# Towards the Formalization of Affordances as Dempster-Shafer Belief Functions

Peter Kaiser, Markus Grotz, Fabian Paus and Tamim Asfour

***Abstract*—For autonomous operation, humanoid robots need to be able to reliably detect affordances in unknown environments. While roboticists generally understand affordances as a framework for representing action possibilities, fundamental aspects of their formalization for robotic action and interaction remain open questions. In our previous work, we considered *whole-body affordances* which refer to actions that incorporate the full body of a humanoid robot. Such actions are commonly found in the area of loco-manipulation. In this work, we report on our approach towards the formalization of affordances as *Dempster-Shafer belief functions* and on the definition of a whole-body affordance hierarchy. The affordance formalization allows the hierarchical composition of affordances and the propagation of affordance-related evidence within a constructed affordance hierarchy. While the affordance formalization has initially been proposed for the definition of whole-body affordances, we intend to apply the theoretical framework to bimanual manipulation affordances in the future.**

## I. Introduction

The detection of affordances in unknown environments is an essential capability of autonomous robots, enabling them to interact with environmental objects. While the theory of affordances [2] provides a largely accepted conceptual foundation, its formalization and implementation in autonomous robotic systems is an open question. Multiple attempts to the formalization of affordances have been proposed and the multitude of available approaches is comprehensively summarized in [3, 10]. In [6], we introduced the concept of *whole-body affordances*, i. e. affordances which refer to actions that incorporate the whole body for loco-manipulation tasks. The successful detection of such affordances allows an agent to interact with environmental objects such as handrails or staircases in order to perform stable locomotion and large-scale manipulation actions. We extended this work in [7] by proposing an hierarchical definition of whole-body affordances and formalized the concept in [5] based on Dempster-Shafer belief functions. The formalization allows the consistent fusion of affordance-related evidence obtained by multimodal experiments and provides the formal means for propagating evidence along an affordance hierarchy. We believe that the approach can be applied more generally to *manipulation affordances* and particularly *bimanual manipulation affordances*.

The authors are with the Institute for Anthropomatics and Robotics, Karlsruhe Institute of Technology, Karlsruhe, Germany. {peter.kaiser,asfour}@kit.edu

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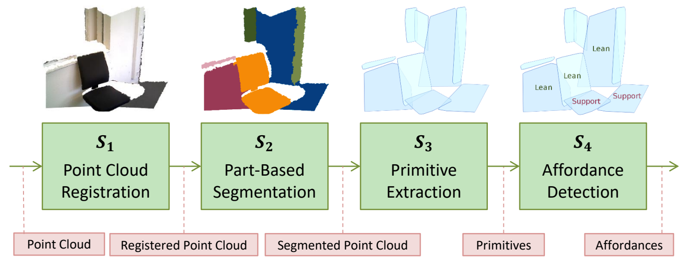


Fig. 1. The perception pipeline for visual affordance detection based on an intermediate environmental representation in terms of geometric primitives.

## II. Perceptual Preliminaries

The affordance formalization introduced in [5] allows the fusion of affordance-related evidence from multiple modalities while visual perception is considered one important source of such evidence. Initial belief from visual perception is subject to further refinement and validation using e. g. haptic experiments. The visual perception pipeline (see Fig. 1) segments an RGB-D scene into consistent segments and subsequently iteratively fits geometric primitives. The resulting simplified representation of the environment is used as a basis for affordance detection.

## III. The Formalization of Affordances

We formalize affordances as *Dempster-Shafer belief functions* $\Theta_a$, defined over the space of end-effector poses $SE(3)$, mapping into the space of Dempster-Shafer belief assignments. Hence, an affordance belief function expresses evidence $\Theta_a(\boldsymbol{x})$ about the existence of an affordance w.r.t. a given end-effector pose $\boldsymbol{x} \in SE(3)$. Formally, affordance-related evidence is expressed by distributing subjective probability mass over the power set of a binary affordance hypothesis space (see [5] for details). Affordance belief functions can be fused in two principle ways: 1) *Dempster's rule of combination* [1] is used for fusing affordance belief functions defined over the same hypothesis space. This process allows the fusion of affordance-related evidence from multiple, potentially multi-modal, sources. 2) *The theory of subjective logic* [4] is used for fusing affordance belief functions defined over different hypothesis spaces by means of logic operations. This process allows logic operations for combining different affordances.

