

LASER TECHNOLOGIES FOR ON-SITE SURVEILLANCE

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Abstract

There are situations, where video surveillance based on automated scene change detection systems may prove to be ineffective. In some cases, the changes in the image are too small to be properly detected. In others, false alarms are generated without objects (or people) moving. These alarms may be caused by changes in illumination, e.g., a faulty lamp or spurious reflections in places near water pools. Further, the absence of illumination during a blackout (whether it is caused by accident or on purpose) prevents cameras from their surveillance operation. There are high security installations for which it is necessary to introduce reliable, independent and effective sensors that can keep the surveillance work even during a blackout. Laser range scanners are electronic instruments measuring the distance from the instrument itself to the outside world along a specific direction. The type of the instrument to use depends on the range of distances to measure. The deflection of the laser beam (e.g., using a rotating mirror) enables the acquisition of the distance profiles of the surrounding premises in a very short time. Alarms are generated by comparing acquired distance measurements (organized as profiles – 2D Laser Surveillance, or in clouds of points – 3D Laser Surveillance) with previously acquired references. This is most effective for real-time detection of even small changes in the environment. The main feature of laser surveillance system is that it measures distances between the instrument itself and the real world, rather than measuring only appearance as video surveillance systems do. As such, any physical change occurring within the field of site of the laser instrument is immediately measured and detected. The fact that laser systems are self-illuminating and do not depend on the external illumination make them quite effective to work during blackouts. The paper introduces laser surveillance and shows how such systems complement well already existing video surveillance systems.

1. INTRODUCTION

Surveillance techniques are based on the detection of changes. These changes can be caused by physical modifications to the environment itself, or caused by moving objects, including people. Small changes in illumination (e.g., a faulty light bulb, or daylight changes) modification should not be considered as relevant changes. Different situations can occur:

- (i) the object (including people) moves within the surveyed area;
- (ii) the object enters the surveyed area;
- (iii) the object leaves the surveyed area;
- (iv) the environment is modified

Two factors should be taken into consideration when designing a surveillance system: a) the time lapse between two surveillance measurements (i.e., sample period), and b) the detection of the change itself. The sample period should be short enough to make sure that all changes are registered and documented. Indeed, the existence of good data is a must for the design of a reliable surveillance system.

The second aspect involves the capability of the used surveillance sensor to generate data that can be used to detect Safeguards relevant changes. These data are stored locally and eventually transmitted to the headquarters of Safeguards inspectorates. A future trend is to pre-process on-site the surveillance data and trigger recording systems to make sure that all relevant events are registered and documented. A second trend is to increase the effectiveness of on-site surveillance systems by bringing together data from multiple independent sensors, preferably operating on different physical principles. This

procedure increases confidence since limitations on one type of sensor can easily be complemented by the characteristics of other types of sensors.

Many surveillance systems are based on the installation of video cameras at selected points in nuclear plants. Scene change detection is achieved by analyzing the images acquired by one or more cameras installed on-site. These techniques are effective in detecting objects moving within the surveyed area. There are situations, however, where video surveillance may prove to be unsatisfactory. In some cases, the changes in the image are too small to be properly detected with automated video scene change detectors. In other cases, alarms are generated without objects (or people) moving. These false alarms can be caused by changes in illumination, e.g., a faulty lamp or spurious reflections in places near water pools. Further, the absence of illumination during a blackout (whether it is caused by accident or on purpose) prevents cameras from their surveillance operation. There are high security installations for which it is necessary to introduce reliable, independent and effective sensors that can keep the surveillance work even during a blackout.

Laser range scanners are electronic instruments measuring the distance from the instrument itself to the outside world along a specific direction. The type of the instrument to use depends on the range of distances to measure. Indeed, whereas for large distances (e.g., between 1 and 200m) it is possible to use time-of-flight instruments, for short distances (e.g., from a few centimetres to about 1.5m) a triangulation laser striping system is more appropriated. The deflection of the laser beam (e.g., using rotating mirrors) enables the acquisition of the distance profiles (or matrices) of the surrounding premises in a very short time.

The main feature of a laser range finder is that it measures distances between the instrument itself and the real world, rather than measuring appearance as video surveillance systems do. As such, any physical change occurring within the field of site of the laser instrument is immediately measured and detected.

This paper introduces laser technologies for distance-measurement and illustrates how they can be used as a complement of traditional video surveillance systems.

