# Advanced Multifunctional Sensor Systems

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**Abstract** This work addresses the role of multifunctional sensor systems in defence and security applications. The challenging topic of imaging sensors and their use in object detection is explored. We give a brief introduction to selected sensors operating at various wavelength bands in the electromagnetic spectra. Focus here is on sensors generating time or range resolved data and spectral information. The sensors presented here are imaging laser radar, multi- and hyper-spectral sensors and radar systems. For each of these imaging systems, we present and discuss analysis and processing of the multidimensional (n-dimensional) data obtained from these sensors. Moreover, we will discuss the benefits of using collaborative sensors, based on results from several ongoing Swedish research projects aiming to provide end-users of such advanced sensor systems with new and enhanced capabilities. Major applications of this kind of systems are found in the areas of surveillance and situation awareness, where the complementary information provided by the imaging systems proves useful for enhanced systems capacity. Typical capabilities that we are striving for are, e.g., robust identification of objects being possible threats on a sub-pixel basis from spectral data, or penetrating obscurant such as vegetation or certain building construction materials. Hereby we provide building blocks for solutions to, e.g., detecting unexploded ammunition or mines and identification of suspicious behavior of persons. Furthermore, examples of detection, recognition, identification or understanding of small, extended and complex objects, such as humans, will be included throughout the chapter. We conclude with some remarks on the use of imaging sensors and collaborative sensor systems in security and surveillance.

**Keywords:** Full 3-D imaging, gated viewing, image analysis, image processing, imaging sensors, laser radar, multi- and hyper-spectral sensors, multi-sensor systems, radar systems, multidimensional data, synthetic aperture radar

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# 1 Background Motivation

Safety and security applications bring several challenging problems at hand. This especially becomes apparent when facing the complex task of surveillance in order to detect and identify any possible threat. Such tasks can, for example, be to detect a person applying an improvised explosive device (IED) on a bus whilst he is being recorded by a surveillance camera, or to identify a person placing out surface laid mines in a remote and desert area without any surveillance capabilities. Thus, both suspicious objects and abnormal behavior of humans are of interest. To accomplish capabilities to handle such tasks, we truly need a variety of tools, e.g. spanning from surveying large areas to providing evidence to be used in the criminal justice system.

The importance of images in security and safety applications needs not to be questioned. Video cameras producing streams of image sequences usually builds up the surveillance systems of today. But many additional problems arise from the surveillance system technologies in use. The most commonly used short-range, passive surveillance systems are not optimal to capture the events and objects in a scene for further analysis and processing, but these systems will still be in use for many more years. Reviewing recordings from these systems e.g. surveillance video, is a time demanding task. It is also very difficult to detect all objects by the human visual system. Another major problem that the existing surveillance techniques provide, and that seriously limits the possibilities of identification in the criminal justice system, is the lack of images rather than lack of analysis methods [10, 11, 24]. The task in a forensic situation, for example, is often to handle situations where the image sequence comes from a single camera, or multiplexed cameras where the image streams are recorded on the same media. Furthermore, camera parameters and the characteristics of the imaging devices and recording conditions are usually unknown or limited, as the circumstances seldom provide calibration procedures to be performed. Moreover, there are many examples of applications where human assisted analysis is no alternative and there is a need for automatic or semi-automatic processing. Hence, we foresee a lot of challenging issues if we want to be able to detect and identify all kinds of events and objects that could cause a threatening situation.

The scientific areas of sensor technique and sensor data processing have evolved significantly. By using sophisticated and existing sensor systems and algorithms, several problems of conventional surveillance systems can be solved. Nowadays there are a large number of new sensors and image processing techniques for tracking and analyzing moving persons or detecting small objects, see e.g. [25]. We introduce somewhat more unconventional sensors for means to present complicated information in a way that can be easily, correctly and quickly understood. Complementary sensors addressed here are gated viewing, full 3-D imaging laser radar, multi- and hyperspectral sensor and radar systems. These imaging systems brings new capabilities such as to penetrate vegetation, clothing, building materials, and can be used despite of poor weather conditions or at long ranges.

But, the nature of the threats against us in our society constantly increases in complexity. Consequently, there are several situations to be handled and that need

**Fig. 1** Example of multisensors for urban monitoring, [4, 35].

even more complicated sensor systems. A possibility to provide better capability is to make use of the additional data provided by complementary imaging sensors. So, in addition to the individual sensors and algorithms, the combination of passive and active sensors are used. This brings flexibility and the capability to enhance our possibility to "see" the threats that we usually are unaware of or believe are unlikely to occur. Not only do we need the capability to "see" the threats, we can also do so without being "seen" ourselves, illustrated in Figure 1.

The work addressed in this chapter emanates from several ongoing activities at the Defence Research Agency FOI on the subject of automatic target identification for command and control in a netcentric defence. The driving force for the research activities at FOI is strongly motivated by requirements that emanates from defence applications and law enforcement. Although, the main applications areas of interest in our research are found in security and safety, there are many other possibilities. Hence, we give some examples of successful imaging systems that in combination with image processing and analysis techniques provide means to e.g. to improve surveillance capacity.

Finally, some concluding remarks on the use of imaging sensors for applications in security and surveillance rounds off the chapter.

## 2 Imaging Sensors

We have got the sensors – but what can they accomplish? What we usually strive for is recommendations and specifications for future sensors systems, and we want the computer do the "dirty work" for us in the process of identifying objects, events and phenomena in image sequences by the use of image analysis and image processing techniques. These methods provides a complement to the human visual system so that we can use the visual information in a better way.

A key issue is provide good quality data – rather than trying to enhance and analyze poor data. This does not necessarily mean that the image quality needs to be of good visual quality. On the contrary, data collected might not make sense when presented to an operator but are very useful in an automatic image analysis process. The importance, though, is that the data quality is of high quality. This, in turn requires knowledge about the sensor in use, regardless being conventional

or being newly developed. Furthermore, we need knowledge about the problem at hand, the depicted scene and the objects of interest. Thus, a useful rule of thumb is to get it right from the start.

