

ATZ **extra**

When machines learn to see
Smart assistance systems
for rough terrain

Smart Assistance Systems for Terrain and Object Recognition

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Electronic assistance systems are standard equipment for road vehicles these days, but require modification when being used in mobile machinery. This is because assistance systems for road vehicles can rely on level and organized surroundings, mobile machinery such as earth-moving machines, however, often operate in uneven and rough terrain. In response, ITK Engineering has developed a smart, camera-based assistance system with technology and algorithms that can be integrated into the next generation of mobile machines.

SAFETY REQUIREMENTS FOR MOBILE MACHINERY

As on the roads, most of the accidents involving mobile machines can be attributed to human error. Limited visibility is the primary cause of fatal collisions and has prompted an overhaul in the visibility requirements for earth-moving machines in the ISO 5006 and EN 474-1. In future, machine operators must have an adequate view of the entire machine danger zone – including people kneeling directly alongside the machine [1]. To meet these requirements, at present camera systems are mostly used to monitor the danger zones. While these systems do allow operators to monitor their immediate surroundings, they require them to constantly concentrate on the monitor – as well as on the machine controls. This may be more than the operator can handle and negatively impact performance [2]. Consequently, it makes sense to assist operators by also using a sensor warning system for the detection of people and objects in areas of poor visibility – with the system even intervening in the controls in a hazard situation. The basic requirement for such a solution is a system that can reliably record the

surrounding terrain while coping with the frequently harsh conditions encountered by mobile machines.

Current sensor and camera technology, coupled with the right image processing algorithms, now allows for assistance systems that are tailored to the customer's individual needs and the specific type of a mobile machine. ITK Engineering has developed a technology demonstrator aimed at construction vehicles on uneven terrain, which takes the shape of a smart camera-based assistance system [3, 4].

SMART ASSISTANCE SYSTEMS FOR UNEVEN TERRAIN

The new technology demonstrator is based on a robust stereo camera and an embedded platform with a multitude of image processing algorithms. The stereo camera consists of two paired mono-cameras that take pictures in tandem. Based on the 2-D image pairs, the system then determines 3-D information such as the distance of objects from the camera and their actual size. These images are then analyzed, **FIGURE 1**, so as to build up a detailed 3-D map of the terrain and its accessibility, and detect people in the machine danger zone and issue a driver

warning. Before use, the system requires a one-off calibration. This is to determine the intrinsic and extrinsic camera parameters required to measure distances accurately and effectively.

IMAGE PREPROCESSING

The first step involves image-enhancing preprocessing steps such as contrast adjustment and noise suppression for the stereo image pair. Image distortions caused by the camera lens are also compensated at this stage. In this step of the analysis, the preprocessed pair of 2-D stereo images is used to determine depth information. As in human vision, this is done based on the distance between corresponding features in the image pair. If we focus on an object in front of us and shut one eye after the other, the object seems to spring back and forth depending on its distance from us. This difference, referred to as disparity, is inversely proportional to the object's distance from us. The human brain uses the disparity between corresponding features captured by the right and left eye to extract depth information.

Computer vision works in a similar way. To achieve this, the system first marks key points in both camera images.

