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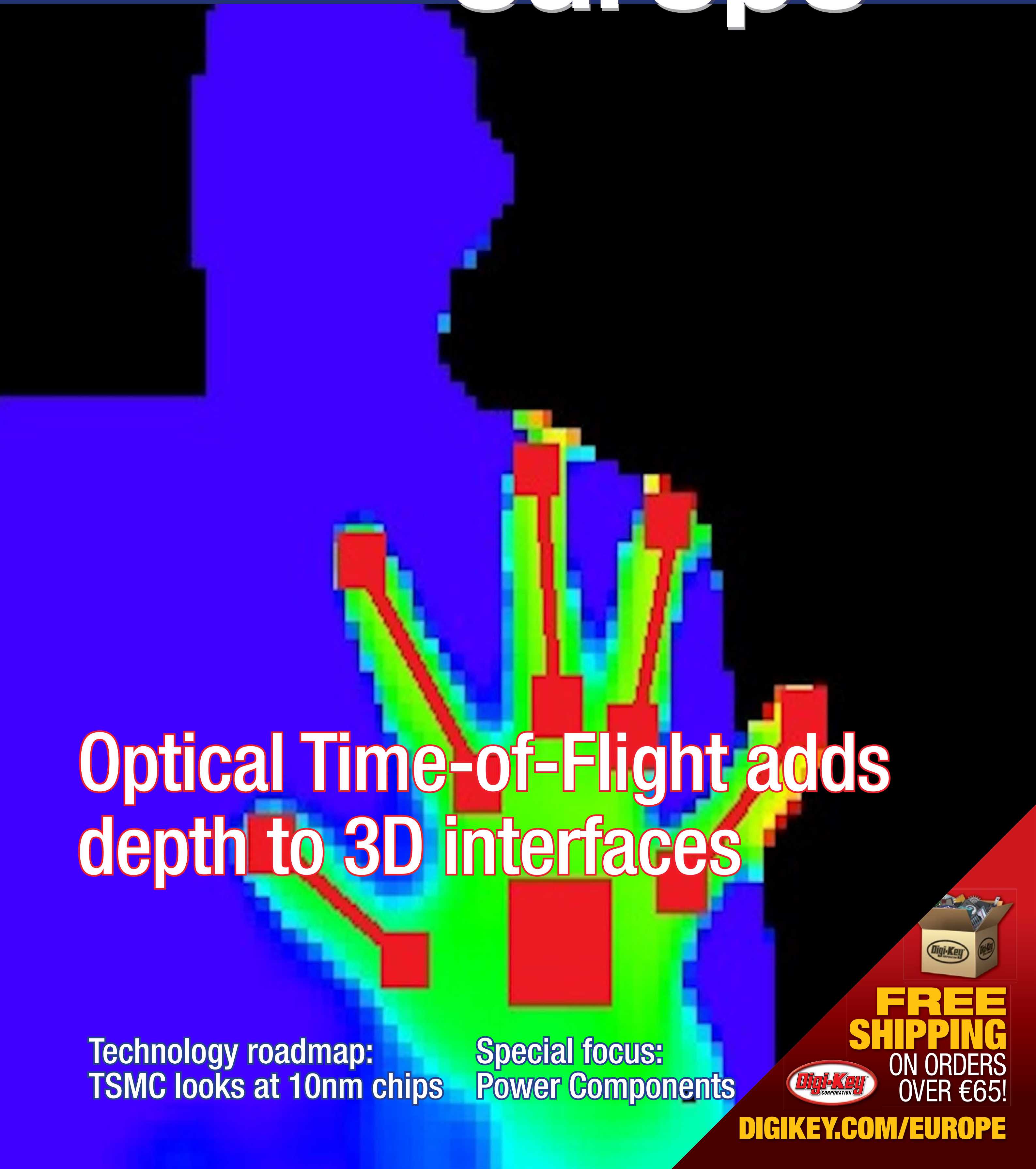

Optical Time-of-Flight adds depth to 3D interfaces

Technology roadmap: TSMC looks at 10nm chips

Special focus: Power Components

Exploiting depth sensing for 3D interfaces and complex image analysis

By Michael Delueg

NOWADAYS INTELLIGENT SENSOR networks have entered many application fields ranging from building and industrial automation to traffic management or medical applications. Intelligent sensors are able to process the sensor inputs on the sensor node and trigger actions autonomously. This allows intelligent sensor networks with information sharing even on bandwidth constrained networks or serial busses. The availability of powerful embedded processors makes it possible to process the input of high-bandwidth sensors like image sensors in real-time for complex image analysis tasks.