The focus here is on laser radar systems (in Section 3), multi- and hyper spectral systems (in Section 4) and radar systems (in Section 5) that are sensors generating complementary time resolved or range data and spectral information, in contrast to CCD- and IR-cameras that passively images a broad spectra of the visual or infrared range. After a brief introduction on each of those imaging sensors we present methodologies and applications by the use of image processing and analysis techniques. One important computer vision task is the understanding of complicated structures representing threats, crimes or other events. Here a major part of the problem originates from the difficulty of understanding and estimating data describing the events taking place in the imagery.

The main objective for using advanced sensor systems is to provide descriptors related to the problem of understanding complex objects from images, such as mines and vehicles (in Section 6) or humans (in Section 7). These descriptors can, for example, be used in a recognition or an identification process. Detection, recognition, identification or understanding of small (covered by a few pixels or sub-pixel sized), extended (covered by many pixels) and complex objects from images provides us with a variety of difficult but challenging problems. Here we use the term *complex* to denote an object that can simultaneously move, articulate and deform, while *detection* is referred to as the level at which object are distinguished from background and other objects of no interest, i.e., clutter objects such as trees, rocks, or image processing artifacts. *Recognition* is used to distinguishing an object class from all other object classes and *identification* is used to distinguishing an object from all other objects.

For any method, either supporting an operator or a fully autonomous method, the whole chain must be taken into consideration, from the sensor itself to what the sensor can comprehend. This includes sensor technology, modeling and simulation of the sensor, signal- and image processing of the sensor data, evaluation and validation of our models and algorithms e.g. by experiments and field trials with well known ground truth data to finally obtain the desired data. The outcome can e.g. be further used for data- and information fusion at higher system levels, such as alerting an operator of the position of a detected suspicious object that, e.g., could be a surface laid mine.

To investigate the performance bounds to reveal the role of the system parameters and benefits of sensor performance, we model and simulate each of the individual sensors. Modeling requires knowledge of the atmosphere, object and background characteristics and there is a need for characterization at the proper wavelengths. But, if we get it right, we can use our models to simulate larger scale sensor system, including different types events, scenarios, object types, sensor types and data processing algorithms. Hereby we have a good platform to analyze the performance of systems of higher levels, as exemplified in Section 6.

# 3 Laser Imaging

Laser imaging range from laser illumination systems enabling active spectral imaging to range gated and full 3-D imaging systems. Coherent laser radars will also provide Doppler and vibration information. We will concentrate on 3-D imaging systems. Real time 3-D sensing is a reality and can be achieved by stereo vision, structured light, by the various techniques for estimating depth information or by range imaging. Laser radar, in contrast to passive imaging systems, provides both intensity and range information, see e.g. [26, 27, 34, 41, 47]. The 3-D image can be derived from a few range gated images or from each pixel directly coded in range and intensity using a focal plane array or a scanning system with one or few detector elements. Each pixel can generate multiple range values. The range information provides several advantages and has impact on many military and also civilian applications. For example, 3-D imaging laser radars have the ability to penetrate scene elements such as vegetation, windows or camouflage nets. The latter is illustrated in Figure 2.

3-D imaging systems are predicted to provide the capability of high resolution 3-D imaging at long ranges at full video rate, supporting a broad range of possible applications.

## 3.1 Laser radar systems

The majority of the early laser radar systems are based on mechanically scanning the laser beam to cover a volume. The 3-D "image" (or point cloud) is then built up by successive scans where each laser pulse (or laser shot) will return intensity and multiple range values corresponding to the different scene elements within the laser beam footprint. In many systems, the full return waveform is captured for each laser shot and stored for further processing. Other systems capture parts of the returning waveform (e.g. first or last echo). The range information provides several advantages when compared to conventional passive imaging systems such as CCD and infrared (IR) cameras. The current development of laser radars, from scanning systems to fully 3-D imaging systems, provide the capability of high resolution 3-D imaging at
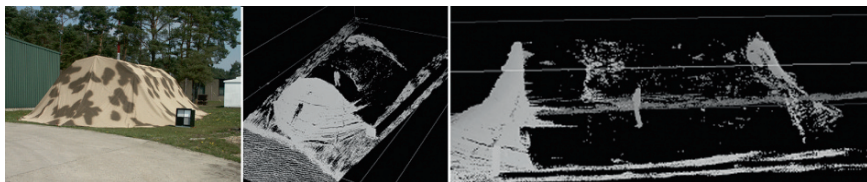


**Fig. 2** A camouflage net scanned by a laser radar system (*rightmost pictures*), revealing a person inside.

long ranges with cm resolution at high video rate. For example, 3-D imaging laser radars have the ability to penetrate scene elements such as vegetation and windows.

The range resolution and the spatial resolution (cross range) depends on the properties of the receiver and are important in system performance measurements. The received laser effect can be described by the laser radar equation as

$$P_m = P_s \eta_s \frac{A_\Delta}{\pi \left( \Phi R/2 \right)^2} \frac{A_m}{R^2} \eta_m t_A^2 \, , \tag{1}$$

where $P_m$ is the received laser power $[W]$, $P_s$ laser power $[W]$, $\eta_s$ transmission of transmitter optics, $\eta_m$ transmission of receiver optics, $\Phi$ laser beam divergence $[rad]$, $R$ distance transmitter-target $[m]$, $A_\Delta$ object effective area $\left[ \frac{m^2}{sr} \right]$, $A_m$ area of receiver $\left[ \frac{m^2}{sr} \right]$ and $t_A$ represents the atmosphere transmission. The range resolution varies with different types od laser radar sensors. The spatial resolution depends on the spatial resolution of the imaging sensor, but also on the atmospherical conditions and the distance to the target.

