Enabling the next generation of smarter self-navigating robots using Hybrid ToF technology

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White Paper - Abstract

Previous generations of robot vacuum cleaners have used a random pattern for cleaning that is inefficient and slow. Next-generation robots are much smarter and generate a map of the environment using sensors to localize themselves. This provides users with a floorplan of their home, from which the rooms and areas can be selected for cleaning or restricted from access. The new robots accomplish this using simultaneous localization and mapping (SLAM). This abstract describes how slimmer robots with new features can be designed using an approach with novel time of flight cameras.

While visual SLAM (vSLAM) uses one or more cameras and requires high computational power to extract depth from the 2D images captured, SLAM uses depth sensors such as time-of-flight (ToF) cameras that provide true 3D images with a high resolution. Depth cameras allow much leaner and more efficient SLAM implementations compatible with embedded processing platforms usually used in applications such as cleaning robots, warehouse robots, tracking drones, etc.

Hybrid Time-of-Flight (hToF) is a novel ToF paradigm that combines a single ToF image sensor with two types of illumination to:

- Support SLAM
- Avoid obstacles
- Detect cliffs

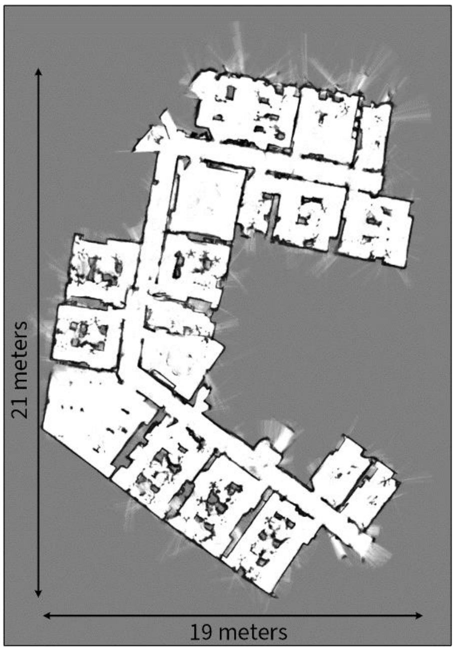

Figure 1: SLAM-generated map using Infineon and pmd's new hToF sensor

Infineon and partners have developed hToF as a cost-efficient depth sensing technology for consumer products. Particularly for consumer robotics, the smaller hToF sensors help designing slimmer robots compared to robots equipped with laser-distance-sensor (LDS) towers. This white paper describes how to build a powerful SLAM solution using hToF sensors and presents the excellent map accuracy that can be achieved with open-source SLAM implementations as well as the reduced processing resources needed.

Figure 1 shows a map generated by SLAM using hToF cameras showing a building's floor with its rooms. The unique hToF technology uses Infineon's high-resolution REAL3™ ToF sensor along with a homogenous flood illumination and a powerful spot grid illumination offering a cost-efficient solution. The hToF camera's broad, 110° horizontal field-of-view (FoV) is ideal for both SLAM and obstacle avoidance. hToF works in all lighting conditions from complete darkness up to bright sunlight and across a large variety of furniture and floor reflectivity and textures. This technology advancement provides a huge advantage over other technologies such as structured light that struggles in bright sunlight, and also stereo vision that has difficulties in darkness and with repetitive textures. While previous generations of robots got stuck under low-clearance furniture objects, novel robots equipped with hToF can navigate in a smarter way even under lower-clearance furniture thanks to the reduced robot height and additional clearance height information from the hToF sensor.

The achievable map accuracy depends on the hToF sensor configuration. One hToF camera is sufficient for SLAM, however, robots with a second hToF camera to expand the FoV generate more accurate maps. In an evaluation study, a R&D robot with two hToF cameras has been used in various office environments. The results are presented in detail in the full version of the white paper. The hToF sensor solution enables the robot to generate precise and consistent maps with excellent accuracy even for challenging environments with glass walls, non-rectangular rooms, dark floor material, and cluttered furniture objects. The 3D depth image data provided by hToF enables smart features such as handling glass walls properly as the frame is detected as a wall.

The computational effort for depth processing of hToF data with pmd's Royale depth library and SLAM using a Google Cartographer implementation has been benchmarked for embedded platforms used in robotics: NVIDIA Jetson Nano, Qualcomm RB5, and Raspberry Pi 3B. The execution time on one core for depth processing of one hybrid frame comprising spot and flood data is 2.24 ms on the RB5 big core (A77), 8.44 ms on the RB5 little core (A55), and 20.3 ms on the Raspberry 3B core (A53). The processor load if a single core is used for depth processing is 2 percent for an A77 at 2.4 GHz, 8 percent for an A55 at 1.8 GHz, and 20 percent for an A53 at 1.2 GHz. On average, Google's Cartographer required 10 percent of an A77 core and 34 percent of an A55 core for the evaluated scenes. These results show impressively that even a single A55 core is sufficient for the hToF depth processing and SLAM simultaneously. This is in stark contrast to vSLAM systems that usually need two or more cores for their processing.

In summary, Infineon's hToF sensors along with pmd's processing offer a powerful solution for consumer robots simultaneously supporting SLAM, obstacle avoidance, and cliff detection. The maps generated by open-source SLAM algorithms based on hToF depth data are accurate and reliable. The solution is computationally lean, requiring only one A55 core for depth processing and SLAM computation.