With the advent of the Kinect as input unit for their console, Microsoft has sparked developments in the area of gesture recognition, novel user interfaces and depth sensors. A depth sensor is an image sensor which provides distance information for each pixel. They usually don't provide color information, but an accurate and robust 3D representation of the scene with X/Y/Z coordinates for each pixel. This eliminates computational overhead for obtaining the 3D data in the next processing stages which is needed for a stereo vision system. Since the sensor output is already robust 3D data analysis functions can be implemented efficiently – see figure 1.

There are a couple of depth-sensing technologies in existence. Bluetechnix uses PMD (Photonic Mixer Device) sensors from pmdtechnologies based on the Time-of-Flight (ToF) technology which is more robust than Kinect's structured light technology. ToF-sensors use a LIDAR (LIght Detection and Ranging) approach for distance measurement.

The target is illuminated by an active IR light source and the distance to the object is calculated based on the backscattered light. The PMD sensor chip uses a modulated light source with a frequency range of 5 to 30MHz. The phase shift between the emitted light and the reflected light at the receiver in conjunction with the known modulation frequency and speed of light can be used to calculate the distance to the object. The depth resolution of the sensor is in the centimeter range or below in good conditions. The use of a modulated IR light and the phase measurement make the sensor robust against difficult ambient light conditions. The whole scene is captured in one shot for high frame rates up to 160fps, limiting motion artifacts.

System design considerations

A system design for an intelligent 3D sensor based on this technology needs to address the following topics: illumination, sensor, optics, power, processing unit and connectivity. While Time-of-Flight is a scalable technology, the choice of field of view (FoV) and range is an important decision. The sensor's lens and the beam of the illumination LEDs must be adjusted accordingly to illuminate the complete FoV of the sensor evenly.

Typical setups for close range applications like a gesture control have a FoV of 90° or more and a range below 1m while people tracking applications might go up to 3-5m but still need to cover the same FoV. At greater distances the FoV usually becomes smaller because too much power is needed to illuminate the area and the area a single sensor pixel represents becomes too big for meaningful analysis. Today's ToF sensors feature a resolution of 160x120 pixels. The achievable range is mostly limited by the amount of power which is available to illuminate the whole scene and still get enough reflected light from the target to get accurate measurements. For each scenario the system designer has to balance an equation of range, FoV and frame rate versus power consumption, heat generation and system costs to achieve an optimal result.

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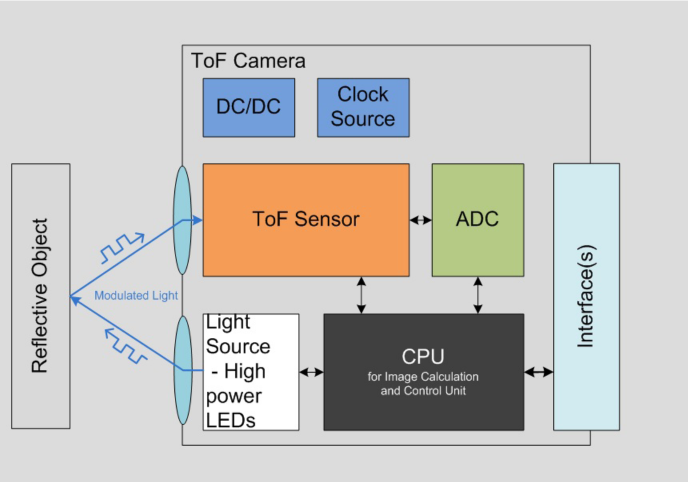

Fig. 1: Basic schematics of a Time-of-Flight system.

The processing unit controls all functions of the sensor and the illumination unit. It processes the raw sensor data and performs enhancements like lens correction or noise reduction. The additional resources can be dedicated on the user application. In terms of connectivity different scenarios are possible. PC based applications may rely on USB to stream the complete image data and power the sensor over USB. Ethernet allows long cable lengths and high bandwidth and the integration into existing IP security infrastructures. In sensor networks bus topologies play an important part when covering large areas with multiple sensors in a line or grid. A 4-wire cable with RS485 plus power supply is a robust choice for chaining multiple intelligent 3D sensors to cover a large room or monitor a conveyor belt. For all connectivity choices the needed bandwidth can scale from several kBit/s to several MBit/s depending on the amount of processing done on the sensor.

