Footstep Planning in Rough Terrain for Bipedal Robots using Curved Contact Patches

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The source-code is provided as the Open-Source Surface Patch Library (SPL): dkanou.github.io

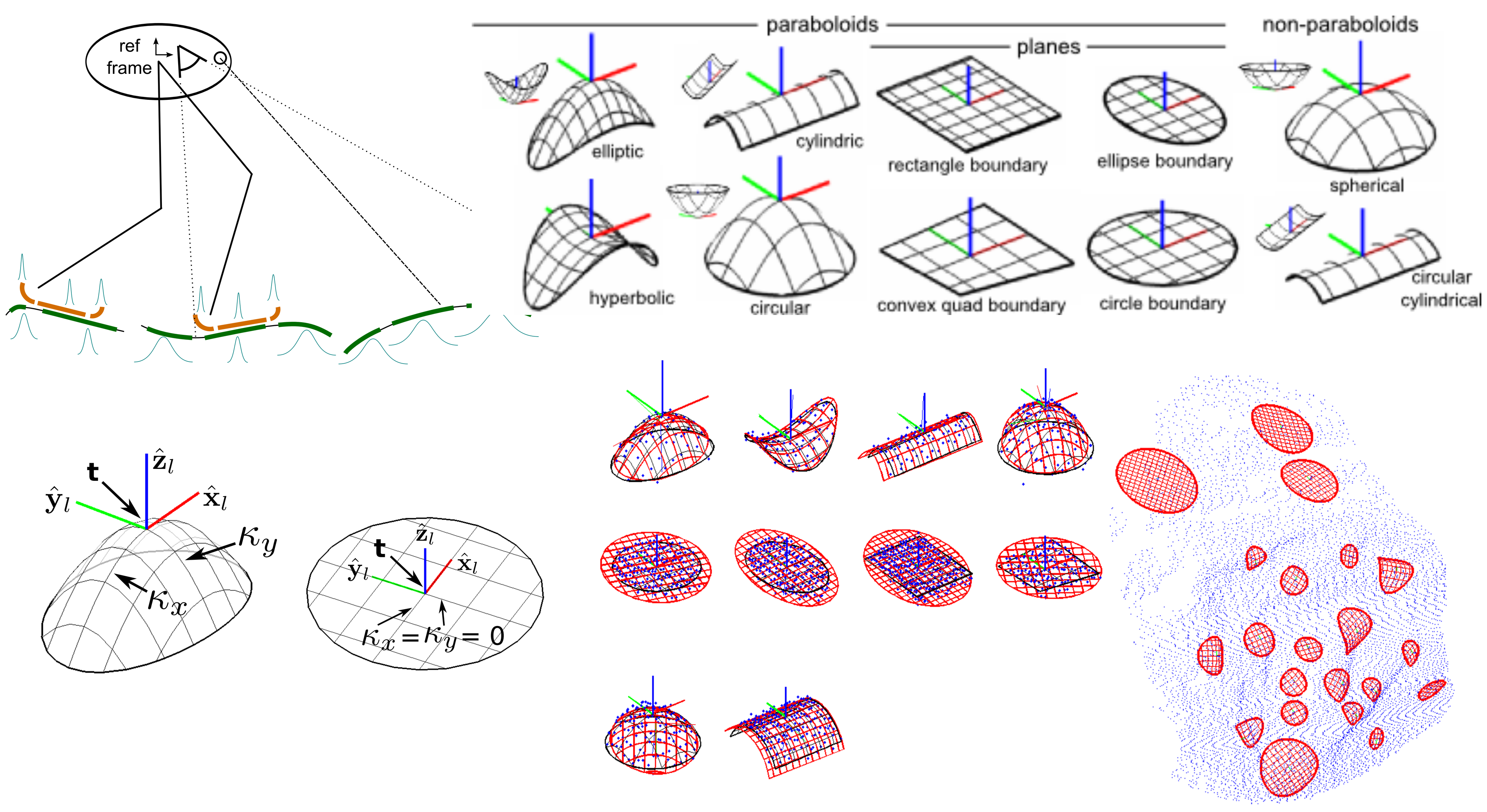
Perceiving Rough Terrain

Hypothesis *[VK11, KV13, KV14, K14, KVT16, T17]*
Sparse 3D footfall affordances can be detected, modeled, and mapped in real-time, using curved surface patches.

