it is still possible to operate [1][2]. It is a characteristic related to the system elasticity and control adaptation. Robot resilience is acquiring more and more importance since researchers are aiming to build systems capable to work in rough and unknown environments, or in strict contact with humans. Based on recent works, we define the resilience of motion of a legged robot as the system capability to recover its balance after unexpected perturbations.

Despite literature presented many robotic systems, at the best of our knowledge, still no common accepted benchmarking techniques exist to assess their performance. Therefore, the proof of robotic system stability is given, nowadays, by means of qualitative methods, like applying external perturbations [3], or walking over rough terrains [4]. These solutions, however, do not measure the capability of a system to perform resilient behaviors, as they only are visual assessments of the system performance. Moreover, those tests are not easy to replicate by other researchers, nor possess repeatability, so they do not allow comparisons between robots or control algorithms [5]. Comparing performance is very important to foster the development of more and more resilient systems. Furthermore, performance characterization will also be indispensable when those robotic systems will approach the market for a wider use out of the research labs. Indeed, performance must be measurable for the development of safety regulations and usage policies.

These reasons motivated the recent activity of the community in the field of benchmarking [6][7], especially for legged systems [8], proposing at the European level some joint efforts to develop common evaluation frameworks, such as Koroibot [9], or the European project Eurobench [10].

In this work, we propose Dysturbance, an evaluation framework that aims to characterize the stability of legged systems subjected to external perturbations. Here, we present the main motivations and concepts that drove the framework development and we report the preliminary experimental results.

II. Dysturbance Conceptual Design

Other fields, such as biomechanics, already developed advanced methodologies for studying human locomotion. Biomechanic literature, indeed, already describes several structures and methodologies to evaluate the performance and motion stability of humans.

Those solutions show that it is important to evaluate the human capabilities to resist to different kind of external perturbations, e.g. asymmetric [11], impulsive [12] or active [13] perturbations near the Center of Mass (CoM) of the

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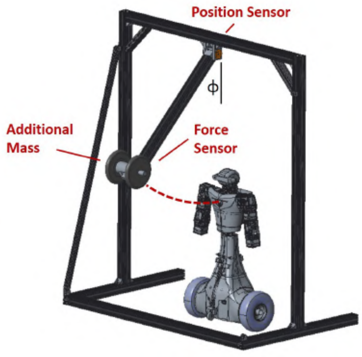
[1] Centro di Ricerca E. Piaggio e Dipartimento di Ingegneria dell'Informazione, Università di Pisa, 56126 Pisa, Italy, monteleone.simone.sm@gmail.com.

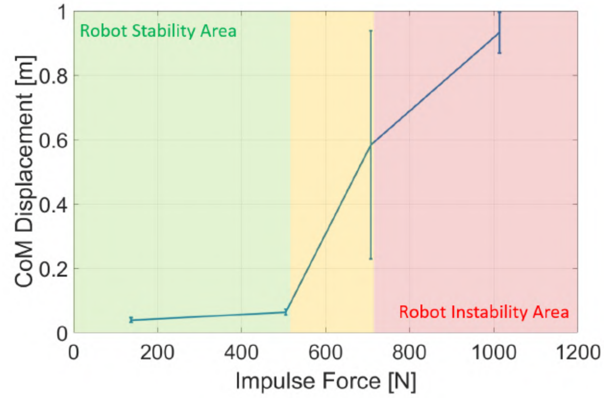
[2] Istituto Italiano di Tecnologia, Via Morego 30, 16163 Genova, Italy.



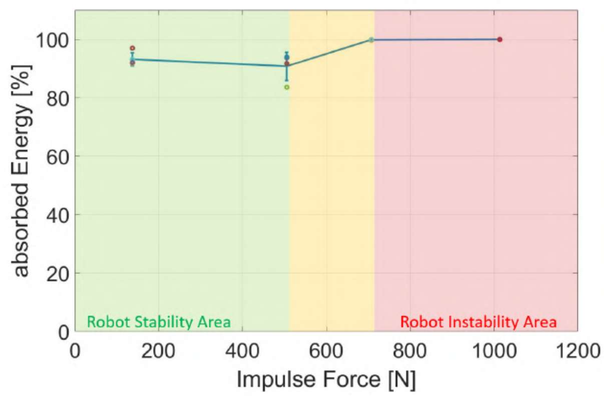
(a)

(b)

Fig. 2: Preliminary experiments on Alter-Ego. a) Schematic visualization of the set-up, and b) a frame of the experiment at the moment of the impact.