There are several concepts for scanner-less 3-D laser radar systems. The technology which seems to draw the largest attention in 3-D imaging for military applications is 3-D sensing flash imaging FPAs, which here is in focus. The remaining techniques are detailed in [34, 41]. A laser flood illuminates a target area with a relatively short pulse (1–10 ns), [45, 46]. The time of flight of the pulse is measured in a per pixel fashion. The position of the detecting pixel yields the angular position of the object element, and the time of flight yields the range. Hence, with a single laser shot, the complete 3-D image of an object is captured.

## 3.2 Modeling and simulation

To model a scene we need to know the characteristics of the system itself and also gain knowledge about the various scene elements. This especially holds for any object we want to detect. For a long time, theories for laser beam propagation and reflection have been developed and adjusted. Many of these theories have been useful to simulate and evaluate parts of a complex laser radar system, but modeling of a complete system was not possible in the early stage. The laser radar technology has become more expensive and a system model was desired to reduce the cost of laser system development and to expand the amount of training data for signal processing algorithms.

The simulation of the reflected waveform from a laser radar system is based on the ray-tracing principle and, inspired by [15], divided into four sub problems. Each sub system contains several parameters controlling the simulation. The abstraction level of the simulation is often a trade-off between complexity and efficiency. Too complicated models would require parameters not understandable by the average user and too simple models would not simulate enough conditions to produce

accurate results. The *laser source* is specified by the wavelength and the temporal and spatial distribution of the light intensity. The *atmosphere model* is simplified and controlled only by the aerial attenuation and the turbulence constant, $C_n^2$, as a function of the altitude. The *target* is a scenario of polygon models and their corresponding reflection properties at the current laser wavelength. Finally, the *receiver* is modeled electronically as a standard receiver from [15]. Since many of these sub-problems contain complex analytic mathematical expressions, especially when combined, we choose to make the calculations discrete, both in the temporal and spatial dimension. Another problem is the trade-off between the computational speed and accuracy. Based on our experience, a reasonable resolution in the spatial domain lies about 0.1 mrad, and in the temporal domain 0.1–1 ns.

The laser radar system model by FOI combines the theories for laser propagation and reflection with the geometrical properties of an object and the receiver characteristics such as noise and bandwidth. Our simulation model has been further developed over the years, through gated viewing (GV) systems and aerial scanning laser radar, up to the forthcoming 3-D focal plane arrays (3-D FPAs). There are several publications by FOI on this subject, see for example [9, 13, 19, 37–40, 43, 44, 48]. Another example is [42] also described in [25], that includes atmosphere modeling in terms of e.g. aerosols and turbulence, image processing, object recognition and estimating performance of different gated viewing (range imaging) system concepts. Moreover, we addressed the object/background contrasts of the reflectance value at eye safe wavelengths to investigate the recognition probabilities in cluttered backgrounds. An advantage with laser systems is the ability to penetrate vegetation. A tool is also developed at FOI for the purpose of estimating the laser returns as a function of distance to the sender/receiver, e.g. useful for detection of hidden vehicles as shown in Figure 3.

## 3.3 Object recognition

The development of algorithms at FOI for object recognition includes methods that aim to support an operator in the target identification task and also more autonomous algorithms. This work is described in [7, 8, 20, 26, 27, 41–43]. To obtain point clouds at long ranges, data achieved by an experimental GV system [25, 42] out to 14 km was used, in combination with a method for reconstruction of the surface structure [7]. This system, however, initially operated at 532 nm that is not eye safe. Thus, the simulation model was essential to estimate the performance of a system operating at an eye safe wavelength, which now is built. Examples of range gated imaging at 1.5 m is found in [47].

A major advantage is that a 3-D cloud often can be directly viewed without any processing. Furthermore, by visually searching a point cloud by varying the viewing distance and angle, objects that are not immediately obvious to the human eye can become easy to detect and recognize, see Figure 4. Fusing data from multiple viewing angles enhances this possibility which becomes an effective method to reveal hidden targets.
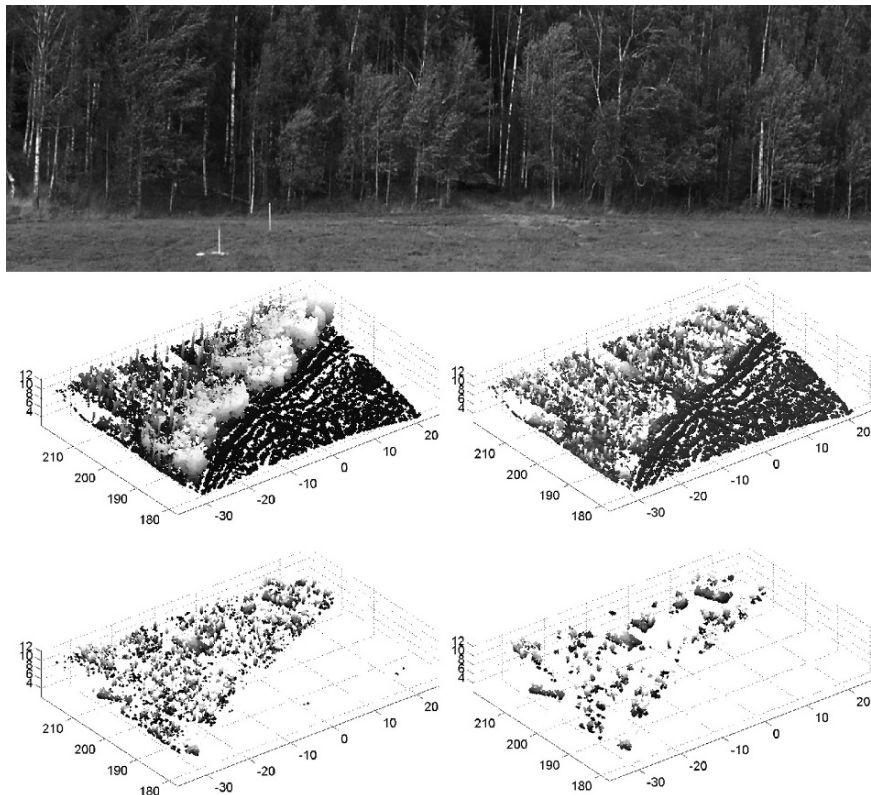
**Fig. 3** The scene for the laser measurement (*upper row*). The raw data from the laser radar system (*middle row to the left*) and the processed bare earth data (*middle row to the right*). All data less than 0.3 m above estimated ground (*bottom row to the left*) and finally the tree streams and noise clutter has been removed, reveling the vehicles (*bottom row to the right*).
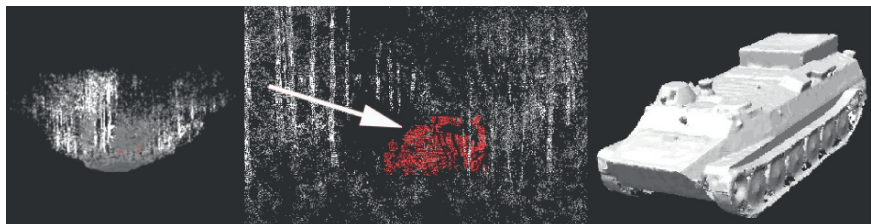


