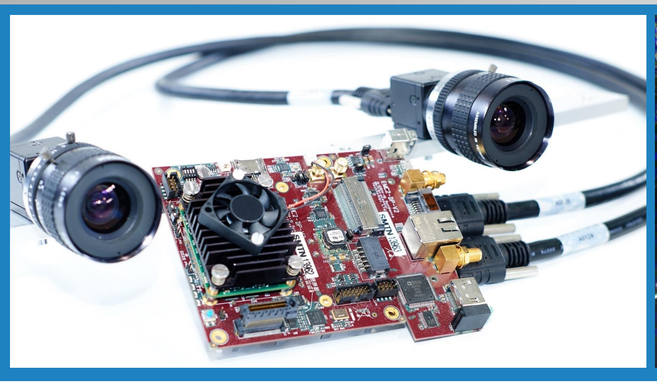
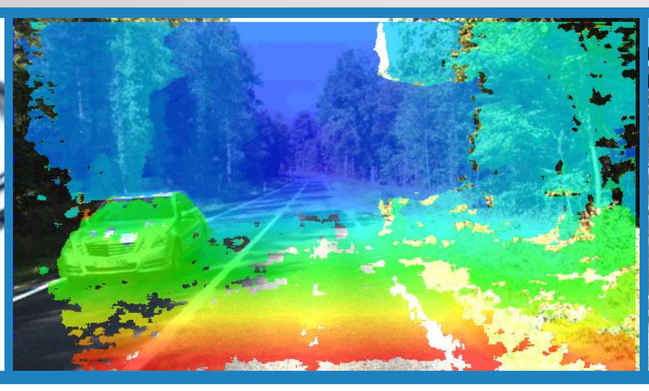
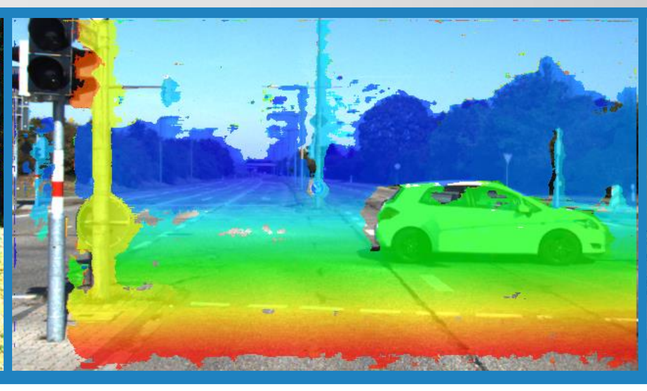
Fraunhofer IOSB

FRAUNHOFER INSTITUTE OF OPTRONICS, SYSTEM TECHNOLOGIES AND IMAGE EXPLOITATION



# REAL-TIME ON-BOARD OBSTACLE AVOIDANCE FOR UAVS BASED ON EMBEDDED STEREO VISION

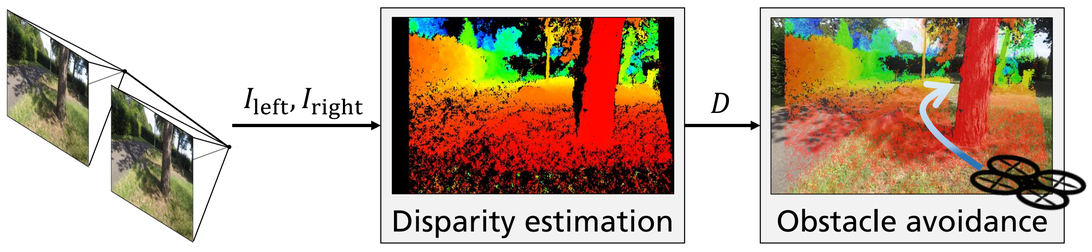
Boitumelo Ruf, Sebastian Monka, Matthias Kollmann and Michael Grinberg

## Motivation

- The increase in the use of UAVs requires an improvement of their usability and safety
- UAVs are equipped with multiple sensors to monitor their surrounding, e.g. obstacle avoidance
- EU Project TULIPP: Development of an ecosystem for low-power real-time embedded image processing systems

## Contribution

- System for real-time obstacle avoidance running on an embedded Xilinx Zynq Ultrascale+




## Disparity Estimation

- Stereo disparity estimation based on SGM (Hirschmueller, 2008), directly synthesized form C/C++ with HLS and deployed on embedded FPGA
  1. Image rectification and matching
  2. 4-path SGM optimization, adopted for streamed processing
  3. Left-Right check and Median filtering

## Obstacle Avoidance

- Reactive obstacle avoidance algorithm computing shortest path around obstacle based on disparity map
  1. U- / V-Map computation (Oleynikova et al. 2015)
  2. Binary filtering and contour detection
  3. Obstacle extraction and waypoint computation

## Experiments

- Runtime measurements

| Operation | Time [ms] | Avg. Time [ms] |
|---|---|---|
| Disparity Estim. (FPGA) | 31.4 – 36.1 | 34.5 |
| Obstacle Avoid. (CPU) | 2.7 – 11.0 | 4.2 |
| Total | 34.1 – 47.1 | 38.7 |

- Disparity estimation deployed on FPGA running at 200 MHz
  - Up to 29 Hz and a latency of 28.5 ms at a frame size of 640x360 pixel and 60 disparities
  - Evaluated Sum of Absolute Differences and Census-Transform with 5x5 support region
  - Quantitative results on KITTI Stereo 2015 benchmark (Menze et al., 2015)

| Cost function | Density | Correct pixels |
|---|---|---|
| Sum of Abs. Diff. | 64.1 % | 76.0 % |
| Census Transform | 74.2 % | 95.4 % |

- Obstacle avoidance deployed on ARM quad-core CPU running at up to 1.5 GHz
  - Hardware-in-the-Loop testing with DJI flight simulator

## Future Work

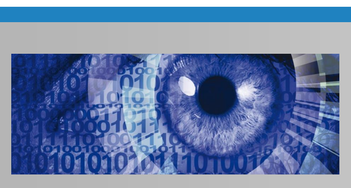
- Perform experiments in the real-world with the embedded system mounted to the UAV
- Evaluate the algorithm w.r.t. energy consumption on embedded FPGA, CPU and GPU architectures

## Literature

Hirschmueller, H., 2008. Stereo processing by semiglobal matching and mutual information. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 30(2), pp. 328–341.

Oleynikova, H., Honegger, D. and Pollefeys, M., 2015. Reactive avoidance using embedded stereo vision for mav flight. In: *Proc. IEEE International Conference on Robotics and Automation*, pp. 50–56.

Menze, M. and Geiger, A., 2015. Object scene flow for autonomous vehicles. In: *Proc. Conference on Computer Vision and Pattern Recognition*, pp. 3061–3070.



Boitumelo Ruf
Video Exploitation Systems (VID)
Phone +49 721 6091 654
boitumelo.ruf@iosb.fraunhofer.de

KIT

The TULIPP project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 688403