People tracking and counting

Multiple applications for such an intelligent 3D sensors deal with people counting, tracking and behaviour analysis. In opposition to HMI applications like gesture recognition these applications cannot rely on the cooperation of the people and require very robust sensor data. A good example for such a use case is people counting in public transportation which provides very important data sets for the operators – see figure 2. During rush hour light barriers or infrared sensors have difficulties to

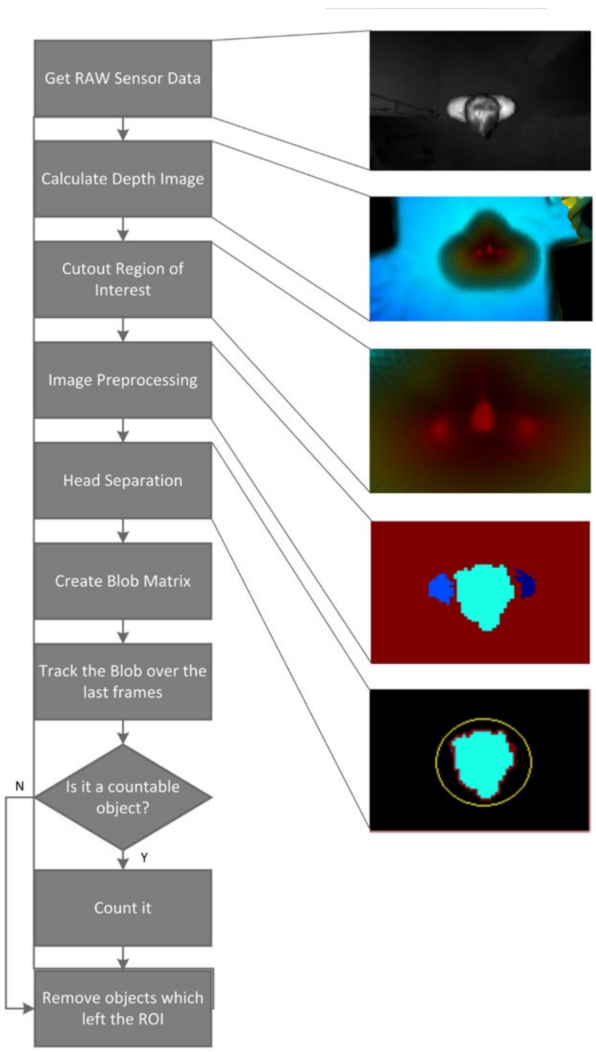

Fig. 2: People counting flow chart from raw sensor data.

handle people standing close together and pushing in or out of a vehicle. To get accurate results the heads need to be counted. The People Counter is mounted above doors or gates looking downwards to the floor with a FoV of 90° as shown in figure 3.

Only the heads are seen by the sensor. Human heads have a specific shape which can be identified in the Depth image. Once such a shape has been detected it will be marked in the so called blob matrix as part of an object of interest. If the blob matrix has been created the tracker tries to identify each object of the new frame if it is part of an already existing object or a new one. If the object is already known the characteristics of the object will be adapted according to the information in the new frame. If the object is new it will be added to the object list. If one or more objects leave the region of interest the characteristics of the objects will be analyzed if they are valid. The counter value according to the direction will be increased and the objects will be deleted. The people counter can be integrated in existing installations by using an Ethernet or RS485 interface. The Ethernet interface enables a complete depth and amplitude image stream for later analysis or for security reasons.

Aside of the tracking of people interactive user interfaces are entering daily life. The key element to every form of gesture and pose recognition is the detection of individual persons and to obtain an accurate skeleton model of the body, the limbs and even separate fingers.

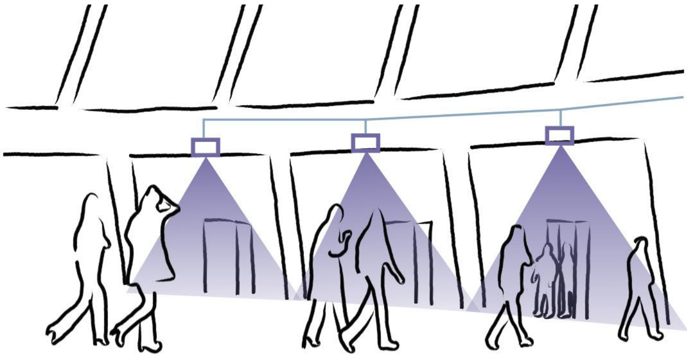
Fig. 3: People counting sensor positions above doors or gates.

Once the skeleton model in 3D for all joints is obtained, the user can accurately point at objects providing a 3D vector to the system to trigger actions. With the high resolution of the sensor and the high frame rate, efficient finger tracking can also be performed to enable sophisticated gesture recognition as shown in figure 4.

The 3D data provided by the sensor is used to derive additional characteristics of tracked or counted objects. As example an autonomous vehicle counter consists of an object presence detector, a vehicle classifier, a feature extractor, a counting application and the interface to an infrastructure management system. The sensor is typically mounted in a top-down view position several meters above a road. That is the standard mounting position for road traffic surveillance and traffic management applications. For toll collection systems or parking management systems the sensor is mounted in a side-front-view position looking towards incoming vehicles providing a good view of the license plate. Design and implementation of algorithms for object presence detection, vehicle classification and feature extraction benefit the depth image. The software is typically organized as a chain of image processing steps.

