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Risk analysis for smart homes and domestic robots using robust shape and physics descriptors, and complex boosting techniques

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ABSTRACT

In this paper, the notion of risk analysis within 3D scenes using vision based techniques is introduced. In particular the problem of risk estimation of indoor environments at the scene and object level is considered, with applications in domestic robots and smart homes. To this end, the proposed Risk Estimation Framework is described, which provides a quantified risk score for a given scene. This methodology is extended with the introduction of a novel robust kernel for 3D shape descriptors such as 3D HOG and SIFT3D, which aims to reduce the effects of outliers in the proposed risk recognition methodology. The Physics Behaviour Feature (PBF) is presented, which uses an object's angular velocity obtained using Newtonian physics simulation as a descriptor. Furthermore, an extension of boosting techniques for learning is suggested in the form of the novel Complex and Hyper-Complex Adaboost, which greatly increase the computation efficiency of the original technique. In order to evaluate the proposed robust descriptors an enriched version of the 3D Risk Scenes (3DRS) dataset with extra objects, scenes and meta-data was utilised. A comparative study was conducted demonstrating that the suggested approach outperforms current state-of-the-art descriptors.

1. Introduction

Scene analysis is a research area spanning a large range of topics, both indoor and outdoor, with applications in navigation systems [42], traffic analysis [6,7], domestic robotics [46], smart homes [9] and more recently the concept of risk detection [18,57] amongst many others. In this work the problem of evaluating risk for indoor applications is considered, more specifically mimicking a human's ability to analyse and identify risks. To this end a quantified risk score for 3D scenes using vision based techniques is provided. The concept of risk assessment is derived from the ability of humans to identify a potentially hazardous environment using a range of attributes, evaluating those specific characteristics based on experience and determining whether a threat is present or not [5].

The definition of what can be considered a risk or hazard in an environment is contextual. What can be considered safe in one environment may not be in others. For example a container of liquid at the edge of a table is risky in a household environment, however in a lab this might pose a far larger danger. Similarly users of the environment will also effect

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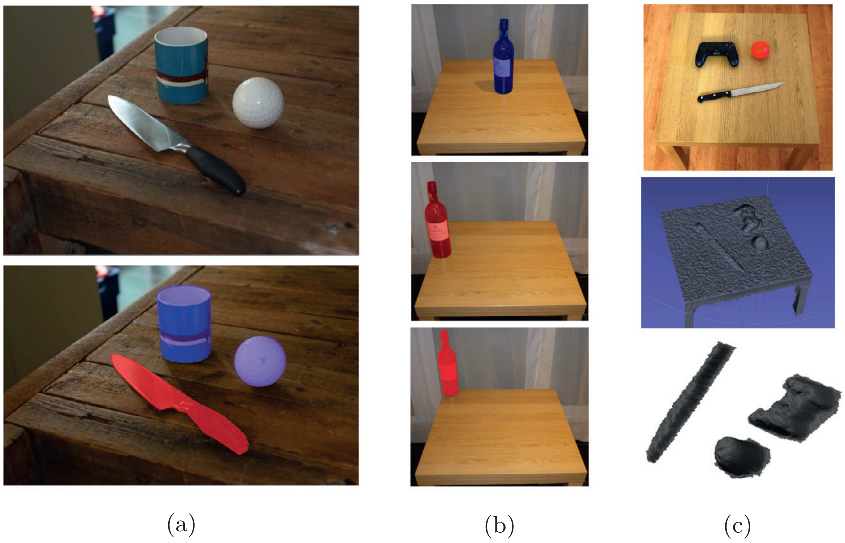

Fig. 1. (a) Example scene with objects demonstrating a variety of intrinsic properties (e.g. sharp, pointed), (b) scene with a variety of stability levels, and (c) a scene reconstructed using Kinect Fusion before and after the plane removal.

how risk is perceived, if the environment contains children or elderly adults the threshold of what is risky may need to change. However regardless of context, the elements that might contribute to the concept of risk can be broken down into components from which a decision can be made. These components include elements such as shape, size, material, temperature, position and many others. With this risk analysis functionality domestic robots could be trained to help avoid potentially hazardous situations. In the Smart Home example; attention could be drawn to these situations and accidents avoided.

The Risk Estimation Framework [17] measures risk as a function of measurable elements in a scene, the methodology relies on a combination of 3D shape descriptors and Newtonian physics based on supervised learning. Firstly, at a global level, the scene is analysed holistically using the concept of scene stability. For example, classifying a glass bottle in the corner of a table as more hazardous than the one placed at the centre (Fig. 1b). Secondly, the scene is analysed at a local level, looking to identify “hazard-related” shape features of objects within the scene. Here the term feature relates to an actual physical property of an object (e.g. sharp, pointed). As an example a knife would have a sharp blade, which would be classified as a “hazard” feature (Fig. 1a). We emphasize that in this system the problem of object recognition is bypassed and only local object properties are recognised, allowing the proposed approach to be more flexible and generic. Additionally this overcomes the problem of similar object classes containing objects which might have different levels of risk, for example a steak knife compared to a butter knife. As with all local level features a model of “hazard features” from a training set is constructed and used to test future unknown examples.

This work is an extension of the paper [17] and introduces the following contributions. A) the novel robust kernel for 3D descriptors in comparison to the work in [18], B) an advanced boosting mechanism that supports complex data for supervised learning, C) a novel shape descriptor based on Newtonian Physics and D) an enriched version on the 3DRS data set. In more details; the robust kernel for 3D descriptors is suggested, which can reduce the effects that outliers have in the supervised learning mechanisms. Secondly, Complex and Hyper-Complex variants of Adaboost [21] are presented, which provide an increase in computational efficiency. Thirdly, the Physics Behaviour Feature (PBF) descriptor is introduced utilising the physical properties of an object to identify hazardous objects. This is achieved through the application of Newtonian Physics and the estimation of an object’s angular velocity after the application of a force. Our final contribution is the enriched version of the 3D Risk Scenes (3DRS) dataset with additional objects, meta-data and risk scenes to create a more challenging and complete dataset for 3D scene risk analysis.

The paper will continue as follows; in Section 2 an analysis of the similar areas of research will be followed by an overview of related work. The proposed methodologies and contributions used in this work will be presented in Section 3. Section 4 will outline our comparative study with other state-of-the-art methods and analyse the results. Finally, in Section 5 conclusions are drawn.

2. Related work

The following section provides an overview of existing work in scene analysis with respect to risk assessment, followed by a review of existing feature descriptors relevant to the methodology.