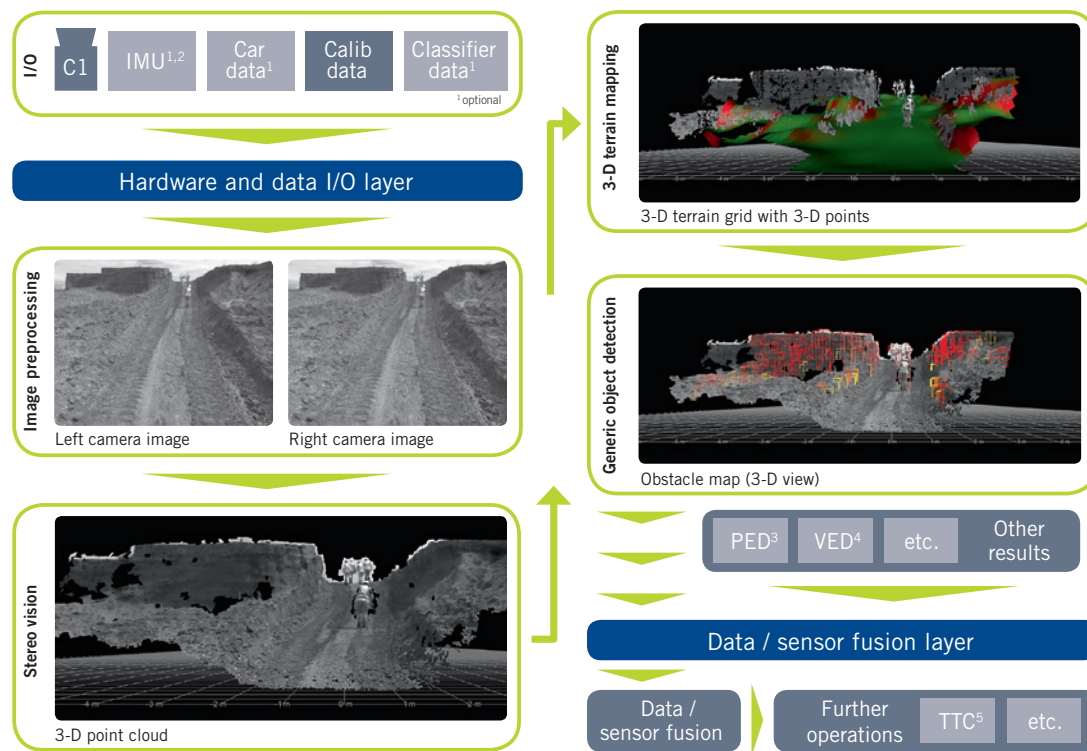


FIGURE 1
Structure of the smart assistance system
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² Inertial measurement unit, ³ Pedestrian detection, ⁴ Vehicle detection, ⁵ Time to collision

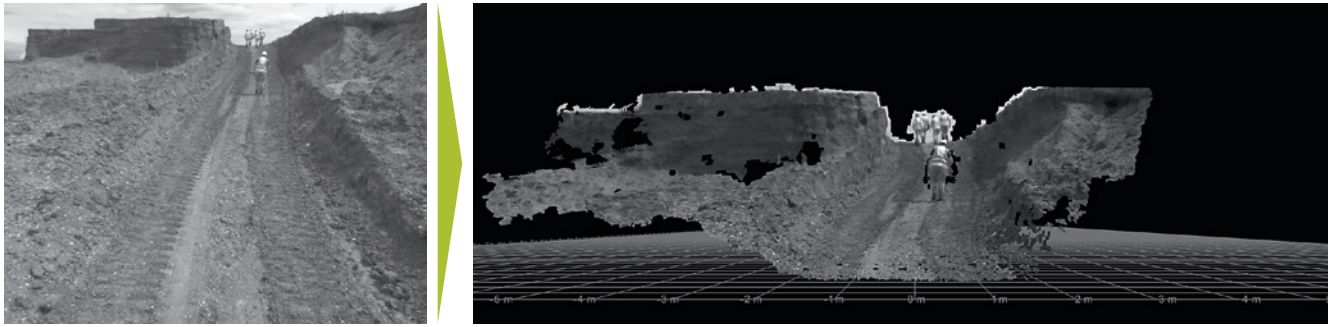


FIGURE 2 Camera image (left); pixels are shown as a 3-D projection – the black areas are missing depth information, as the points lie out of the line of sight or else are covered by other objects (right) (© ITK Engineering)

This is followed up by correspondence analysis, in which matching key points are identified in both images. To speed up the process, the image pairs are arranged so that the left and right images contain the corresponding information in the same row. This is done using the camera information gathered at the calibration stage and epipolar geometry characteristics. As a result, key points can be efficiently matched since the search is restricted to a single row of the image. Finally, the disparity – that is to say, the distance between the points in the first and second image – is used to calculate the distance to the camera and the points' real world x, y, and z coordinates, **FIGURE 2**.