Sparsity of Footholds for Legged Robots requires

1. modeling local contact surface areas
2. online perception algorithms to find them
3. **planning paths for 3D contacts [this paper]**

Environment Representation



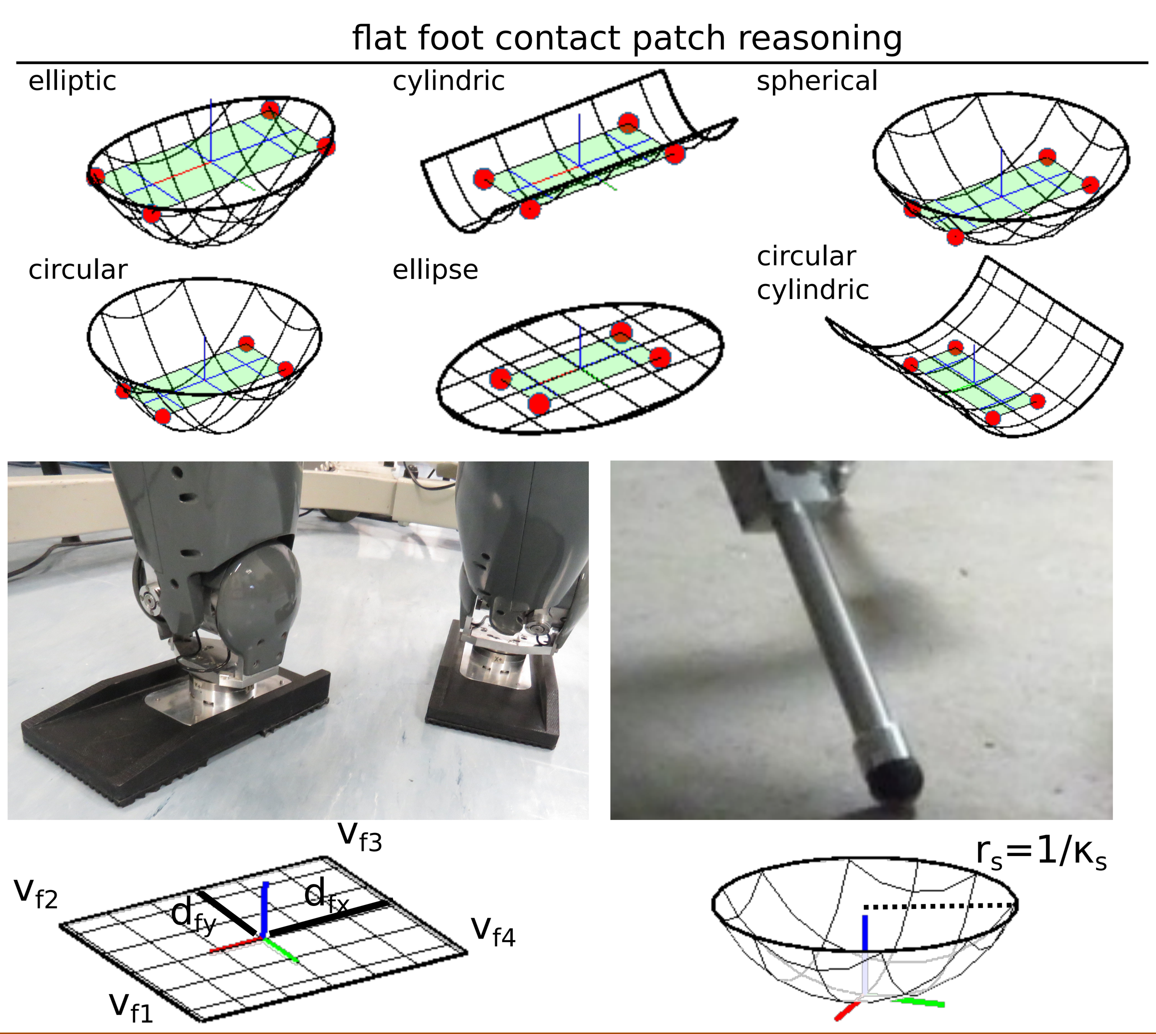
Patch Modeling *[VK11, KVT16]*
- detailed models for 10 bounded curved-surface patch types for contact regions
- minimal geometric parametrizations: curvature, spatial pose, and bounds
- foot-sized boundaries