**Fig. 4** To the *left* is a laser scanned terrain area viewed from a frontal view. In the *middle* is a close up of the point cloud viewed at a different aspect angle to better reveal the target. To the *right* is a 3-D model of the vehicle, also created from scanned laser radar data of high resolution.

Laser radars also have the ability to penetrate Venetian blinds provided there are tiny openings, and thus have the ability to see into buildings. A method for matching 3-D sensor data with object models of similar resolution is detailed in [6]. For GV

data, a combination of a method for 3-D reconstruction and a 3-D range template matching algorithm is developed.

The current problem tackled is methods on extracting object points based on detection from hyperspectral data. In parallel, there are ongoing works addressing methods based on multi sensor approaches for detection of hidden objects, surface laid mines [49] where the objects can be in vegetation [1, 3, 14] and urban environments [4, 5], further described in Section 6. The exchange of information between different sensors, such as CCD, IR, SAR, spectral and laser radar, can provide solutions to problems that are very difficult to solve by using raw data from one single sensor only. Consequently, our work on 3-D imaging sensors for object recognition is incorporated in several multi-sensor approaches.

# 4  Multi- and Hyperspectral Imaging

Multi- and hyperspectral electro-optical sensors sample the incoming light at several (multispectral sensors) or many (hyperspectral sensors) different wavelength bands, see e.g. [2, 12]. Compared to a consumer camera that, typically, uses three wavelength bands corresponding to the red, green and blue colors, hyperspectral sensors sample the scene in a large number of wavelength (or spectral) bands, often several hundred.  Images providing spectral information give the possibility to detect and recognize objects from the spectral signatures of the object and the background, without regarding spatial patterns. The methods used for object detection differ strongly depending on the characteristics of the used sensor and of the expected object and its surrounding background. For example, pattern recognition techniques are used for detection, classification, and recognition of extended objects (covering many pixels). Multi- or hyperspectral images sequences provides means to detect objects of sub-pixel size as well. Although, it is important so specify the system performance from the situation at hand e.g. from matching the object- and background signatures to the spectral bands of the camera (bandwidth, number of bands etc.). Moreover, the spectral bands can be beyond the visible range, i.e. in the infrared domain, which opens up a variety of new applications [12].

Here we briefly describes methods for detecting extended or small targets in multispectral images. In this context we limit the discussion to treat spectral information only, i.e., spatial correlations are not considered. There are two main types of object detection methods. Object detection is, in the first context, is about finding pixels whose spectral signature do not correspond to some model of the background spectral signature but do correspond to a object model, if available. The spectral signature of the target is not assumed to be known, instead spectral anomalies with respect to the background are searched for. The process of detecting unknown targets is called anomaly detection. The second case is when a target model is available, which we call signature-based object detection.

## *4.1 Anomaly detection*

Anomaly detection, detailed in [2] provides new capabilities in object detection where the aim is to detect previously unknown objects as shown in Figure 5.

Anomaly detection is the case when we do not know the spectral signature of the target, and we want to find pixels that significantly differs from the background. We use a background model $B$, a distance measure $d(\cdot)$, and a threshold $t$. We regard a pixel $x$ as an anomaly if $d(B,\mathbf{x}) > t$. Thus, a model for the background signature is needed, as well as an update scheme, i.e., a degree of locality of the model. For example, we could use a local model (estimating the background signature from a local neighborhood only), a global model (using the entire image), or a combination. Then, to measure the distance from each pixel signature to the background model, we need a distance measure. The choice of distance measure is restricted, or even determined, by the model used for the background and thus the assumptions about background spectral distribution. Finally, we need to set the threshold $t$.

A signature-based algorithm for target detection searches for pixels that are similar to a target probe. The target probe is a model of a certain target signature $T$, i.e., the spectral signature of the target or target class is known. Basically, we measure the distance from a pixel signature to the target model and to the background model, and choose the smaller. That is, we can classify pixel $x$ as a target pixel if $d(T,\mathbf{x}) < d(B,\mathbf{x})$.

The detection methods require spatial and spectral models for targets and background. The spatial model is used to define background areas to classify any object areas. The spectral modeling is to represent the properties of the object and background classes in use, There are several possible methods, with the common goal to measure a distance from an object class to the modeled background class in order to classify in what category the pixels belongs to.

