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360° Monitoring for Robots Using Time-of-Flight Sensors

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Abstract. *In this paper, we present a system based on multiple Time-of-Flight (ToF) 3D sensors paired with a central processing hub for integration into robots or mobile machines. This system can produce a 360° view from the robot's perspective and enables tasks ranging from navigation and obstacle avoidance to human-robot collaboration.*

1. Introduction

Today's e-commerce growth and the paradigms of Industry 4.0 in the manufacturing space present new challenges for robotic systems [1]. In order to increase mobility and autonomy of such systems they need to gather and interpret as much information as possible from their surroundings. Approaches for collision avoidance with 1D time-of-flight sensors have been explored [2], the use of several high-resolution sensors would enable applications like human pose estimation and gesture recognition as well as automation tasks such as handling of goods. Close collaboration and additional functionalities are made possible with the setup proposed in this paper which consists of intrinsic 3D Time-of-Flight sensors that can cover 360° around a robot's arm or chassis.

2. System architecture

The multi-ToF platform[1] consists of a central processing module based on a NVIDIA Tegra TX2 processor (the hub) and multiple camera modules that work in parallel (the frontends). This platform architecture allows for the integration of various sensor and camera types.

The ToF sensor frontend for the platform is a compact module designed for close-range detection. Table 1 summarises the technical data and performance of two frontend variants. The frontend is connected

[1]https://www.becom-group.com/goto/multi-tof-platform

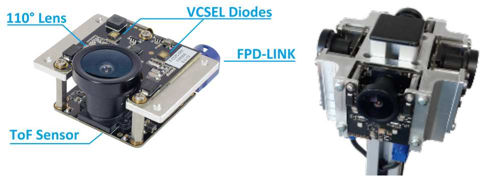

Figure 1. Image of a front-end including descriptions of its components *(left)* and a ring of four front-ends *(right)*.

	QVGA frontend	VGA frontend
Resolution	304 px x 240 px	640 px x 480 px
Field of view	110° x 82°	110° x 82°
Distance range	0.1 – 1.5 m	0.1 – 2.0 m
Operating wavelength	850 nm	940 nm
Framerate	40 Hz	30 Hz

Table 1. Frontend specifications.

to the hub via FPD-Link III, using a cable that also provides the power supply. Four frontends can be arranged as a ring to allow a 360° coverage.

The hub controls the frontends, performs calibration and correction operations on the incoming data, and ultimately calculates depth maps or point clouds. The data is transmitted from the hub via a Gigabit Ethernet connection and supports ROS to gather the individual data streams. The following operations are performed on the hub:

1. Synchronization and triggering
2. Acquisition and depth map calculation
3. Corrections (temperature, FPPN, distance offset, intrinsic and extrinsic)
4. Filtering (spatial and temporal)
5. 3D point cloud calculation
6. Registration and transformation

Operations 1 and 6 are specific to multi-camera systems and are therefore described in more detail in the following sections. The remaining CPU/GPU performance on the hub is available for AI and deep-learning applications.

3. Synchronization

Imaging systems that rely on multiple active sensors inevitably require a synchronization. In the case of the multi-ToF platform, synchronization serves two purposes: On the one hand, it avoids interference effects between the sensors, and on the other hand, it simplifies the registration of the point clouds produced by the individual frontends. The hub can synchronize multiple frontends by using a hardware trigger to start the acquisition of individual frontends. This could be done in a round-robin scheme or by triggering opposite sensors at the same time to avoid interference.

4. Point cloud registration

Each ToF-sensor frontend produces a 2D depth map which can be converted into a 3D point cloud. A consistent 360° view of the environment necessitates the registration of these individual point clouds in a common world coordinate system. Through an extrinsic calibration all sensors of the ring can be combined in a single point cloud which can be transformed in a robot or world coordinate system given a known position of the robot's joints.

5. Advantages and performance

With today's ToF technology, cameras are capable of detecting objects with high framerates and low latencies. Active lighting ensures that data quality is independent from ambient conditions to a high degree. The exact distance measurement accuracy is dependent on the target's reflectivity and distance, but the user can expect a relative accuracy of 1 % based on the distance.

Considering the system's performance in the context of machine learning, ToF cameras provide useful additional information compared to, for example, 2D RGB cameras: Objects can be more easily spatially separated using the 3D point cloud and the corresponding IR greyscale image can be employed when training a network. Training labels can easily be transferred between the four ToF channels (X, Y, Z, and amplitude) at pixel precision. As a result, ToF cameras reveal more information about the observed scene, but labelling the data does not require additional effort. The recognition performance of deep learning algorithms in particular benefits from an increase in the amount of available data.

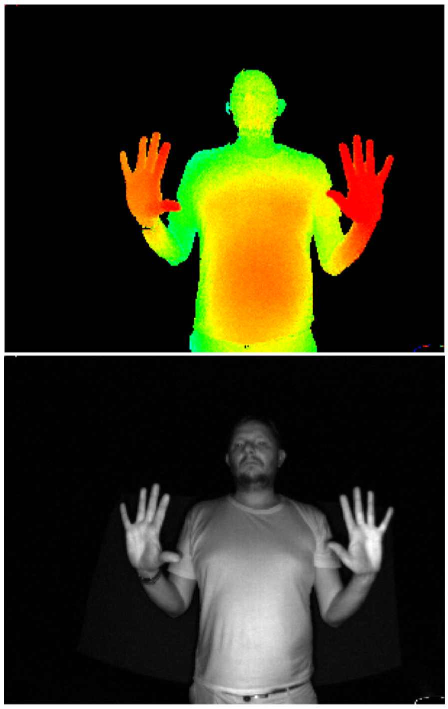

Figure 2. Depth image *(left)*, with red indicating smaller and green larger distances, and the corresponding IR greyscale image *(right)*.

6. Conclusion

In this paper we have presented a hardware platform which uses multiple ToF Sensors and a central processing hub to generate a high-resolution point cloud around an autonomous machine which enables collaborative and safety functions. Further work will include a synchronization of multiple machines working in close proximity using a clock synchronization mechanism over state of the art wireless connectivity hardware.

References

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