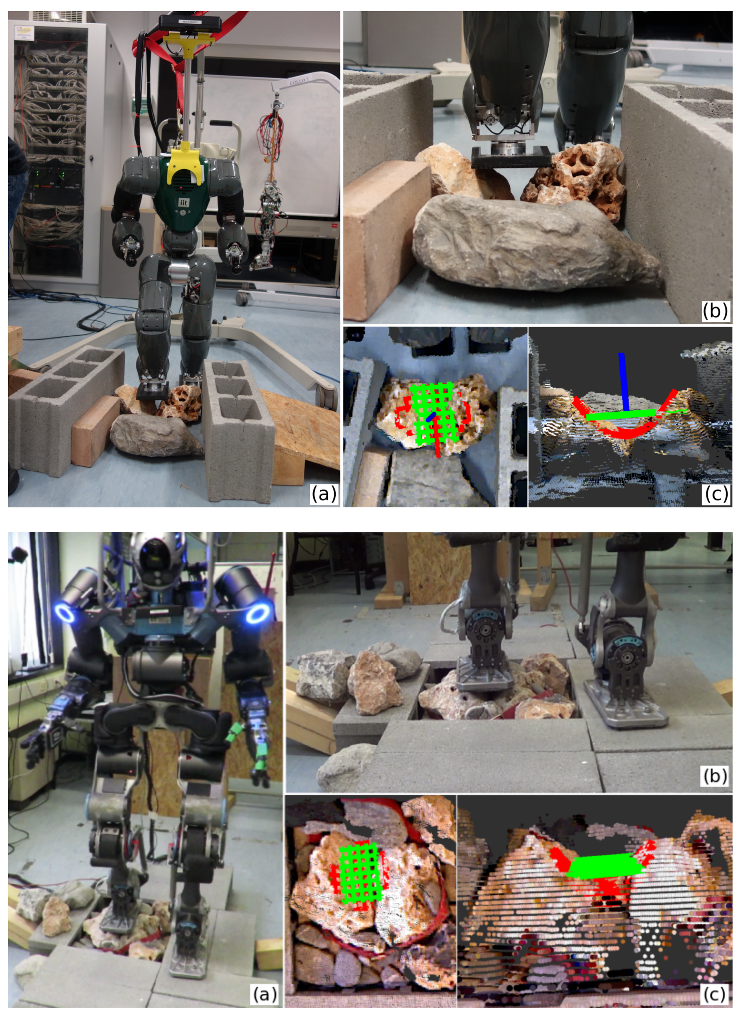
Patch Fitting *[VK11, KVT16]*
real-time nonlinear fitting algorithm to neighborhoods of range data, including quantified uncertainty

Patch Validation *[KV13]*
1. patch fit quality (residual)
2. fidelity to data (coverage)
3. max curvature