Combining anomaly detection with signature based detection can improve detection performance. Moreover is the detection useful as input e.g. to a 3-D laser radar for identification.
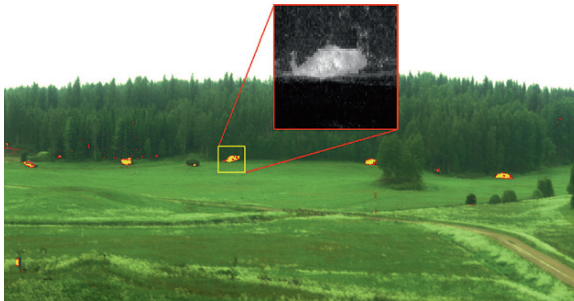


**Fig. 5** Detection of military vehicles by a hyperspectral camera. The targets are in the open and hidden in the terrain and the targets are detected by the signal processing algorithm applied to the data. One of the vehicles, which is under camouflage, is enlarged.

# 5 Imaging Radar Systems

Among the many possible radar systems available and found in the literature see e.g. [50], we will address only a few; SAR and imaging radar systems for penetration of certain materials.

## 5.1 Resolution in a radar system

The concept of resolution of a radar system is usually defined as the width of the impulse response when the signal energy has decreased to half. The impulse response can be divided into two dimensions, range and azimuth. The range resolution is determined by the transmitted bandwidth ($B$) as $X_r = \frac{c}{2B}$ where $c$ is the speed of light and $B = \frac{1}{T}$ where $T$ is the length of the transmitted radar pulse; i.e. a short pulse has a large bandwidth equalling a small resolution cell in range. In reality, the bandwidth is often created by some kind of frequency modulation of the transmitted pulse in order to increase the mean power in the system. The return signal is then compressed in an inverse filter in the system receiver. In azimuth, the resolution is determined by the attributes of the antenna. A radiation beam is created with an opening angle depending on the antenna size vs. the wavelength. The opening angle of the beam will be $\varphi = \frac{0.88\lambda}{d}$ where $\lambda$ is the wave-length and $d$ is the aperture of the antenna. This implies that the azimuth resolution (measured as the distance in azimuth between two point targets, which can be resolved by traditional radar) will depend on the range between the radar and the target area, i.e. the azimuth resolution performance will decrease with range. For most imaging applications the antenna will soon become impractically large when trying to keep a good image resolution at great distances.

## 5.2 Synthetic Aperture Radar (SAR)

The SAR-technology, [50] is a signal processing method for increasing the azimuth resolution of a radar system. The first patent was issued already 1951 for Carl A. Wiley at the Good-year Corporation in the USA but was not widely used until the modern digital technology became available. SAR has the fantastic characteristics of being like a camera featuring all-weather capabilities and range independent image resolution.

   With SAR-technology the azimuth resolution is generated in the signal processing and will be independent of the range from the sensor to the target. The trick is to use a small antenna placed on a moving platform, e.g. an aircraft. The small antenna

will generate a wide beam of radar illumination. The beam must cover the complete area of interest, and the signal is received in amplitude and phase during the fly-by of the platform. By using different mathematical methods, e.g. Fourier methods, the phase history (Doppler shift) of the signal can be analyzed and a synthetic antenna aperture equal to half the length of the flight track, the synthetic aperture $L$, can be generated.

FOI has, since many years, a diverse research program for low frequency radar development for ground and airspace supervision. We have developed the foliage penetration CARABAS system operating in the VHF band (20–90 MHz).

The system is a unique tool for providing information on targets concealed under foliage. It combines unprecedented wide area stationary target detection capacity with the capability of penetration of vegetation and camouflage. The VHF band used, allows target detection at a low surface resolution enabling the large surveillance capacity. The new LORA system, operating in the UHF band (200–800 MHz), is also capable of moving target detection and will be used as a generic research tool.

The research at FOI on SAR provides methods for generation of high resolution radar images. In fact the resolution on ground is independent of the distance from the radar to the target area. In urban environment there is the problem of detecting small objects due to the very strong backscattered signal from buildings and other large structures. The target signal will be obscured by the background clutter in the image. By separating the transmitter and receiver in the radar system and hence creating a bi-static situation this problem can be reduced. Furthermore, by placing receivers on the ground, receiving opportunities are opened for "tomographic" 3-D imaging of the internal structures of the buildings. This is a relatively new field of research that in all probability will enhance the situation awareness in future urban surveillance.

Among the many publications available, we also recommmend [16, 17, 22, 30, 33, 51].

## 5.3 Radar for penetration of materials

Another very promising upcoming technology [23] is the ability to penetrate certain materials, such as clothes and construction materials, with radar. This capability lets us penetrate materials that we cannot visually see through with the human eye. This opens up possibilities in military situations but also in law enforcement and rescue situations.

Researchers at FOI have developed imaging radar systems, capable of delivering through-the wall measurements of a person. Figures 6 and 7 shows the radar images when measuring a person through three different inner wall types at 94 GHz.
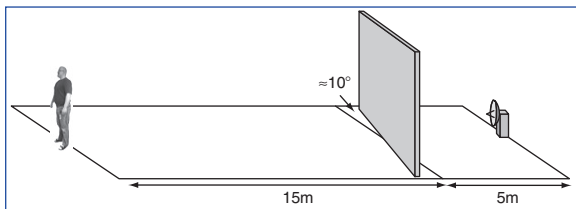
**Fig. 6** Localization of a person behind a wall by measurements carried out at FOI with an in-house developed imaging radar system.
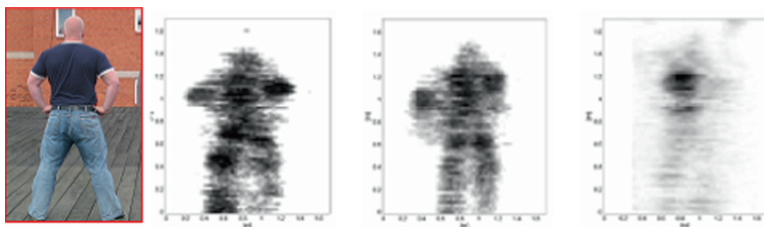


**Fig. 7** Radar images when measuring a person through three different inner wall types at 94 GHz are shown. A 12.5 mm thick plasterboard (*left*). Two 12.5 mm thick plasterboards separated by a 45 mm air slit (*middle*). A 12.5 mm thick chipboard (*right*).