## IV. A Hierarchy of Whole-Body Affordances

The affordance formalization outlined in the previous section follows the idea that whole-body actions can be fun-

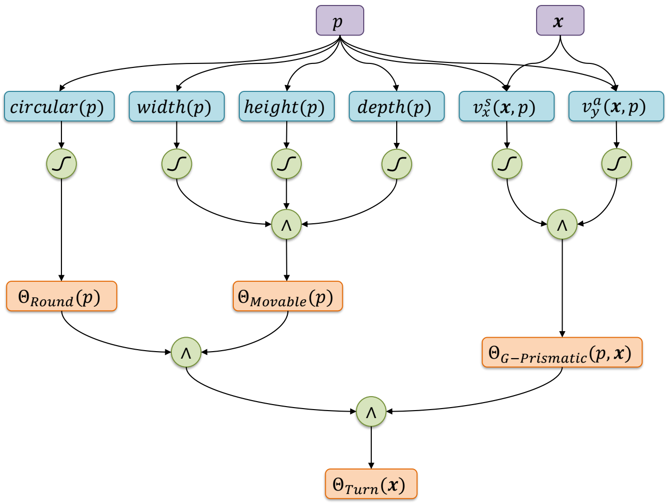


Fig. 2. The hierarchical definition of a *turnability* affordance based on *prismatic graspability* $\Theta_{\text{G-Prismatic}}$ in combination with additional geometric information concerning the underlying primitive.

damentally explained by the involved end-effector contacts. It is further driven by the idea that *higher-level affordances* are composed of *lower-level affordances*, potentially with the inclusion of additional scene information. In [7], we proposed a first attempt to define a hierarchy of whole-body affordances. Fig. 2 visualizes this idea by sketching the hierarchical derivation of an affordance belief function $\Theta_{\text{Turn}}$ for *turnability* based on *prismatic graspability* in combination with a round shaped and presumably movable geometric primitive $p$. Our affordance formalization provides the theoretical means for defining such hierarchical rules and allows the aggregation and the propagation of affordance-related evidence within the hierarchy. Note that visual affordance detection is one out of possibly many sources of affordance-related evidence. In cases where visual perception is unreliable or the robot operates in risky environments, validation actions can be performed and their results fused with the existing belief.

## V. Discussion and Outlook

The formalization of affordances as affordance belief functions and the defined affordance hierarchy have been successfully applied to the humanoid robots ARMAR-III and WALK-MAN in different challenging scenarios [6, 8]. It has further been used for informing high-level shared autonomous control and multi-contact pose sequence planning for humanoid robots in unknown environments [8, 9]. In our future work, we plan to extend the affordance formalization in multiple ways:

*1) Dynamic Environments:* The affordance formalization needs to be extended by mechanisms for fusing evidence taken at different points in time in changing environments. This implies the need for geometric primitive tracking and change detection in order to effectively update the robot's belief.

*2) Scene Understanding:* We think that the reliability of detected affordances will improve when further structural information about the scene is considered. This implies the need for detecting and validating physical relations between primitives, e. g. support relations and joint connections.

*3) Tool-Use:* The affordance hierarchy is rooted in a set of *fundamental affordances* which at the moment consist of elementary power grasp affordances. We will extend this set of fundamental affordances by elementary tool affordances in order to define a hierarchy of manipulation and tool-use affordances.

*4) Bimanual Affordances:* While multi-end-effector and particularly bimanual affordances are possible in the current framework, their computational costs are subject to improvement.

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