Whole-body sensor fusion for localization, mapping and balance estimation of legged robots

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Current locomotion algorithms in structured (in-door) 3D environments require an accurate and low latency localization. The several and diverse sensors typically embedded on legged robots (IMU, coders, vision and/or LIDARS) should make it possible if properly fused. Yet this is a difficult task due to the heterogeneity of these sensors and the real-time requirement of the control. While previous works were using staggered approaches [1] (odometry at high frequency, sparsely corrected from vision and LIDAR localization), the recent progress in optimal estimation, in particular in visual-inertial localization, is paving the way to a holistic fusion [2]. In this line of research, each measurement source provides factors between key frames (state decision variables at given instants), a representation of the environment (a landmark map) and calibration parameters (sensor biases, camera extrinsics, etc.). The estimation problem is then formulated as finding the Maximum A Posteriori of the joint probability distribution, which is an non linear least square problem. This work is a contribution in this direction and comprises 4 axes:

- Visual inertial odometry based on windowed optimization validated on a humanoid robot
- Contact detection and leg odometry
- Wrench sensors integration for center of mass estimation
- Camera extrinsics calibration

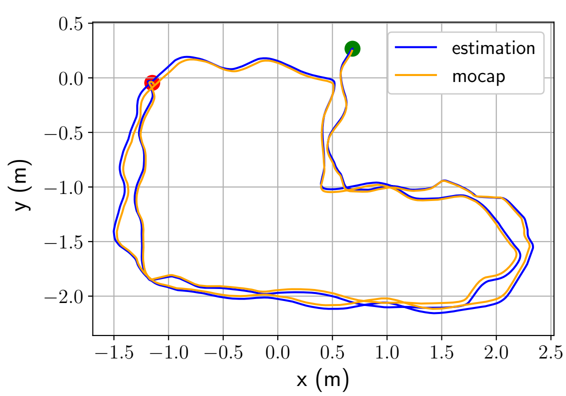

Fig. 1. Visual Inertial Odometry: two loops of the experimental field with camera in hand

First, we propose to quantify how a visual-inertial navigation system can accurately localize a humanoid robot in a 3D indoor environment tagged with fiducial markers [3]. We introduce a theoretical contribution strengthening the formulation of Forster's IMU pre-integration [4], a practical contribution to avoid possible ambiguity raised by pose estimation of fiducial markers and an experimental contribution on a humanoid dataset with groundtruth. Our system is able to localize the robot with less than 2 cm errors once the environment is properly mapped.

This work naturally extends to additional measurements coming from other high rate sensors. We are in particular interested in adding kinematic information limb in contact coders to derive leg odometry factors. This requires an accurate detection stable contacts with the environment, using the feet forces for instance. While humanoid robots can rely on end effector wrench sensors, those are inadequate for most quadruped robots and the contact forces have to be inferred from joint torque sensors and the robot state. Other quantities such as feet velocity or terrain knowledge can then be fused to mitigate potential errors on this estimation in order to properly detect stable contacts.

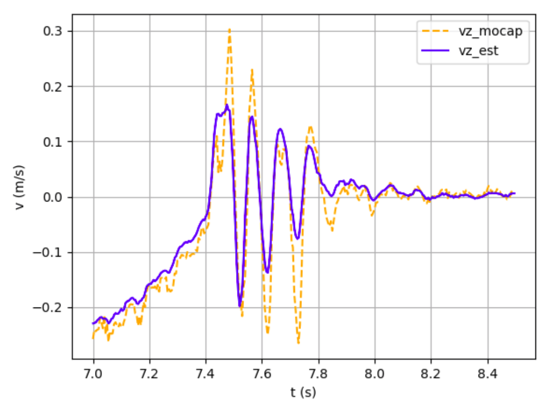

Fig. 2. Visual Inertial Odometry: HRP2 descending stairs (zoom on one step): the robot first lowers its center of mass and then touches the next step with results in vibrations from the impact, properly captured by imu integration.

Another line of research is to estimate the center of mass position and velocity as well as angular momentum of the robot based on wrench measurements and kinematics. Most of existing methods use a cascading approach as in [5], assuming that the position, orientation and velocity of the base is known from an available separate base estimator. We propose a formulation where these quantities are estimated in a tightly coupled manner along with the base quantities

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and derive a novel preintegration algorithm for the wrench sensors, taking into account a variable bias on the kinematic measurement of the CoM.

We also implemented an camera extrinsics calibration procedure fusing leg kinematics and fiducial markers relative measurements. A standing humanoid robot is displaced to extreme statically stable configurations in order to excite the different degrees of freedom of the variable.

References

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