3D Imaging – Development and Possibilities

Abstract — The paper presents results from performing UWSLAM (UnderWater Simultaneous Localisation and Mapping) using calibrated electro-optical stereo cameras and SAAB's real-time stereo 3D-reconstruction algorithms. In order to understand the concept an introduction to stereo triangulation and calibration is given. Moreover image based navigation, image enhancement and map generation is discussed in brief.

1 Introduction

Autonomous or remotely operated underwater vehicles are used within a wide range of applications to perform subsea tasks. The systems are usually equipped with multiple sensors which are used for purpose of navigation, sensing and interaction with the environment. SONARS are usually ideal for long range measurements and mapping but suffer~~s~~ from poor resolution at short range. Performing high precision tasks at close range requires a highly accurate depth perception down to a millimetre accuracy. High-resolution 3D information can be obtained using multiple different sensors and techniques. Most systems with close range measurement capability use active laser sensors (LIDAR) or passive electro-optical cameras to obtain 3D information. Real-time capability and perception is very important for a vehicle in order to navigate and interact with its environment.

2 Approach

The main goal is to reconstruct 3D information from 2D image observations and automatically align 3D information together in a common coordinate system. This can be achieved using a stereo camera approach combined with image based navigation.

2.1 Stereo camera systems

Stereo systems consists of 2 or more calibrated electro-optical cameras. Given a pinhole camera model expressed as K [R t] matrix, each image point can be expressed in homogenous coordinates as a 3D line passing though the camera centre intersecting the image point at (x,y). From a set of point correspondences between image 1 and image 2 we can find the intersection of two projected lines. The intersection gives the desired image point in 3D space. Multiple 3D points are then connected and together they form a 3D-model expressed as a texturized mesh.

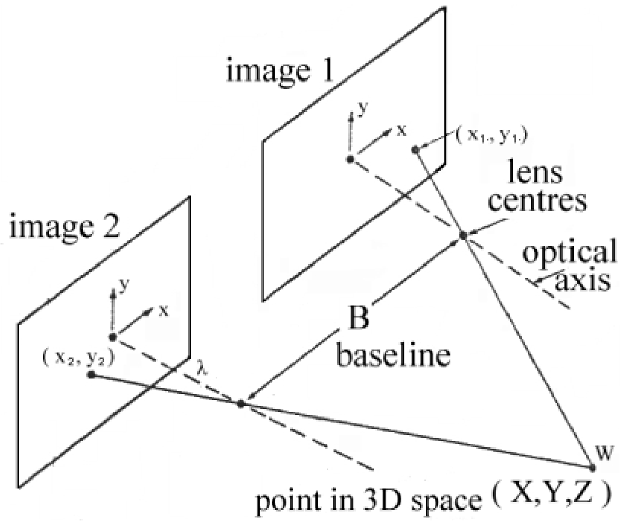

Fig. 1. Stereo triangulation

Point correspondences between cameras are expressed as a dense disparity image d. The disparity image expresses the 2D mapping of a point x_1 in image 1 to point x_2 in image 2; $x_1+d=x_2$. Thereby the disparity image represents the depth information in the scene.

2.2 Camera calibration

The homogenous representation of 2D points requires normalized images without lens distortion which satisfies the pinhole camera model. Underwater images suffer~~s~~ from complex distortion effects due to light refraction through multiple mediums (water, glass and air). In this application a custom designed underwater lens is used which suppresses distortions caused by refractions. The remaining lens distortion can easily be modelled using classical radial and tangential distortion~~s~~ polynomials. All camera parameters are calibrated from underwater observations using the Zhang approach [1]. Using the calibrated camera parameters the images are normalized and rectified before calculating the disparity mapping and the 3D mesh from an observation.