(a)



(b)

Fig. 3: Data from Alter-Ego tests. a) CoM Displacement, and b) absorbed energy. The region of stability are identified by transition forces.

subject, as well as on the distal parts of the body (e.g. [14]). For these reasons, we aim to integrate in a single framework the structure to reproduce different types of perturbations on robotic legged system, the sensing system to acquire relevant data, performance indicators and a tool for analyzing the overall performance of the robot.

Fig. 1 shows the concept of the Dysturbance testbed. The pendulum-like design is inspired by the Charpy test machine for the materials toughness characterization. Since we aim to characterize legged systems stability under different types of perturbations [8], the testbed must be actuated so that it will be capable to exert impulsive, quasi-static, and dynamic disturbances. Another requirement is to accomodate within the same testbed robots of different sizes.

For the above reasons, we identified the following features for the design of the Dysturbance framework:

- **Flexibility**: The necessity to execute different perturbations implies the requirement of an actuation unit to control the system;
- **Repeatability**:to promote the replicability and the reliability of the system and its results, we designed the system using only commercially available components;
- **Tunability**: We must be able to adjust contact location and perturbation amplitude for different size of robots;
- **Stand-alone System**: The benchmark must rely only on measurements provided by the testbed itself to assure comparisons across different robotics systems. To this aim we exploit the commercial sensors integrated into the testbed;
- **Operators Safety**: all tests must be done in an enclosed space where no operators can access it. Furthermore, security protocols must be presents to handle emergency situations;

III. Preliminary Results

To generate reproducible loads, we used the instrumented pendulum shown in Fig.2 [6]. It is worth noticing that the sensing system of the set-up is substantially the same that will be used for the final implementation of the Dysturbance test-bench. Specifically, a magnetic encoder located on the pendulum joint (Austrian Microsystem AS5045) measures its angular position, while on the impact head an uniaxial force sensor (Dytran 1051V4) measures the force at the impact point. The angular position of the pendulum is sampled at 250Hz, while the force is sampled at 10kHz through a DAQ system (NI-6251). Moreover, experimental data were complemented by the measure of the robot state employing a motion tracking system, implemented through Kinovea [15].

Experiments are executed on Alter-Ego [16], a two-wheeled humanoid robot developed by the Research Center ”E. Piaggio” and IIT. We tested the robot stability when subjected to impacts. Impulsive loads are executed increasing the pendulum initial height, aiming to reach the impulsive force that destabilizes the control system causing the robot to fall.

Several reasons motivated the choice of using impulsive loads for the pilot experiments. Firstly, it allowed to study the behavior of a falling robot to get insight for the development of the final actuated testbench. Furthermore, it allowed to test the sensing system in the most challenging operative condition.

Preliminary results are reported in Fig. 3. Mapping the center of mass (CoM) displacement as a function of the impulsive load (Fig. 3(a)), we notice that three areas exist, divided by two characteristic force values (about 500N and 700N). The first area, colored in green, is the one in which the robot is capable to maintain its stability with a probability of 100%. In red is highlighted the area in which the robot, when an impact with such intensity occurs, falls with at least with 40% of probability, while in yellow is highlighted a transition area, in which the robot is capable to resist at least 60% of the times.

Fig. 3(b) shows the percentage of kinetic energy absorbed by the robot during an impact. We highlight how when the robot falls down, the full energy of the pendulum is absorbed, while when the robot remains stable, there is a sort of elastic robot response that returns part of the energy (about 10%). The vertical lines indicates the variance of the acquired data. In both graphs, it is possible to see how Alter-Ego behavior changes drastically depending on the region color.

From the experimental results we derived a set of indices to characterize the performance of the robot. The first is the impulsive force that lead the robot to instability (Fig. 3(a)). The second is the maximum horizontal CoM displacement that the robot experiences when not falling down, which should be small to avoid potentially dangerous behaviors (e.g. other collisions).

We highlight that, to ensure a safe robot behavior in the yellow zone, it should be considered how much displacement is allowed, because the robot may cover a large distance while recovering stability. The last one is the percentage absorbed energy.

IV. Conclusion

In this paper, we presented the preliminary results of our work towards the definition of a new methodology and framework to assess the resilience of motion of legged systems. We discuss the pilot testing with impulsive disturbance performed on Alter-Ego, a two-wheeled humanoid robot, that lead to the definition of a set of performance indicators to benchmark robot balance. As for now, we describe the robot stability performance by means of the two characteristic forces that determine the transition between stability regions, the robot CoM displacement and the absorbed kinetic energy. We hope that our work will foster the improvement of legged systems and locomotion algorithms, facilitating their introduction in the real world.

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