2. LASER TECHNOLOGIES FOR DISTANCE MEASUREMENTS

The range of distances to measure determines the laser technologies to be used. For short distances, i.e., from 5cm to 150cm, laser triangulation (sometimes also referred as laser-striping) equipment is more appropriated. This type of instruments is better dedicated to identification, verification or authentication purposes, in particular of Safeguards seals and labels. For wide-scene surveillance, laser range finders are preferably used. This corresponds to a range of distances between 1.5m to 200m.

2.1. Laser Triangulation Equipment

The basis for triangulation consists of the triangle formed by a distinct point on the surface of the object, one laser pointer and a camera. A laser stripe is scanned in one dimension across the scene. Commonly, a cylindrical lens transforms a low power laser beam into a plane, which is projected onto the object in the field of view of the instrument (Figure 1a). This plane marks a profile-line at the object. All the points of the line are thus marked optically. Looking to the profile-line from the viewpoint of the camera, the line appears to be curved in the image. The lateral displacement shows the elevations and indentations of the object's surface. If the position of the light source, the orientation of the light plane, and the position and orientation of the camera are all known, a vision system can calculate the position of each of the points on the bright line in three dimensions (Figure 1b). For each profile line one picture must be captured. Figure 1c shows a commercially available triangulation based 3D laser scanner.

Table 1 gives an idea of the precision of the distance measurements when a triangulated laser striping technique is used. It should be noted that overall, the precision decreases with the object distance and increases with the spatial resolution of the CCD sensor used in the TV camera.

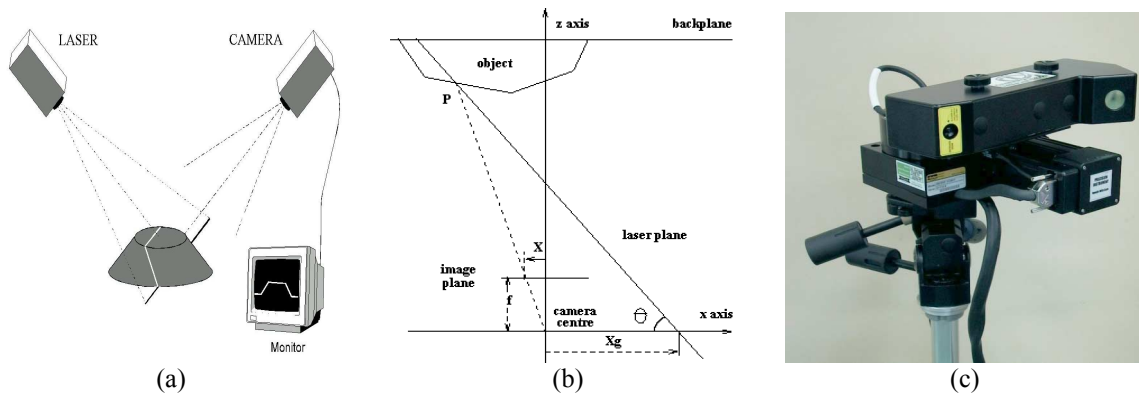


Figure 1: a) Triangulation sensor; b) The geometry of triangulation; c) Triangulation based Laser Scanner

Object Distance (cm)	2.5	8	17	36	120
Precision (μm)	10	25	45	55	210

Table 1: Measurement precision for different object distances

2.2. Laser Range Finders

A laser range finder (LRF) is an electronic instrument that measures the distance between the instrument itself and the first object encountered by the emitted laser beam, along a given orientation (i.e., azimuth and elevation). By measuring distances directly, it is possible for LRFs to distinguish between changes in the environment from changes in illumination. The horizontal deflection of the laser beam (e.g., using a rotating mirror) enables the acquisition of horizontal distance profiles of the surrounding premises in a very short time. The comparison of this profile with a reference profile is most effective for detecting in real-time any small changes in the environment.