CAPTURING UNEVEN TERRAIN

To map terrain in 3-D, the first step is to generate an elevation map. In order to efficiently model the terrain, this is done using a fixed grid structure on the x-y plane. Each 3-D point has a specific set of coordinates that are assigned to a

cell within the grid. Not only is using a grid structure efficient, the height distribution of points within a grid cell also helps to determine whether an individual point belongs to an object or is part of the terrain. Next, a spline approximation is applied with limited degrees of freedom to get a rough model of the terrain. This provides a general idea of the terrain ahead, for example slopes, inclines, or steep terrain. Then, based on this rough approximation, a second, more exact spline approximation with more degrees of freedom is applied to provide a picture of the finer details of the terrain, **FIGURE 3**.

IDENTIFYING COMPLEX OBJECTS

Once the terrain has been modeled, the information on gradients helps determine accessibility, **FIGURE 3**. The terrain map can also be used to identify objects by comparing a grid cell with the calculated terrain and considering statistical measurements of the point distribution within the cell. Individual

cells marked as obstacles are agglomerated into entire objects with the help of a connected components algorithm, and the minimum distance of these objects from the vehicle is calculated, **FIGURE 3**. Each individual object is also tracked using a Kalman filter in order to eliminate noise and individual false detections, thereby stabilizing object recognition. The system also calculates the direction of movement and the speed of the object. As the terrain map in **FIGURE 3** shows, while inclines and dips are retained, it is also possible to accurately place objects such as diggers, stones, and people.

DETECTING PEOPLE IN THE DANGER ZONE

At this stage of the analysis, deep learning techniques are applied to the objects detected on the terrain to further classify them. That is to say, the system automatically determines whether an object near to the machine is a person or not, **FIGURE 4**. Deep learning relies on statistical data

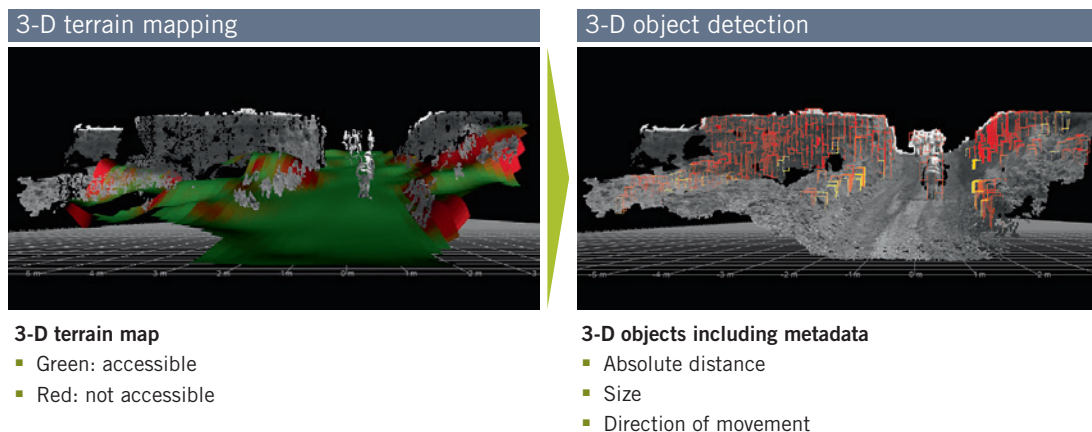


FIGURE 3 Object detection (on the left a 3-D terrain map color coded on the basis of local gradients and with all the 3-D data in grey is shown – red symbolizes a steep local gradient; on the right, the 3-D data with detected obstacles is visualized) (© ITK Engineering)

analysis algorithms from the field of machine learning, which have established themselves as a valuable tool in machine vision in recent years because of their accuracy in identification.

