Whole-Body End-Pose Planning on Uneven and Inclined Surfaces

Henrique Ferrolho\textsuperscript{1,2}, Vladimir Ivan\textsuperscript{2}, Yiming Yang\textsuperscript{2}, Wolfgang Merkt\textsuperscript{2}, Rosaldo J. F. Rossetti\textsuperscript{1}, and Sethu Vijayakumar\textsuperscript{2}

\textsuperscript{1} LIACC, DEI, Faculdade de Engenharia da Universidade do Porto, \{henrique.ferrolho, rossetti\}@fe.up.pt
\textsuperscript{2} School of Informatics, Informatics Forum, University of Edinburgh, \{v.ivan, yiming.yang, wolfgang.merkt, sethu.vijayakumar\}@ed.ac.uk

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{NASA’s Valkyrie pelvis kinematic split (left), and bi-manual end-pose planning on inclined supports (right).}
\end{figure}

End-pose planning for humanoid robots is the process of finding a valid stance location and balanced collision-free reaching configuration. Once a valid end-pose has been calculated, it can be used as a goal state for footstep planning or whole-body motion planning \cite{3}.

This paper outlines a platform-agnostic technique for planning valid collision-free end-poses in cluttered environments while accounting for uneven terrain. The principles proposed in this work on humanoid robots are scalable to legged-platforms with arbitrary number of supports (e.g. quadrupeds).

Yang et al. \cite{4} presented a novel end-pose planning algorithm that combines a Dynamic Reachability Map (DRM) and an inverse Dynamic Reachability Map (iDRM). DRM and iDRM capture collision volumes of robot poses computed offline and allow to efficiently update the data structure online. The proposed method splits the humanoid upper- and lower-body at the pelvis link providing a trade-off between coverage, success rate, and the computational cost. The increased coverage allows to plan end-poses on flat terrains at different heights, but the feet orientations are still constrained to a horizontal plane.
Fig. 2 shows the diagram of the proposed approach. To achieve foot alignment on uneven terrains, we extract candidate support regions from the environment. These are then used for evaluating lower body sample suitability.

During the first stage (1) a paired iDRM-DRM is used to find a list of whole-body samples that are collision-free and satisfy the task goals (e.g. hand position and foot alignment with the support surface). These samples are then used to seed a non-linear optimization-based inverse kinematics (IK) solver [2] in stage (2). This step is required to position the hands at the desired grasping pose, and to align the feet perfectly with their respective support region. The resulting end-pose is then tested for static stability in stage (3) using a robustness metric proposed in [1]. The process is repeated until a valid end-pose is found.

Our main contributions are twofold: (i) the introduction of a mechanism for sampling foot locations from candidate support regions, and (ii) the evaluation of robot poses using a more robust stability metric. Splitting the upper body DRM and the lower body iDRM enabled us to store a large number of samples in each data structure to cover the space of both support foot positions and orientations. This made end-pose planning in complex and cluttered environments possible, whether the robot needs to stand on flat ground, steps, or inclined supports. To do this, our method has to check the combinations of upper and lower body poses online; however, our experiments have shown that the added computational time spent iterating through the combinations of partial poses is relatively low, resulting in an average planning time of 318 ms per query.

References
2. Tedrake, R., the Drake Dev. Team: Drake: A planning, control, and analysis toolbox for nonlinear dynamical systems, \url{http://drake.mit.edu} accessed: 2017-06-12