Editorial: Visual Navigation and Mapping Outdoors

The problem of navigation and mapping using vehicles equipped with sensors has been an extremely active research area in robotics during the past 20 years. The promise of autonomous cars, airplanes, helicopters, and submarines drives these research efforts. Many researchers have reported excellent results, but so far the most successful systems have required the use of laser range-finder sensors and predominantly aimed to build 2D maps of planar or approximately planar environments. Recently, researchers have started to tackle larger and less structured environments by taking their vehicles outdoors. At the same time, the price of digital cameras has fallen steeply, with a comparable increase in resolution and speed. This opens the possibility of using such information-rich sensors to extract much more detail from the environments, beyond the capabilities of bulkier and more expensive laser sensors. Camera systems can also be integrated onto a wide variety of platforms operating on land, in the air, and underwater. Navigation and mapping with standard cameras as the main sensory input is considered much more challenging because cameras are bearing-only sensors and do not return range and bearing information available from laser sensors. The challenges of solving problems such as robust feature detection, data association, and computationally efficient large-scale state estimation are thus much harder than when using a laser scanner. However, combinations of cameras or sequences of camera poses do offer full 3D information and thus an enormous potential for applications requiring range and highly detailed measurements at the same time.

The focus of this Special Issue is on publishing high-quality research in the use of visual sensors for navigation and mapping in challenging outdoor environments: urban, suburban, off-road, underwater, and airborne. Among the topics considered in the call for papers were the following: bearing-only/monocular systems; multicamera systems; mapping with omnidirectional cameras' vision in combination with other sensors; environment representations; visual loop-closing techniques; large-scale visual navigation and mapping; urban, suburban, and off-road mapping; underwater applications; and airborne navigation and mapping. This Special Issue stems from the full-day workshop organized by the guest editors as part of the 2009 IEEE International Conference on Robotics and Automation that took place in Kobe, Japan, on May 12, 2009. According to the conference organizers, the workshop was the most highly attended of the whole conference, confirming the interest in this area of robotics.

This Special Issue contains eight papers, including two field reports, which exemplify the possibilities of visual systems for autonomous navigation in terrestrial, airborne, and underwater environments. The paper by Krajnik et al. describes a visual navigation system that, based on the map-and-replay technique, uses monocular vision, a compass, and odometry information to learn feature headings along a route and then be able to follow the same route. The system uses monocular vision to correct only the robot's heading and leaves distance measurements to the odometry. The authors demonstrate that using this method for closed trajectories, the robot location uncertainty is bounded. Extensive experiments show the performance of the method in different situations: indoors, outdoors, with obstacle avoidance, with changes in lighting conditions, with seasonal changes, and even in night conditions using streetlamps as features. The authors won the 2008 and 2009 RoboTour Outdoor Delivery Challenge with this system.

The field report by Furgale and Barfoot describes a stereo visual navigation system that can be taught a route and then be able to follow it autonomously. During teaching, the system builds a sequence of overlapping submaps. During repeat, the robot uses the database of submaps to repeat the route using stereo vision only. Extensive field results over many kilometers are used to evaluate the robustness of the system in GPS-denied environments. The multimedia material is especially illustrative, impressive, and useful.

The paper by Piniés et al. presents a novel algorithm for mapping large environments using a graph of conditionally independent submaps. The proposed method, CI-Graph SLAM, constructs a spanning tree that ensures that neighboring submaps are conditionally independent and that the current submap in which the vehicle is operating is always up to date. This allows old submaps to be updated at any time by propagating information along the spanning tree between the current map and the old submap. To recover the full map, a single propagation through the whole spanning tree is performed, and the resulting estimates are shown to be consistent with estimates using a single extended Kalman filter–based SLAM algorithm. The work presented here extends the authors' previous work, illustrating how the method can be applied to maps with many loops and validating the system both using large-scale simulation and on real data collected by a robot equipped with a trinocular vision system operating in both indoor and outdoor environments.

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The article by Sibley et al. describes the use of a sliding windows filter for 3D surface estimation using stereo vision. The attractiveness of the presented approach lies in its scalability from an offline batch least-squares solution to a fast online incremental solution that runs in constant time. Depending on the sliding window, the approach scales between full bundle adjustment on the one side and the extended Kalman filter on the other side. The paper focuses on entry, descent, and landing missions of planetary rovers, but the solution presented by the authors is valid for the whole field of SLAM problems. The authors provide convincing arguments that the optimization approach offers a number of advantages over traditional filtering approaches for the problem at hand.

The paper by Civera et al. addresses the problem of efficient outlier rejection for the visual SLAM problem. The proposed approach integrates random sample consensus outlier rejection with extended Kalman filtering. By exploiting probabilistic information from the Kalman filter in the random sample consensus procedure, the minimal sample size can be reduced to one. This leads to significant computational savings without losing discriminative power. The authors evaluate their approach in two scenarios: first, six-degree-of-freedom motion estimation using a monocular camera and second, long-term robot trajectory estimation combining monocular vision and odometry data. The experimental evaluation illustrates the advantages of the proposed approach and its usefulness for vision-based navigation systems.

The paper by Bryson et al. describes a system that combines an IMU and GPS with a monocular vision camera, all mounted in an unmanned aerial vehicle. Using SLAM techniques, the vehicle is used to acquire terrain information of the environment overflown. A detailed mosaic is then built using bundle adjustment techniques. The resulting terrain mosaics are precise and detailed enough for classification tasks such as weed detection. This system paper shows that standard SLAM, mosaicking, and classification techniques can be integrated in a demonstrable system. Experiments in a 4×6 km environment are impressive and convincing.

The paper by Elibol et al. presents a method for generating 2D mosaics of the seafloor using monocular imagery collected by an underwater vehicle. The main contribution of the work is in the examination of the requirements for selecting which images to match when searching for loop closures. Many existing systems perform an exhaustive search of previous images to detect matches in images that are not in time-consecutive order and thereby close loops when the vehicle revisits a previous area of a survey. The authors show how observation mutual information can be used to select among candidate image pairs if an estimate of the vehicle trajectory is maintained. The proposed technique is compared with metrics based on expected overlap, a random selection of prior images, and a metric that combines expected overlap and mutual information for selecting candidate images to match. Results are presented using data collected by a small underwater vehicle equipped with a monocular camera and are validated against a full bundle adjustment technique. The proposed method for selecting candidate image matches is shown to perform favorably against the full bundle adjustment case with significantly lower computational cost in terms of attempted matches between images.

Finally, the field report by Williams et al. describes the role of the autonomous underwater vehicle Sirius on a research cruise to survey drowned reefs along the shelf edge of the Great Barrier Reef in Queensland, Australia. Sirius provided georeferenced, high-resolution, optical validation of seabed interpretations based on acoustic data. Its capabilities and its operation are described in the context of the multiple systems used in the cruise. The data processing pipeline involved in generating SLAM-based navigation, large-scale 3D visualizations, and automated classification of survey data are also described. Results illustrate the type of data products possible with such a system and how they can inform the science driving the cruise.

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Guest Editors