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MODEL-BASED SPACECRAFT POSE ESTIMATION AND MOTION PREDICTION USING PHOTONIC MIXER DEVICES

Abstract

This contribution addresses a novel sensor system for motion detection and prediction. The system involves a PMD (photonic mixer device) camera using phase shift measurements of modulated infrared light, which provide distance and reflectivity information on each pixel of the obtained image. The paper investigates the sensor characteristics and feasibilities for applications in autonomous spacecraft docking, while the sensor and the proposed algorithm may also be useful in spacecraft formation flying and several other applications. Key issue is to capture the motion information of a (non-cooperative) target spacecraft, include relative velocity between the target and the chaser spacecrafts, as well as the rotational speed and axis of the target. Note qualification of the hardware itself is not in the scope of this paper.

Data processing and evaluation under different conditions are the main concerns of this preliminary study. In particular, the following topics are of interest: signal pre-filtering (e.g. adaptive smoothing of the distance, removal of distorted single-pixel measurements), parameter optimization (e.g. integration time of the sensors), feature detection, extraction and matching. A new algorithm based on rotation- and scale-invariant features commonly used for scanmatching in high-resolution images is developed. This algorithm matches features detected by the camera against a known model of the target, instead of establishing a correspondence of features between two frames. Since standard 2D features- on which extensive research has been done- do not work well in the proposed 3D scenario, a novel feature descriptor has been developed, using the distance measurements apart from reflectivity, and taking into account the typical properties of today's time-of-flight cameras (e.g. low image resolution in terms of pixel count, distance-dependent signal attenuation, noisy distance measurements) as well as the additional effects caused by 3D object rotation and movement. Features are detected using the reflectivity information, what allows pose estimation even for highly symmetric objects, as long as a planar surface of the object is visible, providing unique patterns of lighter and darker areas.

The performance of the PMD camera and the proposed data processing are evaluated in diverse scenarios considering factors like different relative velocities and angles, rotational speeds (which are known to cause intense, characteristic motion artifacts in the distance image), illumination (leads to erroneous distance measurements, caused by oversaturation and high DC offsets) and surface material (what may cause reflection or total absorption of the emitted light) of the target spacecraft.