Before a deep learning algorithm can differentiate between a person and another object, it must first be pre-trained. In this first step, the algorithm builds up an identification pattern based on an array of different pictures of people fed into it. Once it has been taught, the algorithm can be implemented within the assistance system and automatically differentiate people from other objects in the stereo images.

Not only can deep learning algorithms accurately identify people, they can also be trained to identify a wide range of other objects, including signs or animals. Algorithms can also be trained to identify multiple different object classes at once.

SAFEGUARDING AND SYSTEM INTEGRATION

The selected algorithms as described above need to be integrated and verified and validated along with a range of other software modules on a suitable



FIGURE 4 Detection of people (obstacles detected are color-coded based on their distance from the camera (green: far away; red: close by); in addition, any pedestrians are marked with a frame) (© ITK Engineering)

hardware platform. Just securing the camera-based person and object recognition system requires large volumes of reliable test images or virtual test environments with relevant scenarios involving mobile machinery at work. After the hardware and software has been successfully verified using an electronic control unit suitable for the machine, that unit must then be securely

integrated into the respective machine. The machine manufacturer that launches the machine on the market is bound by a wide range of normative regulation and is obliged to ensure the functional safety of its machine [5]. This process is outlined in **FIGURE 5**. Quite aside from the issue of functional safety, cyber security is a growing concern in an age of digitalization and connectivity of mobile machinery. We will not go any further into these concerns here, but experience in developing these sorts of solutions for road vehicles has shown that it involves considerable development work.

SUMMARY

When heavy utility vehicles, agricultural and mobile machines are moving tons of material, workplace safety is a primary concern. System developers and machine operators are confronted with new challenges as they contend with uneven and partially inaccessible terrain, complex obstacles, and difficult environmental conditions with strong vibration and contamination. Smart assistance systems that have already proven themselves in road vehicles can also be applied to mobile machines to improve workplace safety and productivity. They are based on a range of complex algorithms and electronic control units with high-performance processors. Together with a robust system of sensors and actuators, these hardware/software solutions must be securely integrated into mobile machines. The process of system integration must take into account both