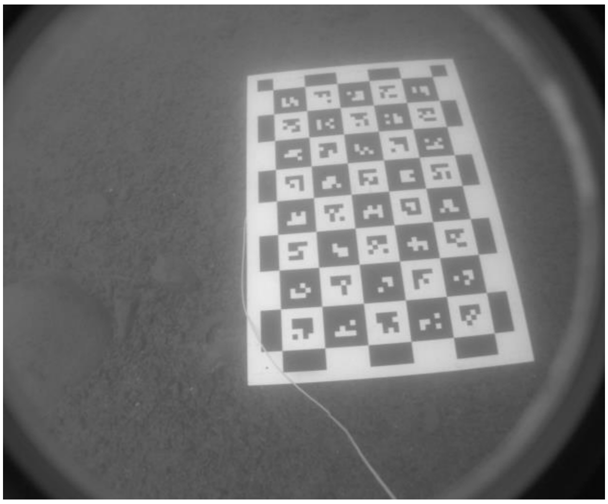

Fig. 2. Calibration camera observation

2.3 Image based navigation

A moving platform requires the ability to perform image based navigation, or visual odometry, in order to align 3D reconstructions over time. By tracking landmarks, i.e. points, in the scene over consecutive images it is possible to estimate the relative movement [R t] by using their associated 3D positions. In theory only three points are needed to estimate the relative movement, but since the 3D points are noisy in general, several points are used in a least-square sense together with RANSAC [2] in order to suppress the noise in the final solution.

2.4 Underwater image enhancement

Underwater imaging suffers from hard conditions due to low light and turbidity. Particles cause backscattering of light which limits the visibility. Many different image enhancement algorithms exist, but an example of one that proves to be useful is ~~e.g.~~ CLAHE (Contrast-Limited Adaptive Histogram Equalization) [3]. The goal is to enhance local image features to improve stereo reconstruction and image based navigation in poor underwater conditions.

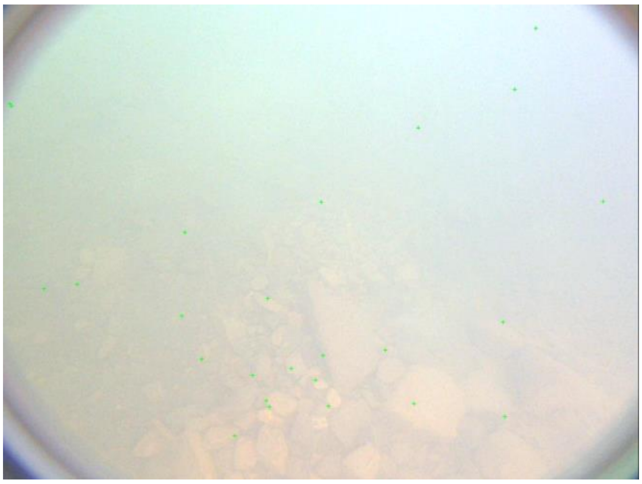

Fig. 3. Underwater image with low visibility

Fig. 4. Enhanced image using CLAHE.

2.5 3D map generation

The 3D map is generated by selecting multiple key frames representing the scene. A key frame is an observation selected at a position [R t]. A key frame is added if the platform has navigated to a new location according some condition. 3D information from adjacent observations is merged into the closest key frame to ensure a dense representation of the world. The 3D map is represented as a texturized 3D mesh (vertices, faces and full-colour textures). The 3D map can be used for real-time analysis, object detection, localization, and measurements. It is also possible to export and align the 3D map with other sensor data.

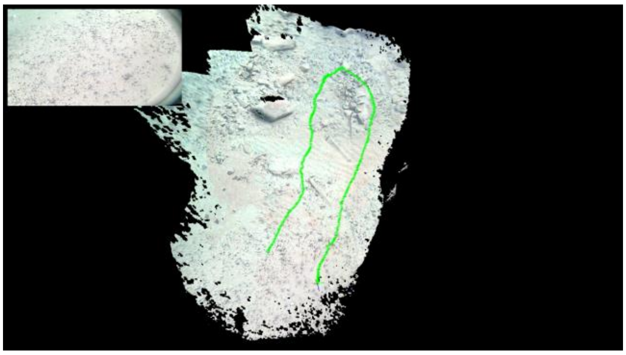

Fig. 5. 3D map generated from multiple stereo observations

2.6 Real-time optimization

The algorithms used for image based navigation and stereo reconstruction are highly optimized. In order to achieve this, parts of the code need to be hand-coded in assembly language in order to overcome the limitations of the compilers when it comes to independent pixel processing in images. Also, most platforms today, even embedded ones, offer a multi-CPU environment which enables threading of the algorithms. In order to gain maximum optimization in the algorithms both of these methods are combined.