Object presence detection is the first system task in many such applications. Such systems are nowadays often based on conductor loops or ultra-sonic sensors. Both technologies are well introduced, rather cheap, but require a certain effort in installation and cabling between sensors and processing logic. The task of installation has significant impact on the costs of vehicle counting applications. The ToF-sensor gives the ability to replace those technologies, to reduce cabling effort and to add quality and new functionality to the system. The software identifies significant changes in the depth images as an indication of object flow and segments the indicated regions of consecutive depth images for further object classification. The goal of object classification is to identify different types of vehicles. This filter stage may drop all kinds of detected objects that do not classify as vehicles. The algorithm identifies shape of bonnet, shape of windshield, and also measures width, height and length of the vehicles. These parameters are used to classify vehicles into trucks, vans, SUVs, sedans, motor-cycles, etc.

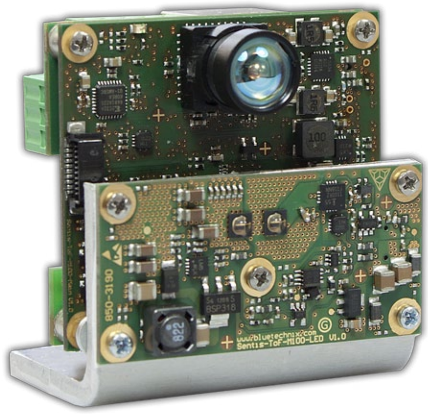
Fig. 5: The Sentis M100 integrated ToF 3D sensor solution by Bluetechnix.

Additional features of a vehicle from the depth image are detected and notifications can be passed to the infrastructure when the vehicle has entered a specific zone in the depth image. That feature may be used to trigger further activities of the infrastructure. Toll collect systems or parking management systems may need to read the license plate. The ToF-sensor aids that task by identifying the location of the license plate. It identifies the license plate as a cube-shaped, prominent structure in the depth image and passes the location information on to a license plate recognition.

An integrated solution

The Bluetechnix Sentis M100 shown in figure 5 is an example for a commercially available 3D sensor using a PMD PhotonICs 19k-S3 Time-of-Flight sensor with 160x120 pixels and a range of 3m. The onboard Processor, a DualCore Blackfin BF561 enables applications operating at frame rates up to 40 fps. This specific smart sensor is tailored towards the integration into existing housings and can be connected via Ethernet or a RS232/RS485 interface. Additional GPIOs can be used to trigger other devices and actions.

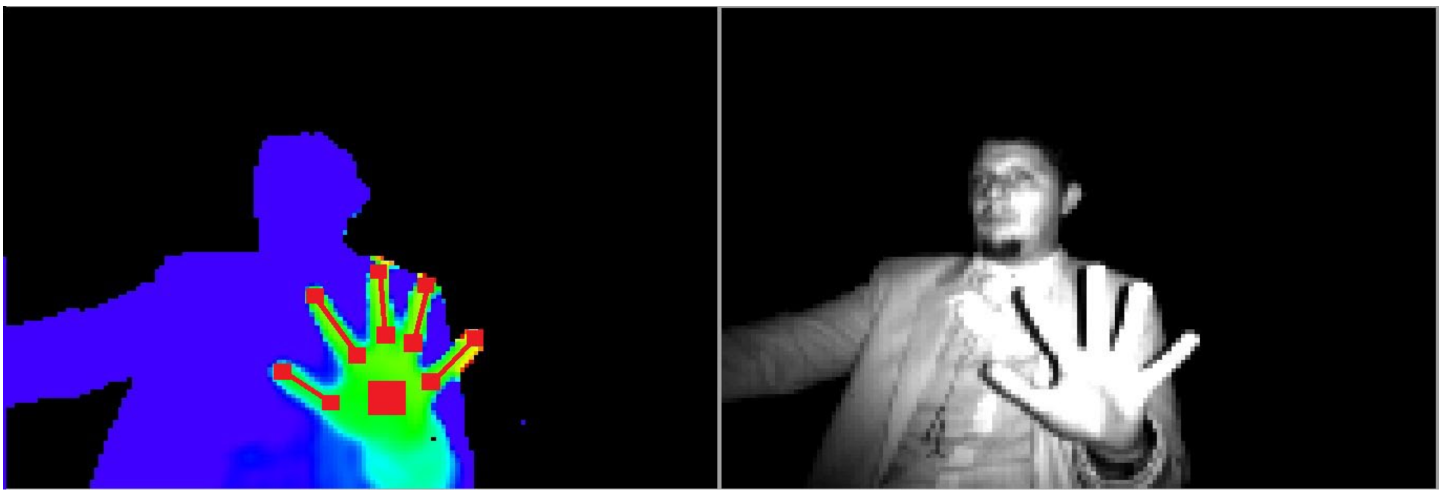
Fig. 4: Using a depth image and a greyscale image for hand tracking.