Timing: ~0.6ms per neighborhood with 50 points

Flat Foot Contact Patch Reasoning





Patch Contact Reasoning *[KV14, K17]*

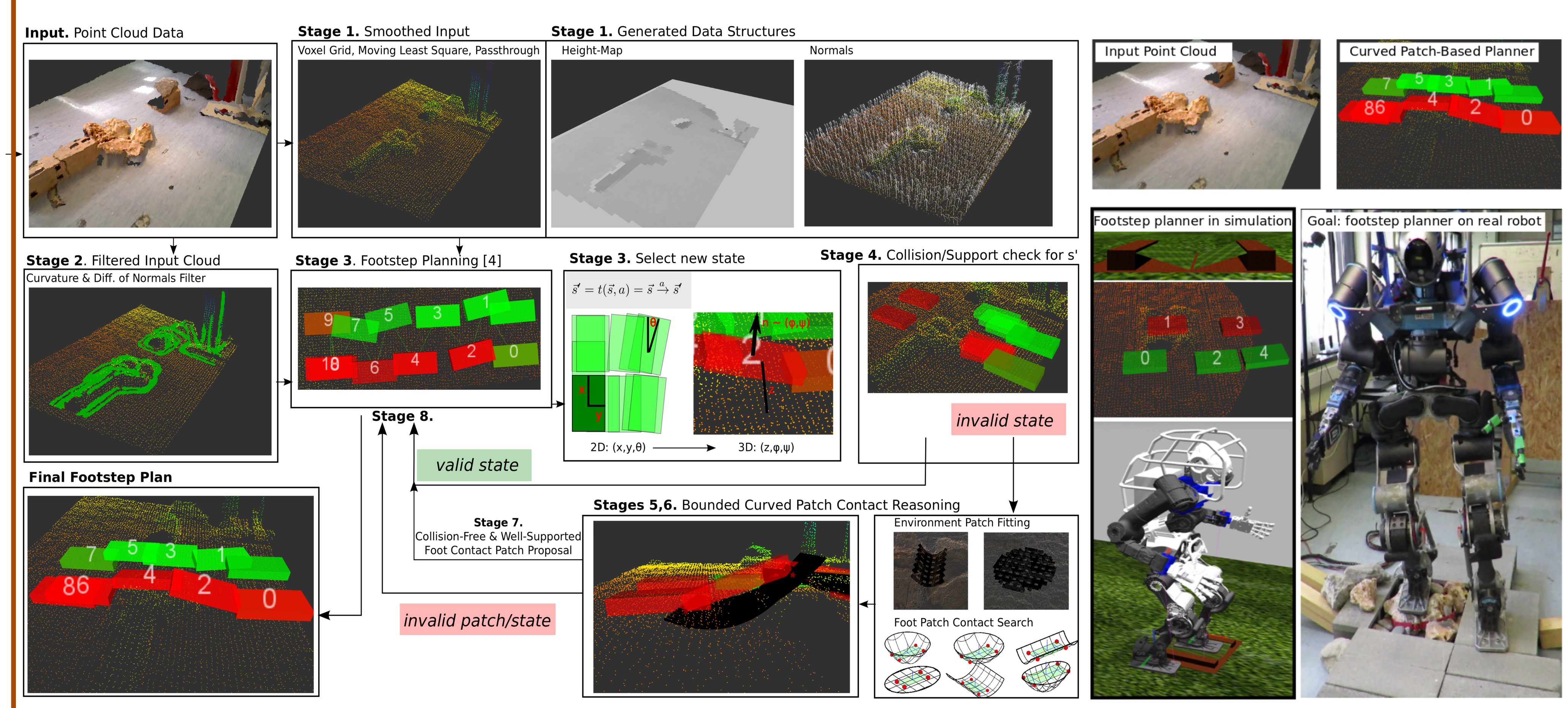
1. visual contact analysis between flat/spherical feet and curved rough ground surfaces

2. contact modeling based on bounded curved patches, both on the sole of the robot and in the terrain

3. visual localization of footholds in the environment's point cloud, through a fast path fitting process and a contact analysis between patches

4. experimental validation of the framework, using range data for rough terrain stepping demonstrations on the COMAN and WALK-MAN humanoids

Footstep Planning in Rough Terrain



3D Footstep Planning *[S14, current paper]*

1. a new visual-based footstep planner for rough curved terrains, for bipedal robot locomotion

2. contact modeling between a flat foot and local curved surfaces, as bounded curved patches

3. extension of an ARA* flat-surface footstep planner to handle rough curved surfaces, e.g. rocks

4. experimental validation of the framework, using range data for rough terrain stepping using the WALK-MAN humanoid in simulation