3. Results and discussion

SAAB has developed a 3D image system for real-time 3D reconstruction underwater based on electro-optical cameras. It uses calibrated cameras within the visual range to create a full-colour 3D map using stereo triangulation and high precision image-based navigation in real-time.

In an underwater scenario the system can perform real-time acquisition and measurements of objects and provide efficient 3D maps to navigate ~~in~~with. The system can perform autonomous or operator-supervised inspections of structures, station keeping, survey and mapping of underwater environment using real-time acquisition of 3D data. It is capable of acquiring 3D reconstructions for an augmented reality presentation which can be used by a vehicle operator in order to enhance the understanding of the vehicle surroundings.

Cameras within the visual spectra are used and these are supported by on-board vehicle lights and a robust algorithm to handle ~~har~~difficult conditions such as low light and turbidity caused by particles. The 3D information has high-resolution and structures can be measured with a precision down to a few millimetres at close range.

Fig. 6. 3D reconstructed object on the sea floor

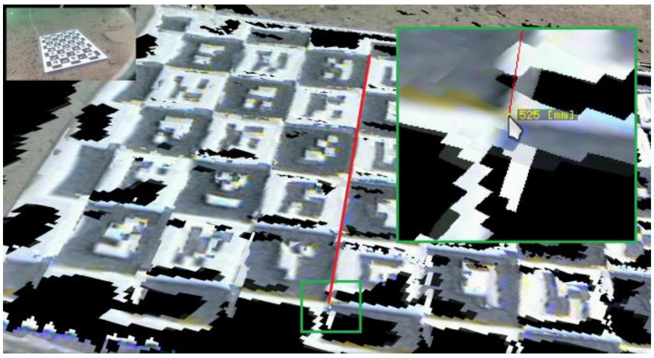

Fig. 7. 3D measurement of a calibration board

4 Conclusion

In comparison with other 3D imaging systems such as SONAR and LIDAR the system has a shorter maximum range but higher spatial resolution and provides colour information useful for detection and data interpretation. Most underwater 3D reconstruction systems on the market require~~s~~ a post-processing step and therefore cannot be used in an real-time loop obtaining valuable information during the mission. The system uses inexpensive industry cameras and is a cost-efficient solution for short-range 3D imaging. Since the system provides 3D information and measurements feedback in real-time the limited underwater mission time can be used more effectively.

References

[1] Z. Zhang, "A flexible new technique for camera calibration'", IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol.22, No.11, pages 1330–1334, 2000

[2] Martin A. Fischler & Robert C. Bolles. "Random Sample Consensus: A Paradigm for Model Fitting with Applications to Image Analysis and Automated Cartography", June 1981

[3] Zuiderveld, Karel, "Contrast limited adaptive histogram equalization", Graphics gems IV, Academic Press Professional, Inc., pp. 474–485, 1994

Author/Speaker Biographies

Jimmy Jonsson is 45 years old and has more than ten years of experience within the image processing area. He ~~and~~ has gained broad knowledge within areas such as Real-Time Stereo Processing, Image Based Navigation and Camera Calibration. During ~~the~~his employment at SAAB Jimmy has been involved in several missile projects such as the naval missile RBS 15 and Air-to-Air missile IRST-T. Between 2010 and 2012 Jimmy worked with camera based Active Safety Systems for the automotive industry at Autoliv Electronics AB. Since 2012 Jimmy has focused the image processing work at SAAB on the products of start-up companies for the civil industry, involving Stereo Camera Systems for various types of applications. Jimmy currently holds a position as Image Processing Specialist at SAAB Dynamics.

Fredrik Lundell is 32 years old and ~~,~~ has a masters degree in Computer Science and Media technology from Linköping's University focusing on image processing and visualization. He has 8 years of experience with software development and signal/image processing. He started his career as a consultant at Combitech, with assignment for SAAB Aeronautics. As a consultant he worked as a software developer and~~,~~ scrum master, also ~~and with~~on data analysis for a support system to the Gripen aircraft.

Since 2016 Fredrik has h~~o~~eld~~s~~ a position as Image Processing Engineer at SAAB Dynamics. Fredrik has mainly worked with Stereo Camera systems, Camera Calibration and Machine Learning for various applications within the civil industry through SAAB Ventures.