Introduction

Legged locomotion necessitates estimates of base pose (position and orientation) and velocity for localization and control. Further:

▸ Estimation must be task agnostic; walking involves intermittent contacts, reactive gait and unknown terrain.
▸ Exteroceptive sensor data is unreliable in unstructured environments; rely only on proprioceptive sensors and leg kinematics.
▸ We extend the filter proposed in [1] from a point-foot quadrupled to a humanoid by exploiting the fact that a single humanoid flat foot contact fully constrains the relative base pose.

→ Summary: the addition of foot rotational constraints significantly simplifies singular cases: the maximum rank loss of the observability matrix is reduced from 5 to 2 in single support, resulting in increased performance in walking tasks.

Background

An Inertial Measurement Unit (IMU) measures base acceleration (\(\ddot{r}\)) and angular velocity (\(\dot{\omega}\)). However:

▸ IMU data is afflicted by noise modeled as a time-varying bias (b) plus white noise (w).
▸ Sensor measurements must be transformed into the world frame through the integrated orientation (C).
▸ Measured acceleration must be compensated for gravity (g).

→ Problem: purely integrated IMU sensor data results in a rapidly drifting pose.

\[
\dot{\omega} = \omega + b_\omega + w_\omega
\]

→ Solution: since encoders and kinematics models are known to be accurate, use leg kinematics for drift correction.

▸ Essentially, a humanoid in single support becomes a fixed-base manipulator with the IMU as its end-effector whose relative pose can be calculated from kinematics.

Overview

▸ Error is corrected using kinematics; an Extended Kalman Filter (EKF) tracks the base pose and velocity, foot pose and biases.
▸ IMU data is integrated for prediction and the relative pose of the foot in the base frame, computed from measured joint angles, is used for correction whenever at least one foot is in contact.

Results

The following plots show the base pose during a 120 second simulated walking task with double support periods shown in gray. The flat foot filter performs better than the point foot filter overall, as confirmed by the RMS errors in the following table.

<table>
<thead>
<tr>
<th>Error</th>
<th>Point Foot</th>
<th>Flat Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>dx(m)</td>
<td>0.0088</td>
<td>0.0042</td>
</tr>
<tr>
<td>dy(m)</td>
<td>0.0046</td>
<td>0.0017</td>
</tr>
<tr>
<td>dz(m)</td>
<td>0.0025</td>
<td>0.0019</td>
</tr>
<tr>
<td>(\dot{r})(rad)</td>
<td>0.0010</td>
<td>0.0010</td>
</tr>
<tr>
<td>(\dot{\phi})(rad)</td>
<td>0.0011</td>
<td>0.0013</td>
</tr>
<tr>
<td>(\dot{\psi})(rad)</td>
<td>0.0079</td>
<td>0.0055</td>
</tr>
</tbody>
</table>

The superior observability of the flat foot filter results in less drift due to fewer encountered singularities. Further, the additional orientation constraints limit yaw error. Ongoing work includes the implementation of the filter on the actual humanoid as well as the integration of new sensors.

References

Nicholas Rotella
Michael Bloesch
Ludovic Righetti
Stefan Schaal

1 CLMC Lab, University of Southern California
2 Autonomous Systems Lab, ETH Zurich
3 Autonomous Motion Department, Max-Planck Institute for Intelligent Systems

Articles cited in this document include:

1. [1] An Inertial Measurement Unit (IMU) measures base acceleration (\(\ddot{r}\)) and angular velocity (\(\dot{\omega}\)). However:

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