There are some unique characteristics of laser range systems, which make them effective in Safeguards applications. The characteristics include:

- Self-illuminating: the instrument generates its own light illuminating source and thus can operate during blackouts;
- Independence of ambient lighting: the instrument works well both in dark and illuminated conditions;
- High accuracy distance measurements: typically about 1 cm for a 100 m range; Short range scanners: better than 0.5 mm for a 1.5 m range.
- Fast data acquisition: typically more than 10,000 distance measurements per second;
- Measurement of the distance of an object, its size, speed and direction of motion: this information can be most useful for distinguishing normal moves from security (or safety) related ones;
- Stand-alone operation: the instrument may be designed to work on its own, with no requirement to be connected to a host computer;
- Wide scanning angle, typically, 360° by 90° .
- High spatial resolution, i.e., number of distance measurements per solid angle (typical: more than 10 samples per degree).
- Easy interfacing: typically RS232, Parallel port or Ethernet.

These features coupled with simple and efficient alarm detection algorithms make laser range systems a natural complement to already installed surveillance systems.

A LRF is characterized by the fact that it measures distances as a direct consequence of the propagation delay of an electromagnetic wave, i.e., a small aperture, low divergence, and laser beam. Figure 2 represents a general description of the working principle of a LRF. Table 2 includes some definitions related to its practical use.

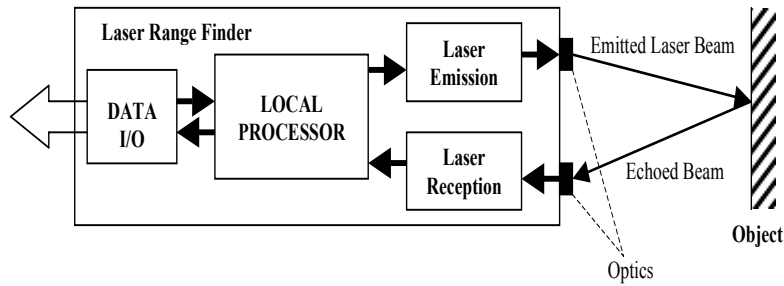


Figure 2: General schematic of a LRF



Figure 3: 3D Laser Range Scanner

Parameter	Description
<i>Integration Time</i>	Related to the number of individual internal distance samples made for each measurement. The final result is normally an average of multiple samples, decreasing therefore the noise associated to each single measurement.
<i>Depth Resolution</i>	Measures the ability to distinguish two objects at slightly different distances. The depth resolution is related to the instrument's dynamic range, i.e., to the noise level of the output.
<i>Reflectance Measurement</i>	Corresponds to the reflectance of the target object (i.e., the reflected energy) at the wavelength of the laser beam (normally in the infrared band).
<i>Spatial Resolution</i>	Measures the ability to distinguish two targets at different distances when placed side by side. A factor to a high spatial resolution is the small aperture and low divergence of the laser beam. It is very much dependent on the laser beam scanning mechanism
<i>Ambiguity Interval</i>	Refers to the distance interval where a distance measurement is unequivocally made. It is a parameter specific to continuous wave systems (see below).

Table 2: Description of some parameters characterizing a LRF

2.3. Laser Range Scanners

An LRF measures distances along the orientation of the laser beam. To measure a horizontal distance profile, or to map the distances to the complete environment (i.e., range image), requires the deflection of the laser beam. This is achieved either by moving the instrument itself or by deflecting the laser beam with a computer-controlled mirror. Most available laser scanners work with spherical coordinates. Table 3 describes some features for selecting a laser range scanner. Figure 4 shows a commercially available 2D laser range scanner. In Figure 4 b) it is possible to see a mirror placed at a 45° angle, which in operation rotates around a vertical axis. This deflects the vertical laser beam and transforms it into a horizontal surveillance plane. Figure 3 shows a commercially available 3D laser range scanner. The laser beam is deflected vertically (elevation) by means of a rotating mirror prism. The rotation of the top part of the instrument changes the azimuth.

3. LASER SURVEILLANCE SYSTEMS

3.1. 2D Laser Surveillance

Given a 2D reference horizontal distance profile, any changes to this profile can be associated to the existence of intruding objects. Incoming data is thus analysed in real-time. Profile differences cause the generation of an alarm. It is therefore useful to “understand” what is an object. Within the current discussion, an object is “something” detached from the background. This is to say that there is a strong distance discontinuity between the object itself and the background, as illustrated in Figure 5.