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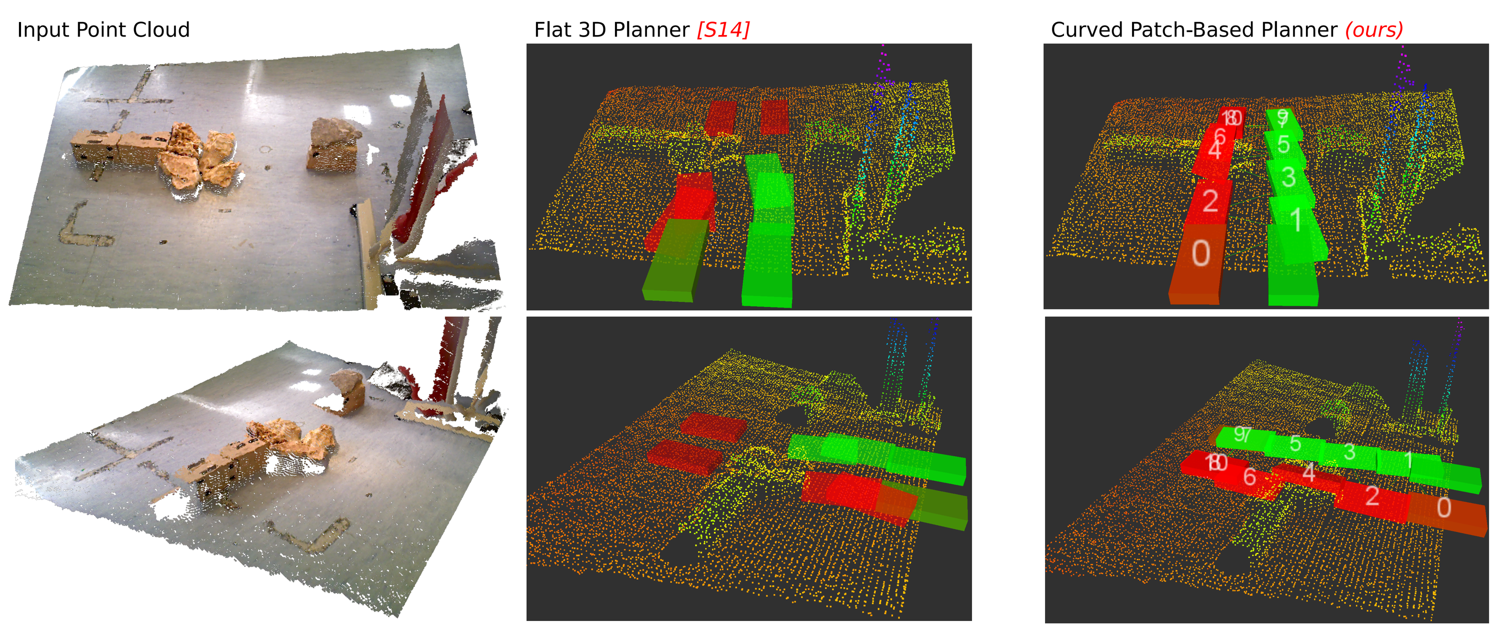
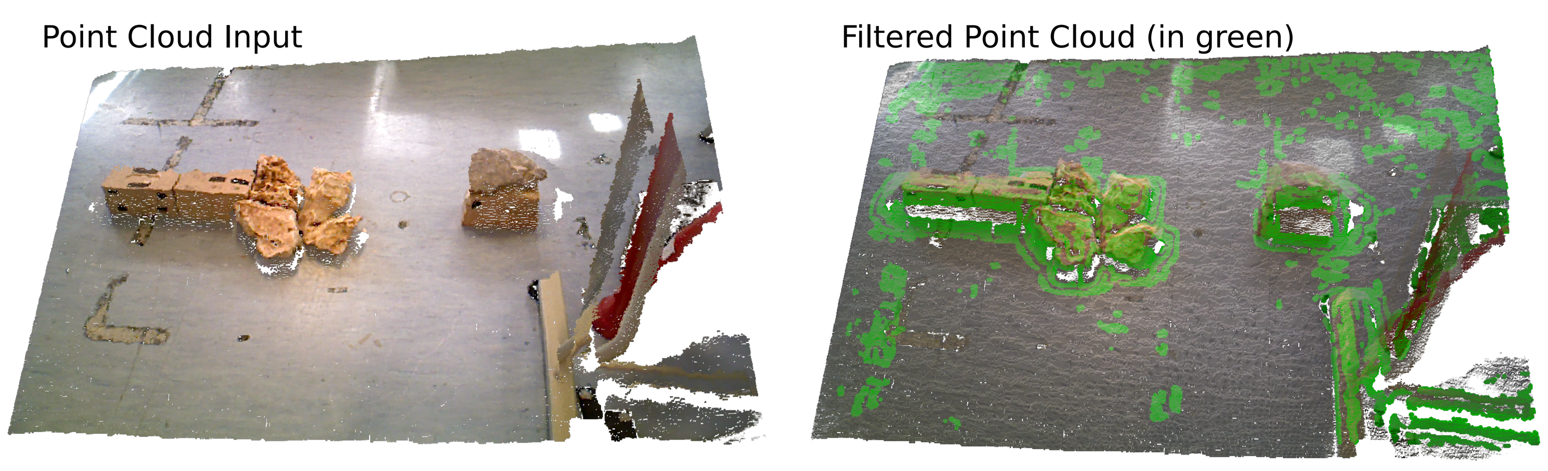
Footstep planning over a rough curved terrain