# 6 Multisensor Approaches

As mentioned, the complex task of surveillance to detect and identify any possible threats brings the need for multifunction and multisensor systems to have the flexibility to meet the environmental subsystems at hand, see e.g. [1, 3, 28, 29].

## 6.1 Detection of surface laid mines

Methods for detecting surface laid mines on gravel roads are being investigated in a national research program at FOI. Among other basic issues, is the idea in [8] that human-made objects are expected to appear more structured than surrounding background clutter. Another key issue is to base any detection method on the phenomenology of the surface laid mines, striving for to select the right combination of sensors to provide optimal data as input to the detection algorithms.

Using data from laser radar has shown some promising results [21]. This method basically relies on a fusion of intensity and hight features obtained from laser radar data. Although intensity usually is useful as a feature for separating mines from background data, is will not be enough for desired system performance. A gravel road is a relatively flat surface and hence the height above the ground plane is a feature that improves the separation of mines from the road. However, for more complex environments, such as forest, the height feature worsens the separation of the

mine from the background, which motivates a search for other features. In [49, 53], 3-D data received from the laser radar is used to extract features relevant for mine detection in vegetation. These features varies with the nature of the vegetation. By involving data from an infrared (IR) sensor, synchronized with the 3-D laser radar data, additional features can be extracted. These features are evaluated to determine what combination that gives robust anomaly detection. A method based on Gaussian mixtures is proposed. The method tackles some of the difficulties with Gaussian mixtures, e.g., the selection of number of initial components, the selection of a good description of the data set, and the selection of which features that are relevant for a good description of the current data set. The method was evaluated with laser radar data and IR data from real scenes.

## 6.2 Urban monitoring

In recent years, significant research related to tasks in an urban environment has started, see e.g. [35]. Many sensor systems are, for instance, able to handle detection, but for classification and especially for identification, there are still many unanswered questions. Additional research is needed e.g. in sensor technology, data processing and information fusion. Consequently, there is a broad spectrum of challenging research topics. Here we present some resent examples from the ongoing research activities at the Swedish Defence Research Agency FOI that can contribute to the Swedish Armed Force's ability to operate in the urban terrain.

It is of importance to handle monitoring of the urban environment in a broad perspective, spanning from the everyday civilian surveillance situation to a full-scale war, bearing in mind that the border between law enforcement and military operations is somewhat fuzzy especially when considering terrorist activities. During military operations, surveillance systems are useful for detection of trespassing, tactical decision support, training and documentation to mention a few. The demand for fast and reliable information sets high requirements for data processing, spanning from fully automatic processes to visualization of data to support an operator. In the end, decision-makers from low rank soldiers to high commanders must be given the support required for different situations. Visual surveillance systems already exist and are increasingly common in our society today. We can hardly take a walk in the center of a modern city without being recorded by several surveillance cameras, even less so inside shops. The rising numbers of surveillance sensors, although being very useful, also introduces problems. Problems arise on how to get an overview of the surveillance data, and how to preserve the personal integrity of the people being watched by the sensors.

Overview is one of the greatest obstacles in a surveillance system with a large number of sensors. The most common type of surveillance sensor is video camera networks or other types of cameras. Images and video give rich information about the world, but are difficult to interpret automatically. Therefore, it is most common

that the images are interpreted by a human operator of the surveillance system. The human operator of a surveillance system is not seldomly showered with a large number of images of micro events that are difficult to position in space and in time. However, there are upcoming technologies to handle this. In 2004 FOI defined a number of urban surveillance situations. The purpose was to exploit an approach to create a framework for surveillance of urban areas. From these scenarios, we built up a concept for future large area monitoring where situation awareness is critical. Subsequently, on May 13 2004, we launched a field campaign in an urban environment, "The Norrkping riot". A number of our different sensors, being both off the shelf products and experimental set ups, provided useful data. The sensor data were fused by projecting them onto a 3-D model of the area of interest. By combining technologies, methods for data analysis and visualization we introduced new concepts for surveillance in an urban environment, and suggestions on how to realize these concepts using technology developed at FOI.

This concept is built around a 3-D model of the urban area to be surveyed. In this virtual environment, the cameras from the real environment are represented by projectors that project the camera views onto the 3-D model. This approach has several advantages. The context in which each camera is placed is visualized and becomes obvious. The spatial relation between different cameras hereby becomes obvious. Imagery from several cameras can be studied simultaneously, and an overview of the entire area is easily acquired. Even if the idea is not completely new, it is not widely used, and it improves the general situation awareness tremendously. In the 3-D model, all available sensor data can be visualized in such a way that their context and mutual relations are immediately visible. We have developed a research platform for visualization of the surveyed area. The platform is a visualization tool built at FOI on open source software that visualizes 3-D models and projects textures from input video, and is controlled using either a user interface or by commands over a network.

The actual key to making this into an operational system is that the 3-D model can be automatically generated, [5].

The key issue with the multiple heterogeneous sensors concept is to make use of the benefit brought by new capabilities by new and cooperating sensor systems. Besides conventional acoustic, seismic, electro-optical and infrared sensors, this can e.g. include range gated imaging, full 3-D imaging laser radar sensors, multispectral imaging, mm-wave imaging or the use of low frequency radars in urban environment. Assume, for example, that we have a sensor that can localize gunfire. The position of the sniper can then immediately be marked in the 3-D model, which gives several interesting possibilities. If the shooter is within the field of view of a camera, he is pointed out by marking the location of the shot in the 3-D model. The shooter can then be tracked forwards and backwards in time, searching for pictures suitable for identification and also warn others in the area. Regardless if the shooter is within the field of view of a camera or not, the shooter's field of view can be marked in the 3-D model. The marked area is a risk area that should be avoided and warned for. The same functionality can be used in a deployment scenario, aiding

the placement of sensors, snipers and people. Other examples are passage detection sensors, sensors that track or classify vehicles, sensors that detect suspicious events or behavior.