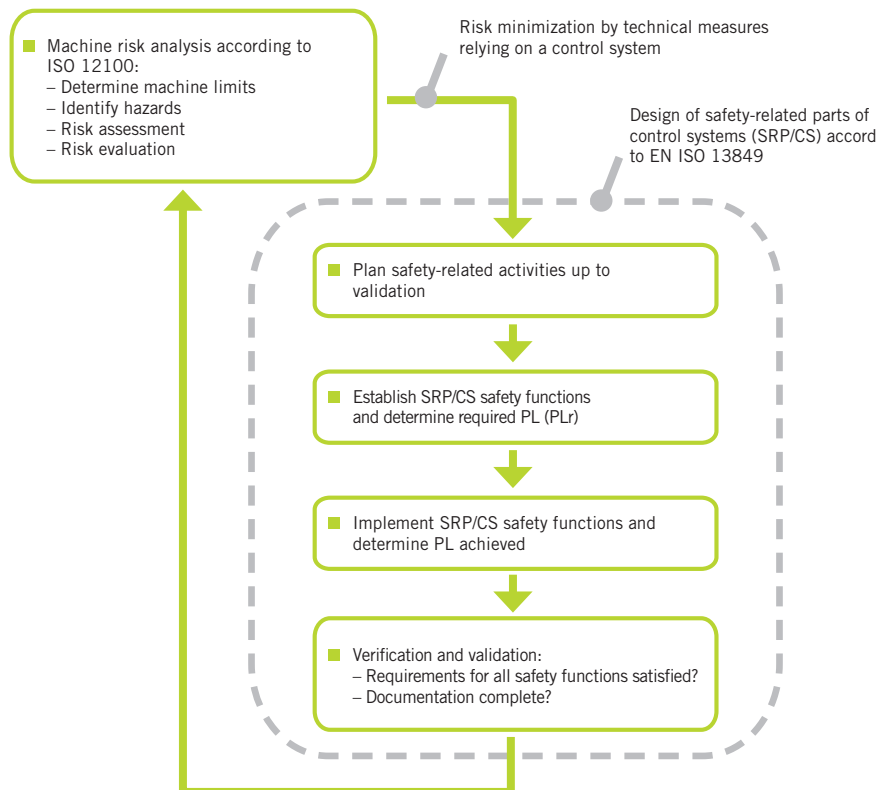


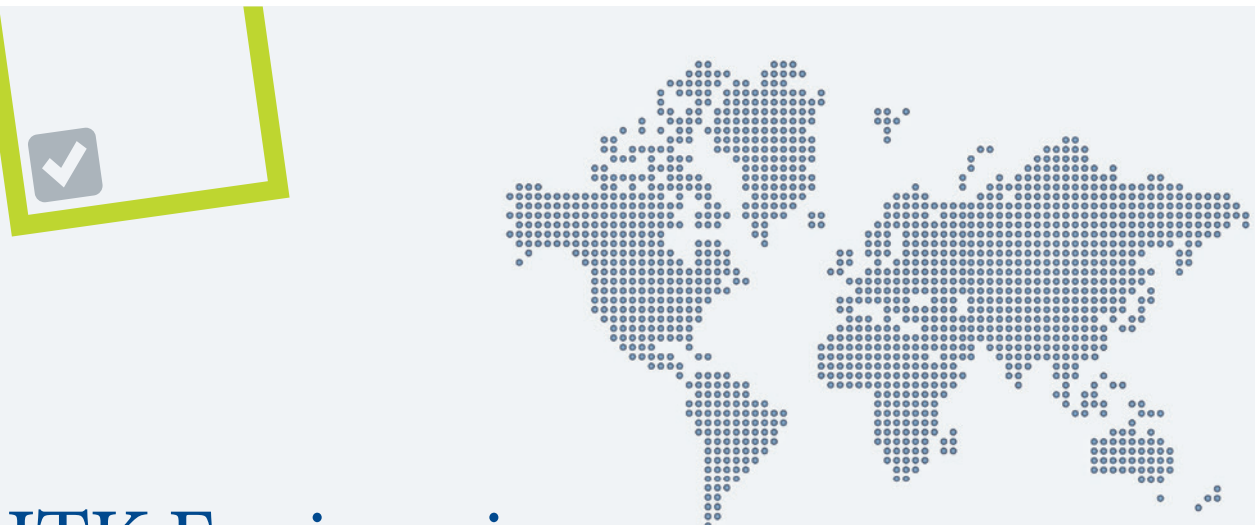
FIGURE 5 Process for designing safety-related control systems (© ITK Engineering)

the considerations of functional safety and cyber security. What we need is a modular approach on the software and hardware level and a standardized process of system development so that we can implement powerful, cost-effective, and easily integrated solutions.

REFERENCES

- [1] N. N.: Empfehlung Sicht beim Einsatz von Erdbaumaschinen und Walzen. Online: www.bgbau.de/praeuv/fachinformationen/arbeitsmittel/sichtfeld-von-erdbaumaschinen/downloads/empfehlung-sicht-beim-einsatz-von-erdbaumaschinen-und-walzen, access: November 20, 2017
- [2] Rinneberg, S.: Assistenzfunktionen für Erdbaumaschinen mittels Identifikationstechnologie. München, Technische Hochschule, Dissertation, 2016

- [3] Kramarczyk, P.: Assistenzsysteme für die Baustelle. In: CVC News (2017), No. 1, pp. 25–27
- [4] N. N.: When machines learn to see. Online: www.youtube.com/watch?v=wy34QtmslgM, access: November 20, 2017
- [5] N. N.: Funktionale Sicherheit. Online: www.netzwerkbaumaschinen.de/material/download/nwBMA_FuSi.pdf, access: November 20, 2017



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