Uneven Flat Terrain Footstep Planning, using ARA* *[S14]*

1. **States, Actions, and Transition Model**:

   6DoF s = (x, y, z, φ, ψ, θ , f) $\qquad \vec{s}' = t(\vec{s}, a) = \vec{s} \xrightarrow{a} \vec{s}'$

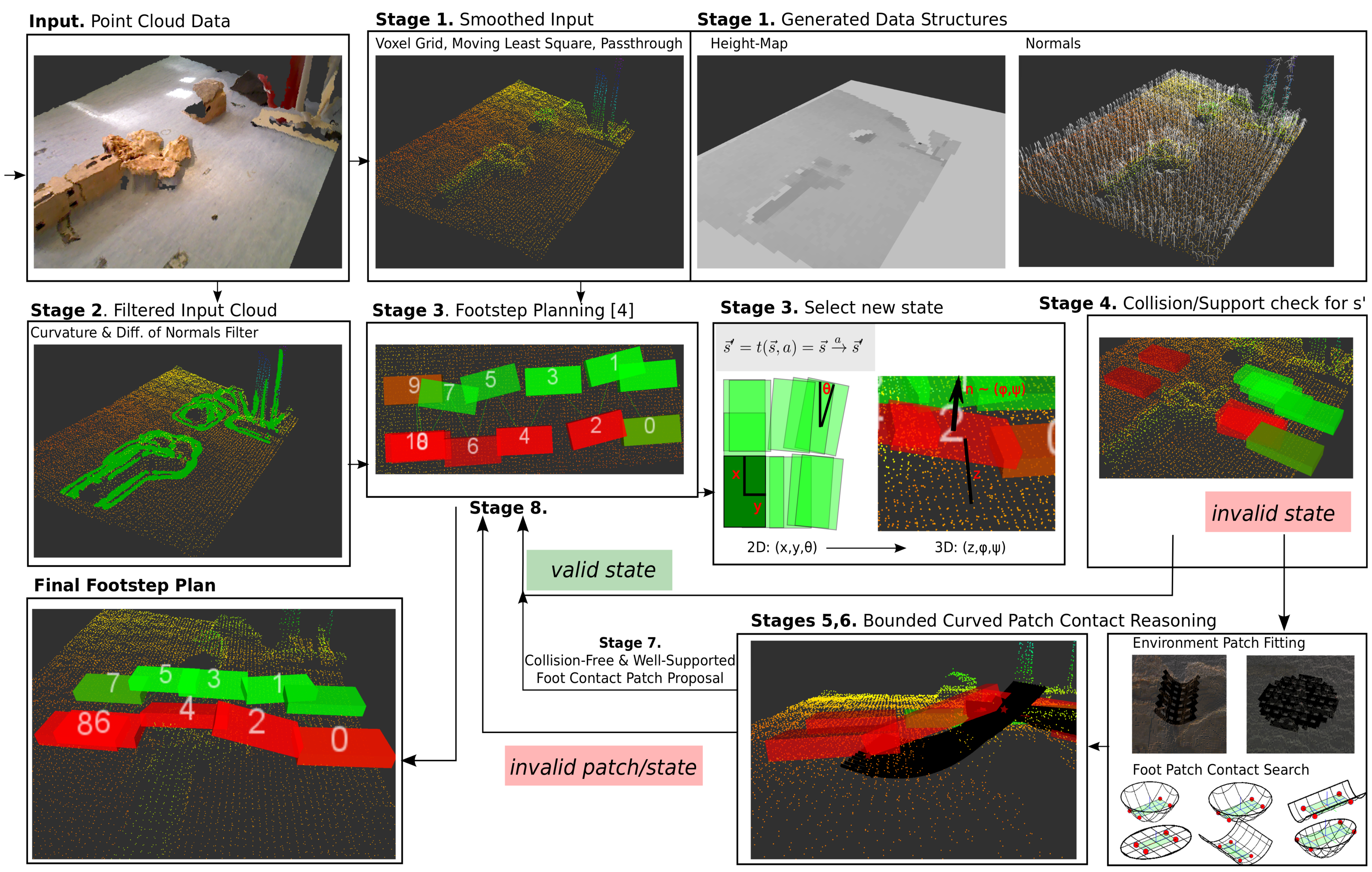
2. **Cost Functions and Heuristics**: i) minimal #steps, ii) shortest paths, iii) low torso acceleration, iv) footsteps with enough terrain support.