## 6.3 Sensor networks for detecting humans

A network of acoustic sensor nodes can also be used to locate gunshots, and also track sound sources. For example, technology used in military applications for tracking ground vehicles in terrain can be modified to fit in with an urban scenario. The output of the sensor network is synchronized with all other information in the system and user specified or general areas can be displayed in the 3-D model with a classification tag to indicate the type of event, see [4].

Passage detection sensors can be used for determining when people and/or vehicles enter a surveyed area and the other sensors should be activated. Several types of passage detectors are commercially available. Ground alarms for example, that react on pressure, i.e., when someone walks on the sensor (that consequently should be placed slightly below the ground's surface). Further examples are fibre-optic pressure-sensitive cables, laser detectors that react when someone breaks an (invisible) laser beam and seismic sensors, e.g., geophones that register vibrations in the ground. All of these were used in the "Norrköping Riot" supporting the imaging sensors in situations where these suffer from drawbacks, further described in [4].

## 6.4 Multisensor simulation

A multisensor simulation (MSS) tool is developed at FOI, systematically incorporating and synchronizing results from a very large number of sensor research projects. Detailed terrain-models, e.g. from laser radar data [5], is an important building block. As is our results from estimating and simulating the signatures of objects and scene elements in the operating wavelengths of the sensors in use. Hereby we achieve high realism and quality in signals and signatures. Included is object models for estimation of realistic target signatures. The MSS lab also integrates a variety of sensor simulators and signal- and image processing via HLA interface. Finally, we have developed a tool for verification and validation of the simulated sensor system, mainly based on the sensor platform, weather condition, sensors, environment, and the function needed to accomplish a certain task.

Providing high accurate signatures to physically based simulation of the scene elements in a realistic, high resolution 3-D environment model had resulted in a very promising resource for various applications. An example of using the MSS lab is to predict and analyze the performance of a mission by an unmanned airborne vehicle that performs automatic target recognition, as seen in Figure 8.
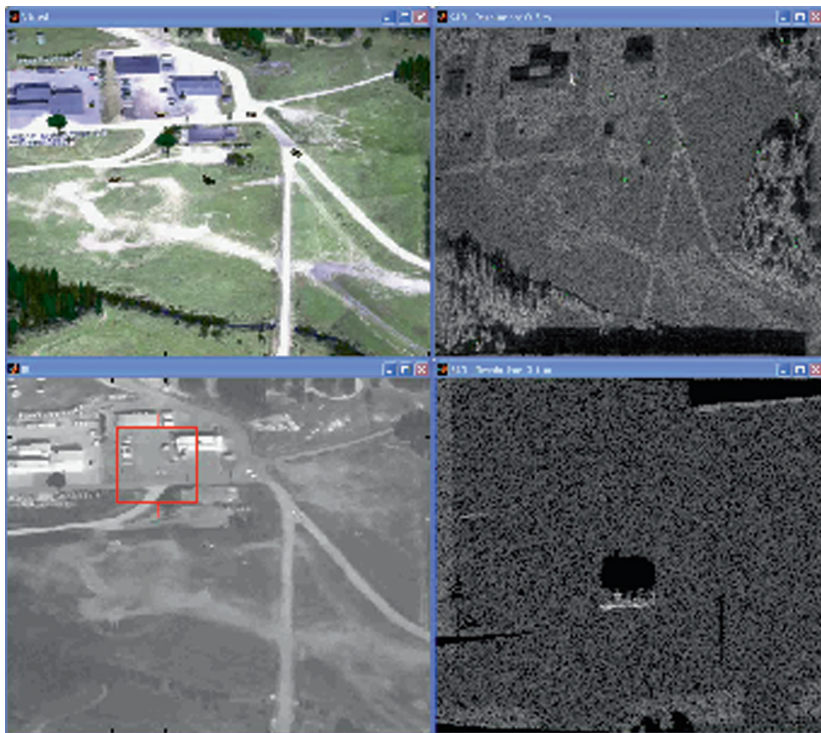
**Fig. 8** Simulation of a mission by an unmanned airborne vehicle that performs automatic target recognition. A high resolution 3-D model from laser data is used, modeled as seen by sensors operating in the visual range (*upper left*), IR range (*lower left*), respectively, and by a SAR (*upper and lower right*).

## 7 Detecting Humans and Analyzing Human Behavior

An important issue, especially in security applications, is to address humans, which are complex to detect, identify or to analyze behavior and intention of either a particular individual or a group, [4]. Another strong motivation to our research at FOI is the need for methods to separate our troops from combatants, non-combatants and even temporal combatants. The latter can for example be a civilian picking up a an IED from his back-pack in a mole, throwing it and injuring people. Likewise, integrity preserving surveillance is a new and important area, stressing the importance of providing technologies that serve the community, not act against it. This will be discussed below.

### 7.1 Preserving integrity

We have introduced the term integrity preserving surveillance to denote various technologies enabling surveillance that does not reveal people's identities. The

implication for integrity preserving surveillance is that people generally do not like to be watched and/or identified, and, furthermore, the use of surveillance cameras is often restricted by law. Integrity preserving surveillance systems put high demands on functionalities like robust classification and tracking of people and vehicles. The scenario below explains some of its potentials. We want to deploy a surveillance system in certain areas in a city. The problem is that we know that this is unpopular among the city's inhabitants, and the solution can be an integrity preserving system. The system maps, as described above, the videos on a 3-D-model of the areas, but replaces people and vehicles with blobs or symbols. The original and authentic videos are encrypted and stored at an institution that the local population have trust in. The processed videos can even be publicly displayed, for example on a web server. The semantic data used for image processing is also used for behavior analysis and warning, e.g. in case of suspicious activities.