Parameter	Description
<i>Horizontal Resolution</i>	Refers to the minimum horizontal angle between two consecutive range measurements. It is normally dependent on the mechanical design.
<i>Vertical Resolution</i>	Refers to the minimum vertical angle between two consecutive range measurements. It is normally dependent on the mechanical design.
<i>Max. Horizontal Speed</i>	Maximum scanning speed along a scan with a fix elevation. Some instruments allow this speed to be programmed.
<i>Max. Vertical Speed</i>	Maximum scanning speed along a scan with a fix azimuth. Some instruments allow this speed to be programmed.
<i>Max. Horizontal Scanning Angle</i>	Refers to the widest horizontal scanning angle available (typically 360°)
<i>Max. Vertical Scanning Angle</i>	Refers to the widest vertical scanning angle available (typically between 90° and 180°).
<i>Programmable field of view</i>	Refers to the possibility of letting the user specify interactively the horizontal and vertical angle limits for the scan.

Table 3: Description of some parameters characterizing a laser range scanner.

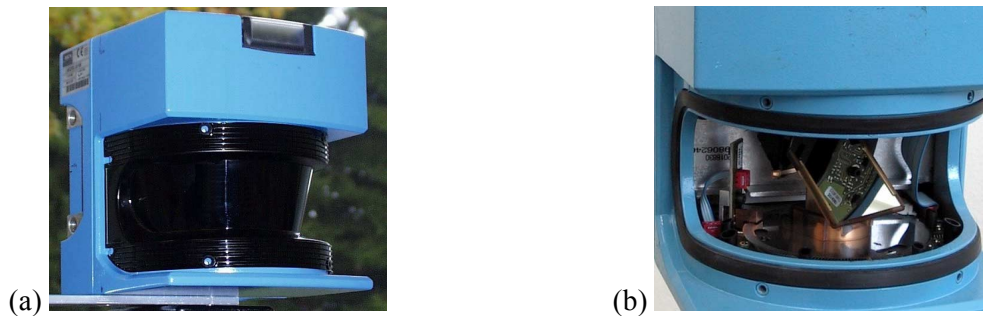


Figure 4: 2D Laser Range Scanner; a) Complete system; b) Rotating mirror.

The distance of an object to the measuring instrument is easily extracted from the distance profile, as the distance minimum, as illustrated in Figure 6. The size of the object involves some processing in what concerns determining the object extremities. This is obviously dependent on the expected object shape and pose. Generally speaking, the extremities of the object can be found whenever strong distance discontinuities are found, i.e., those points where the laser beam “jumps” from the object to the background surface.

There are many factors influencing the accuracy with which the dimensions of an object can be determined. Above all, it depends on the sampling resolution, i.e., the number of samples per angular unit. More details can be found elsewhere [1].

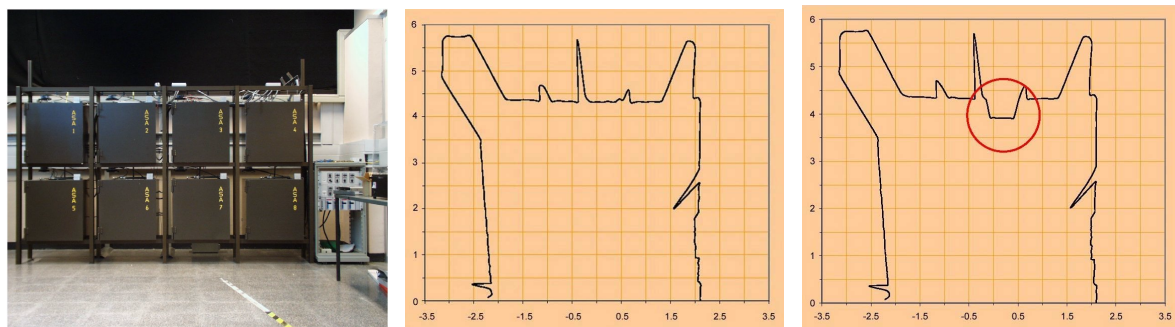


Figure 5: Distance Profiles measured with SICK laser scanning system
a) Environment under surveillance; b) Reference profile; c) Detection of a change in the environment.