$$\hat{h}(\vec{s}) = (\vec{s} - \vec{s}_{\mathrm{goal}}) + c_\theta \cdot \|\Delta\theta\| + c_{\mathrm{step}} \cdot n_{\mathrm{steps}}$$

3. **Collision Check, and Ground Contact Support**: the terrain is modeled as a height-map and each point in the captured point cloud is associated with a local normal. The foot is sampled equidistantly in order to check for: i) collision and ii) ground contact support

4. **Curved Patch-Based Foot Contact Reasoning:** when the surface is curved the foot either collides with the terrain (concave surfaces) or does not have enough support (convex surfaces). There is a need for curved contact patches.

Algorithm



Input: An organized point cloud *pc*. The foot size (length, width) $f_s = (f_l, f_w)$.

Stage 1: Smoothed Input and Data Structures

Stage 2: Filtered Input Cloud

Stage 3: Footstep Planner Core

Stage 4: State's Collision/support Check

Stage 5: Contact Patch Generation

Stage 6: Contact Patch Re-estimation

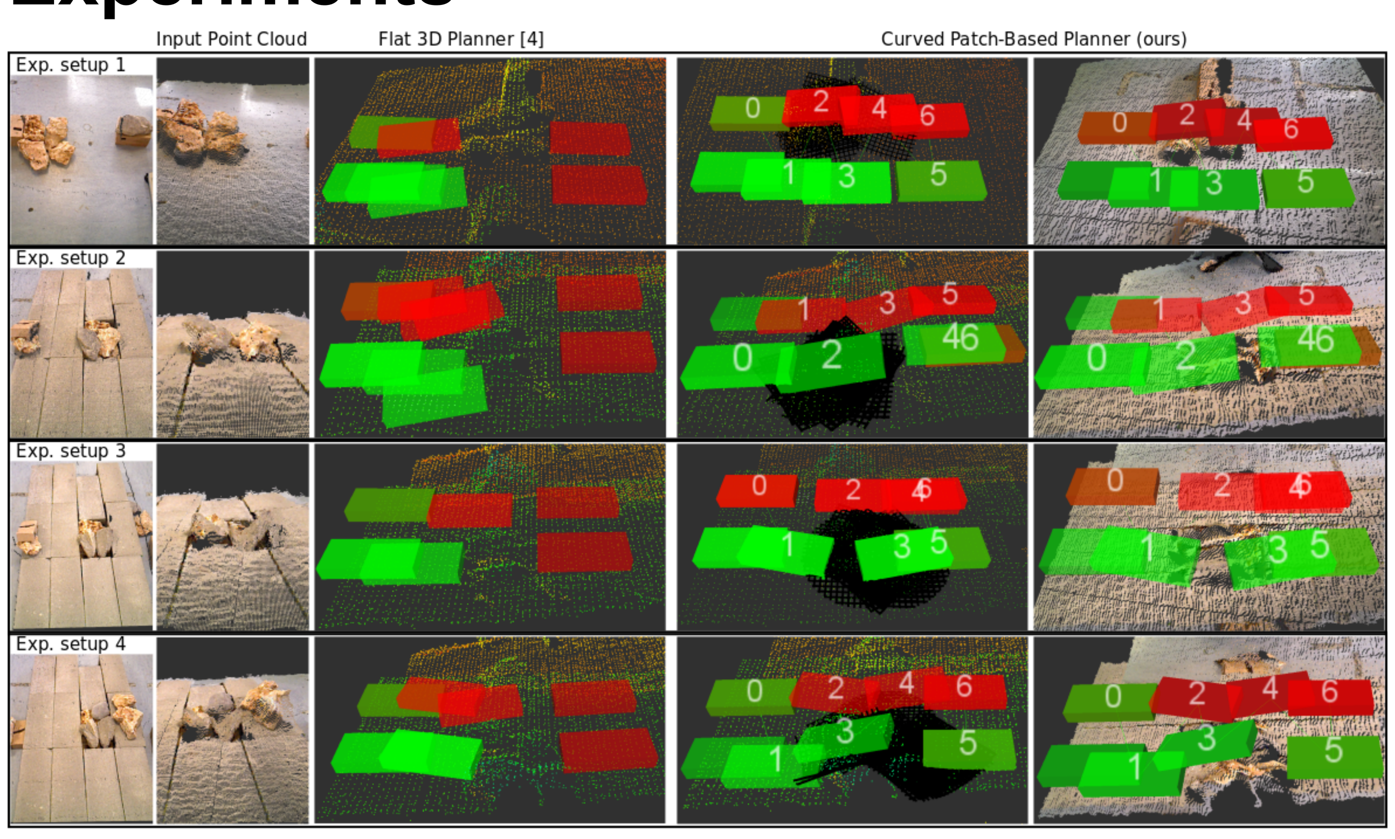
Stage 7: Contact Patch Validation

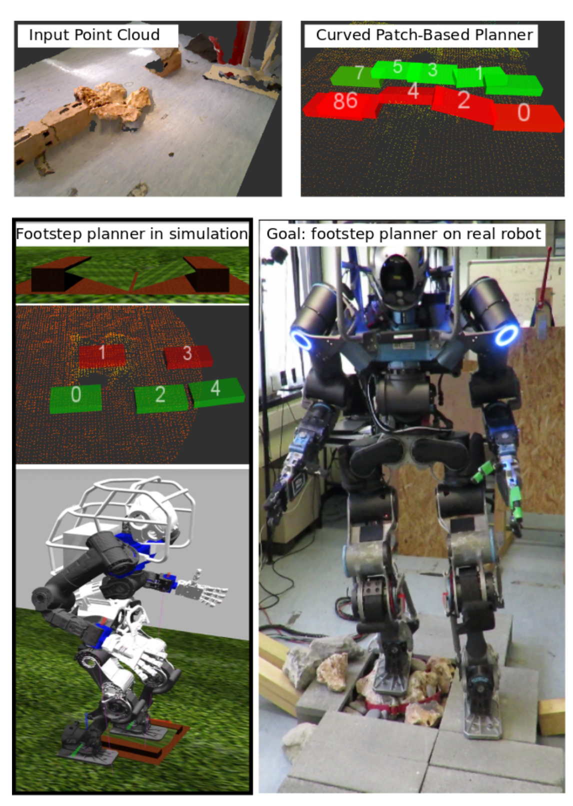
Stage 8: Contact Patch State Estimation

	Exp. 1	Exp. 2	Exp. 3	Exp. 4
steps (curved):	6 (2)	6 (2)	6 (1)	6 (1)