## 7.2 Automatic analysis of humans

Most environments that are interesting to survey contain humans. Currently, automatic analysis of humans in sensor data is limited to passage detectors and simple infrared motion detectors. More complex analysis, like interpretation of human behavior from video, is likely to be performed by human operators. With the recent rapid development in computing power, image processing and computer vision algorithms are now applicable in an entirely different way than a few years ago, especially those for looking at humans in images and video. The benefits of automating analysis of human behavior are mainly robustness. If the video surveillance data is analyzed by a human, a certain error ratio is to be expected due to the human factor, i.e., fatigue and information overload. By automating parts of the process, the human operator can concentrate on interpretation based on the refined information from the human-aware system.

A basic capability of a human-aware system is the ability to detect and locate humans and other moving objects in the video images. This could either be used in a stand-alone manner in the same way a trespassing sensor is used, or for initializing tracking or recognition systems. A method for detection of human motion in video, based on the optical flow pattern, has been developed at FOI. For the purpose of masking out individuals or groups of people from a surveillance video sequence, in order to reveal their activities to a human observer but not their identity, we present each individual in the image masked out with a separate color. An advantage with this technique is that it greatly enhances the human understanding of the activity in the scene.

Our work now is focused on analyzing human motion, see Figure 9. This is to train a system to recognize what can be considered as normal, e.g. that a waist paper basket is emptied every day about 10 o'clock. Hereby, we can detect any deviation from what we have classified as normal, e.g. that a person puts a suspicious object in the same waist paper basket, at ten in the evening, that later on explodes.
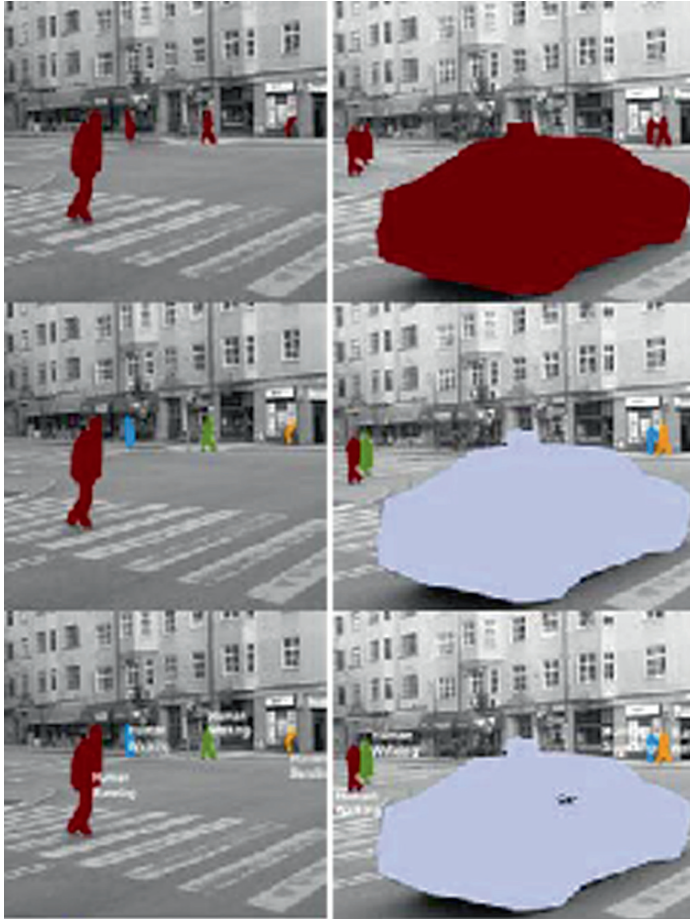
**Fig. 9** An illustration of the process of localization and classification of humans and vehicles to recognize human motion. Foreground and background separation (*upper row*), separating the foreground into distinct objects (*middle row*) and activity recognition from shape (*bottom row*).

Hence, the goal is to understand human motion and human interaction from images, to be able to detect anomalies. We also want to be able to understand an classify actions, which has to be considered in the current role and environment. In the area of analysis of humans in video, the focus has moved from tracking of humans in video [18], via articulated tracking and tracking in 3-D [25, 31], towards analysis of human motion on a higher level [52]. Due to the increased computational power, focus has also shifted from logic-based methods to probabilistic methods that learn from training data. Tools from probability theory and machine learning has enabled the development of efficient and robust methods for, e.g. 3-D articulated tracking [31], sign language recognition [36], face expression recognition [32] and methods for biometric analysis of humans.

# 8 Concluding Remarks

Here we have given some insight in FOI's research on sensor technologies and methods for advanced multifunctional sensor systems. The driving force is brought by the defence capability needs for operations in the urban environments. Urban environment is difficult to monitor, being built up by complex structures and situations to monitor. Small object like mines and IEDs are difficult to find and identify. Moreover, humans are perhaps even more complex to detect, identify or to analyze behavior and intention of either a particular individual or a group. However, we foresee that the ongoing research and technical development of new imaging technologies are important contributions to the Swedish Armed Force's ability to perform several tasks in various terrain and conditions. By developing techniques and methods for object identification and situation analysis, we can provide tools and specifications for future systems.

Examples of new imaging technologies are 3-D imaging laser radars, multi- and hyperspectral imaging and new trends in the radar region of the electromagnetic spectra, such as bi-static SAR. These systems have the ability to penetrate e.g. vegetation, clothing material and certain building structures. It also provides detection and recognition of small or extended target. With the recent rapid development in computing power, image processing and computer vision algorithms are also being developed for applications such as looking at humans in images and video. Moreover, we have emphasized the importance of having proper knowledge and information on the close environment (weather, turbulence etc.), that brings factors that can seriously degrades the performance unless handled correctly. Thus, we need to look at the whole problem at hand in close connection to the sensor/sensors in use. We have also given some application examples on new and approved capabilities from using combined sensor and methods.

Conclusively, using advanced multifunctional sensors and considering the whole chain, from the sensor itself to what the sensor can comprehend, we can provide means to a variety of new and complementary capabilities of importance, such as detecting object and abnormal behavior of humans.

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