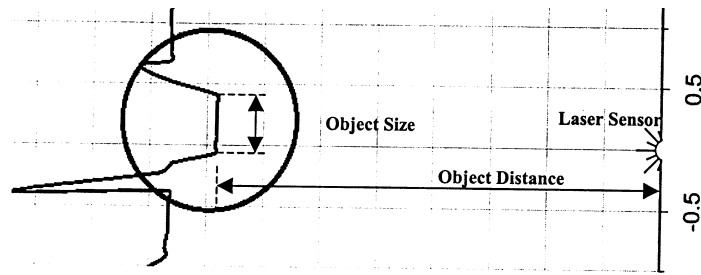


Figure 6: Measuring the distance and size of an object [Refer to Figure 5]

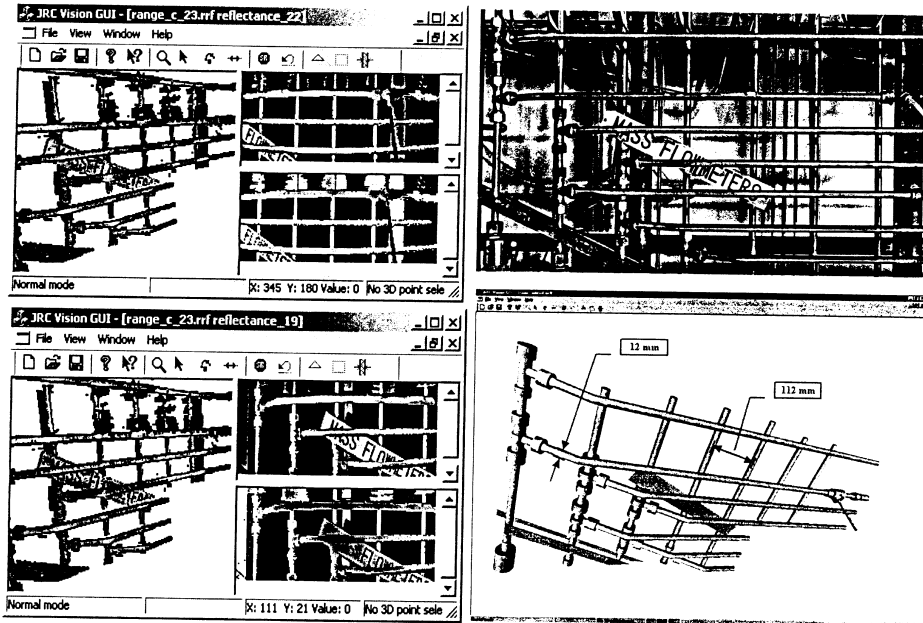


Figure 7: Cloud of points of TAME pipe work, and corresponding CAD model

3.2. 3D Laser Surveillance

2D laser surveillance systems can already detect most of the changes occurring in a Safeguards area. If the change, however, occurs below or above the surveillance plane, it will not be obviously detected by the laser system. There are two alternatives:

- (i) Install multiple 2D laser surveillance systems [either parallel or with intersecting orientations]
- (ii) Introduce 3D laser surveillance

3D laser surveillance is achieved by deflecting the laser beam in several azimuths and orientations. In the end, the system builds up a *cloud of points* representing the distances to the environment in the field of view. This cloud of points makes an exact spatial representation of the environment being surveyed, all equipment and objects [2,3]. Figure 7 illustrates the cloud of points obtained when measuring a pipe work inside a plant. Since the model is based on the measurement of the real distances it is possible to automatically extract any changes that have occurred since a previous inspection [4].

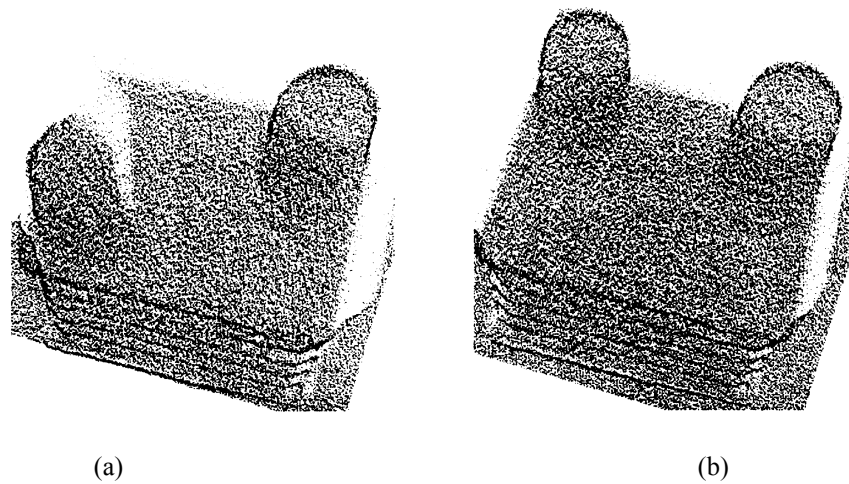


Figure 8: Cloud of 3D points of two containers:
 a) initial position; b) new position after having moved backward the left container