exp. states:	18	64	71	36
retr. steps:	270	809	759	210
fit. patches:	32	44	34	28
drop. patches:	28	19	27	24
path cost:	1.32	1.55	1.34	1.43
total planning t:	16.3s	21s	15.3s	17.4s

TABLE I
FOOTSTEP PLANNING STATISTICS

Experiments





References

[VK11] M. Vona, D. Kanoulas, "Curved Surface Contact Patches with Quantified Uncertainty", IROS 2011.

[KV13] D. Kanoulas, M. Vona, "Sparse Surface Modeling with Curved Patches", ICRA 2013.

[KV14] D. Kanoulas, M. Vona, "Bio-Inspired Rough Terrain Contact Patch Perception", ICRA 2014.

[K14] D. Kanoulas, "Curved Surface Patches for Rough Terrain Perception", PhD Thesis, 2014.

[KVT16] D. Kanoulas, N. Tsagarakis, M. Vona, "Uncertainty Analysis for Curved Surface Contact Patches", Humanoids 2016.

[T17] N. Tsagarakis, et al., "WALK-MAN: A High Performance Humanoid Platform for Realistic Environments", JFR 2017.

[K17] Dimitrios Kanoulas, "Vision-Based Foothold Contact Reasoning using Curved Surface Patches", Humanoids 2017.

[S14] A. Stumpf, S. Kohlbrecher, D. Conner, and O. von Stryk, "Supervised Footstep Planning for Humanoid Robots in Rough Terrain Tasks using a Black Box Walking Controller", Humanoids 2014.