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HABILITATION THESIS

“Solutions for modeling and perception of dynamic 3D environments”

ABSTRACT

This thesis presents the scientific activity and achievements of the candidate after defending his PhD thesis at the Technical University of Cluj-Napoca on 12.12.2009, and receiving the PhD title confirmation by the Ministry of Education and Research’s Order No. 3492, dated 23.03.2010. Before the PhD defense, the candidate’s research activity was focused on model-based object tracking for driving assistance applications, using the stereovision as measurement source. After finishing the PhD, the candidate remained active in the field of stereovision based perception, focusing on two major directions: designing solutions for modeling and tracking freeform dynamic 3D environments, and solutions for space surveillance based on large baseline stereovision. For both these directions, the results obtained were significant enough to warrant publication in several ISI journal articles and conference papers.

1. Solutions for modeling and tracking freeform dynamic 3D environments: while many environments can be broken down into discrete pieces that can be modeled by geometrical entities such as boxes or parametrical curves, and the parameters of these geometrical entities can be tracked, sometimes the environment gets too complex, or the level of detail needed by the perceiving actor exceeds the assumed simplifications. For these reasons, alternative, freeform models such as occupancy grids and elevation maps can be employed. The candidate’s objectives were to create new freeform world models, based on the occupancy grid and elevation map paradigm, and use them for world tracking.

The occupancy grid solutions found in the literature were mostly dedicated to static environments, the dynamic solutions being few and, from the candidate’s point of view, cumbersome and limited. The candidate’s proposed dynamic occupancy grid solution is based on dynamic particles that are the building blocks of the world, having position and speed, and which can migrate from one grid cell to another. In this way, a multi-modal probability density of the cell’s state, which includes occupancy and speed, is naturally represented. The particles are created and destroyed based on stereovision-derived measurement information, using a computationally efficient resampling algorithm. The particle population allows, at cell level, the estimation of occupancy and speed. The dynamic properties of the cells can be then used, if needed, for extraction of geometric objects, which will already have speed and orientation, even without model based tracking.

The elevation map solutions available in the literature were exclusively dedicated to static environments. The solution proposed by the candidate, the particle-based dynamic elevation map, is able to successfully model and track complex dynamic environments, estimate the heights of the map cells, and the cell’s speed. The main challenges faced in designing the system were related to incorporating the 3D uncertainty of the stereovision into the particle weighting process as a multi-modal measurement model, and designing a particle motion mechanism that can handle quickly enough the dynamic elements of the scene. The novel world model, the particle-based dynamic elevation map, was extended even further with gray level information, so that the tracking process can benefit from the image aspect of the scene, besides the 3D information, and also for a more detailed description of the perceived environment.

2. *Large baseline stereovision for space surveillance:* the Earth is surrounded by a huge number of orbiting objects, at various distances, travelling through space at various speeds. Some of these objects are useful, and some are simply leftovers from old space missions or from previously operating satellites. As the space is getting crowded, the importance of keeping an eye on the objects orbiting the Earth grows. Multiple techniques for space surveillance exist, some relying on active ranging such as RADAR, but mostly based on optical devices, which merely receive the light reflected by the targets, and thus require significant less power to operate. The existing techniques for optical based space surveillance rely on image sequences produced by a single image source (a single telescope), and use the orbital constraints for determining the target's range. The candidate saw an opportunity in the space surveillance field, the use of stereovision for automatic detection and ranging of the Earth orbiting objects. As the distance of these objects is in the range of thousands of kilometers, the baseline of the Earth-based stereoscope had to be in the order of kilometers or tens of kilometers. In order to achieve a functioning system, the following challenges had to be overcome: synchronization of the two observation stations, without the possibility of using a common trigger signal, as normal stereovision systems employ; intrinsic calibration of the optical systems; continuous calibration of the rotation matrices using stars as reference points, as the systems track the sky and therefore its orientation has to be continuously updated; detection of the candidate satellite features from the images, sometimes in a low contrast condition and in the presence of significant sensor noise (caused by long exposure and high gain, needed to increase the sensitivity); the challenge of stereo matching and 3D parameters computation. An experimental system capable of detecting and ranging satellites in the LEO, MEO, GEO and HEO orbits has been successfully set up.

The main achievements and results detailed in Chapter (b-i): *Scientific, professional and academic achievements.*

The candidate's near future research activity will be focused on the two main directions that have produced the results described in this thesis: modeling and tracking complex, dynamic 3D environments, and stereovision-based space surveillance.

The main challenges that will be tackled in the context of dynamic environment modeling and tracking are:

- Developing a dynamic world model and tracking solution that will integrate the stereovision information in the measurement process without first transforming it into a raw elevation map. The raw stereo information will include disparity and grayscale values for each pixel in the image, and the measurement model will relate these values and their uncertainty directly to the tracking mechanism. In this way the error of the measurement can be estimated with much better precision, which will improve the tracking results.
- Transforming a world model and tracking method into a sensor fusion technique, by integrating multiple measurement sources in the measurement process. As an intermediate representation, either the dynamic occupancy grid or the dynamic elevation maps are suitable for this attempt.

The main challenges that are still open in the field of stereovision based space surveillance are:

- Improving the quality of the range estimation, by an in depth analysis of the sources of uncertainty in the measurement process and devising solutions to remove these uncertainties.
- Designing a tracking algorithm based on estimating the state of the target, state which is in fact made out of the orbital parameters. A method for determining the orbit parameters from the stereo results, and a prediction system capable of propagating these parameters, have to be designed.

For the long term, the candidate estimates that his research will be focused on perception systems for robotics, driving assistance applications and space surveillance, but also on generic computer vision topics.

A more detailed description of each topic can be found in Chapter (b-ii): *Scientific, professional and academic future development plans.*