Benchmarks and tests on HRP2

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***Abstract*— In this work we report results from a campaign of measurements in a laboratory allowing to put a humanoid robot HRP-2 in a controlled environment. In particular we have investigated the effect of temperature variations on the robot capabilities to walk. In order to benchmark various motions modalities and algorithms we computed a set of performance indicators for bipedal locomotion. The scope of the algorithms for motion generation evaluated here is rather large as it spans analytical solutions to numerical optimization approaches able to realize real-time walking or multi-contacts.**

I. Introduction

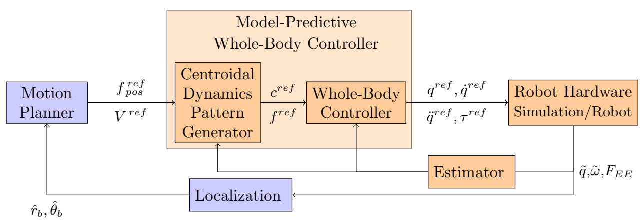

Fig. 1. General architecture to generate motion for a humanoid robot. In this paper the boxes in orange are the one benchmarked, whereas the blue boxes are not benchmarked

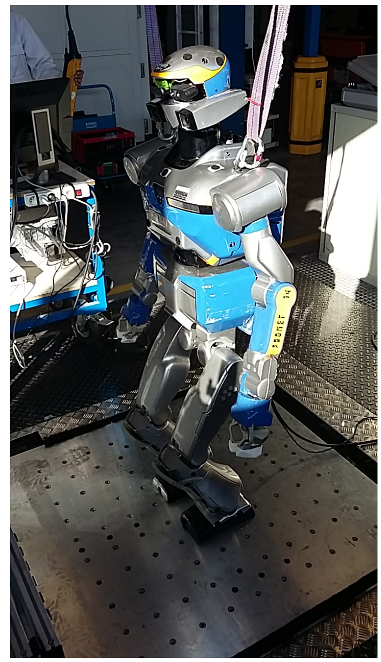

Fig. 2. HRP2 on translationnal platform

A lot of algorithms are developped to improve motions of humanoid robots. They often use architectures following the general framework depicted in Fig. 1. Based on an internal representation of the environment and the localization of the robot ($\hat{r}_b$ and $\hat{\theta}_b$ being respectively the base position and orientation), the **Motion Planner** (**MP**) plans a sequence of reference end-effector contact positions (f^{ref}), or a reference center of mass linear velocity combined with a reference waist angular velocity (V^{ref}). These references are then provided to a **Model-Predictive Whole-Body Controller** (**MPWBC**) which generates a motor command for each joint (joint torques (τ^{ref}), positions (q^{ref}), velocities ($\dot{q}^{ref}$) and accelerations ($\ddot{q}^{ref}$)). This block is critical in terms of safety as it maintains the dynamics feasibility of the control and the balance of the robot. The **Model-Predictive Whole-Body Controller** (**WBC**) can be expressed as a unique optimal control problem but at the cost of efficiency in terms of computation time or solution quality. This is why this controller is usually divided in two. First trajectories for the robot center of mass c^{ref} and the positions of contacts with the environment f^{ref} are found using a **Centroidal Dynamics Pattern Generator** (**CDPG**). And, in turn a **WBC** computes an instantaneous controller that tracks these trajectories.

The approaches used in this presentation are based on mathematical optimization which is broadly used in the humanoid robotics community. More precisely, the problem of the locomotion can be described as an **Optimal Control Problem** (OCP). This optimization problem is difficult to solve in its generic form. And specifically the dynamic constraint is very challenging. Most of the time the shape of the problem varies from one solver to another only by the formulation of this constraint. The difficulty is due to two main factors: 1) There is a large number of degrees of freedom (DoF). In practice we need to compute 36 DoF for the robot HRP2 shown in Fig.2 on a preview window with 320 iterations ($1.6s$) to take into account the system inertia. 2) The system dynamics is non linear.

At this stage we need indicators to compare the efficiency of these algorithms using different assumptions.

II. Related work

A. Benchmarking

Different methods exist to benchmark robot control architectures, in [1] the authors argue that robotic challenges are

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an efficient way to do so. This benchmarking was however costly as the robots had no system to support them in case of fall. In addition, as it is mostly application driven it is necessary in evaluating the system integration but not the independent subparts. As a first step, the simulation proposed by [2] is necessary but one step further is to benchmark a real humanoid platform. For this presentation we used a more systematic decomposition of the humanoid bipedal locomotion [3]. This work focuses on evaluating the **MPWBC** and **WBC** on the Robot Hardware.

B. KPI

In this context and in collaboration with the H2R project, a detailed set of key performance indicators (KPI) have been proposed [3]. These KPI try to capture all the bipedal locomotion patterns. Specific sub-functions of the global motor behaviors were analyzed. The results are expressed as two different sub-function sets. First, the sub-functions associated to body posture task with no locomotion. And second the same sub-functions but including the robot body transport. The initial condition may vary depending on the experiment to perform. This is the idea of the intertrial variability. The sub-functions are also classified by taking into account the changes in the environment or not. Each of these functions can be evaluated for different robots using the criteria explained in [3]. The performance are classified in two sub categories, quantitative performance and human likeness. In addition there are indications on the last two columns if the criteria is applicable on a standing task or on a locomotion task. Again, all the team owning a robot had had to perform an evaluation of these KPI, considering the current and potential state of their robots and controllers. A part of these KPI were applied during the European project Koroibot. The goal of this project was to enhance the ability of humanoid robots to walk in a dynamic and versatile way, and to bring them closer to human capabilities. In this presentation, we are focusing on the evaluation of these KPI in collaboration with our LNE partners.

III. Experiments

The benchmark was organized considering three main axes : equipments in LNE, algorithms and KPI. Each axe contains different points and should be validated with all the points of the others. Number of combinations were reduced by the feasibility in some cases and we limited number of trials between 3 and 5.

These are the setups used in the national laboratory of tests and metrology (LNE):

1. varying temperature room,
2. tilted surface,
3. horizontal translations platform,
4. weights for bearing,
5. force sensor for pushing,

We have tried different algorithms in order to accomplish several tasks :

1. 10cm stairs with **CDPG** [4],
2. 15cm stairs and handrail [4],
3. walking on a beam **CDPG** [5] [6],
4. walking on flat ground using [6],
5. walking on flat ground using [7],
6. stabilizer described in [8] and [9],

Here are the KPI chosen within [3]

1. walked distance,
2. success rate,
3. max tracking error,
4. duration of the experiment,
5. mechanical joint energy,
6. actuators energy,
7. cost of transport,
8. mechanical cost of transport,
9. Froude number.

In this presentation, we show how the KPI evolve according to the setups and the algorithms.

IV. Conclusion

From all these results and experiments few major results come out. First the temperature plays a roll on the energy consumed during a motion. We observed that the colder the room is the more mechanical and electrical energy is consumed. We also noticed that the more the motion is at the limit of stability the more the stabilizer has to inject energy into the system to compensate for potential drift. This create a noticeable increase in energy consumption, e.g. in when the robot walk on a beam, step over obstacle, walk on stepping stones. However the most expensive motion is climbing stairs which is clearly a challenge for future potential applications where stairs are involved.

Finally in terms of cost of transport, the algorithm proposed by [4] seems to be the most efficient and the most versatile. Its main disadvantage during this campaign was the lack of on-line implementation compare to [5] and [7].

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