3D laser surveillance algorithms analyse the 3D data collected from the real world by comparing newly incoming data with a reference 3D mapping [5]. Distance discrepancies above a given absolute tolerance (e.g. a few centimetres) are immediately detected and an alarm generated. Figure 8 illustrates some measurements made in our laboratories with two containers placed on top of a box. The left container is slightly moved backwards and that is visible in the new cloud of points. For the sake of comparison, the move of the container would not be sufficient for an automatic scene change detection system trigger an alarm when the surveillance camera is looking horizontally at the scene.

4. INTEGRATED ARCHITECTURE FOR SURVEILLANCE SYSTEMS

Figure 9 show two types of possible architectures for a combined laser and video Surveillance system.

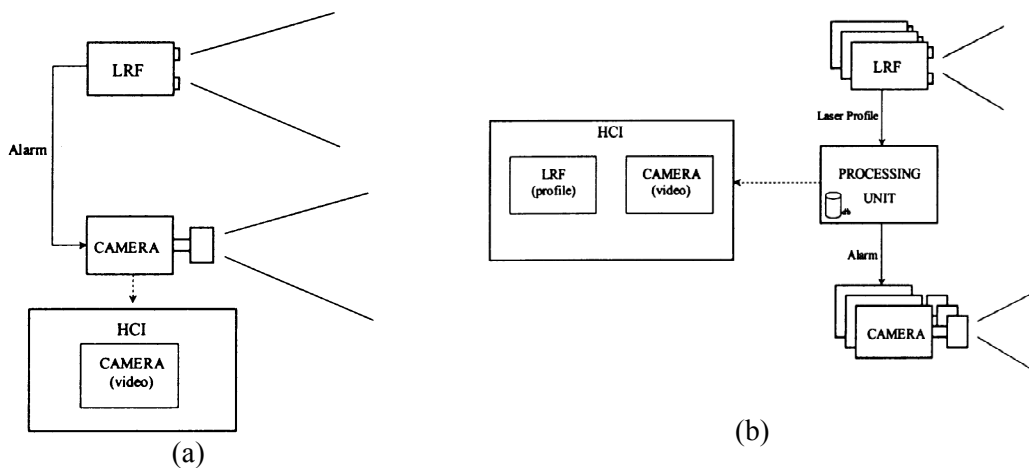


Figure 9: Architecture for a combined laser and video Surveillance system

In Figure 9a the laser scanner has on its own memory a reference contour (i.e., set-up by a Safeguards inspector) that is compared in real-time with the current profile from the area being surveyed. Whenever there is a difference between the two profiles an alarm is generated into the camera and a snapshot or a sequence of time stamped snapshots (e.g. N images before and M images after the alarm) are saved in the camera module. In this architecture the profile generating the alarm is lost and the only register are the pictures from the video camera. The main advantage of this architecture is its simplicity and low cost. A more sophisticated architecture is shown in Figure 9b. In this case all distance measurements are processed on an external processing unit (e.g., small embedded, industrial or palmtop PC) allowing for intelligent algorithms for alarm generation and for the use of multiple

laser scanners and multiple cameras. All profiles generating the alarms are stored in the processing unit and can be checked in parallel with the video image sequence during the review process. Another main advantage of this architecture is the independence from hardware suppliers mainly in what concerns laser scanner manufacturers. Both architectures can be easily interfaced with already approved camera surveillance systems.

5. DISCUSSION AND CONCLUSIONS

Technologies for distance measurements are achieving a good degree of maturity. Indeed, it has been possible to witness a big increase in the number of products (and manufacturers). This is particularly true for 3D laser range scanners, where 6 different models were introduced in the last 3 years. Further, improvements in the basic electronic components led to better depth resolutions, precisions and accuracies.

Laser technologies for distance measurement are non-intrusive in the sense the equipment has reasonable small dimensions and can be placed at traditional Safeguards observation points. Further, the fact that the laser beams are low power and eye-safe does not interfere with normal operation work, including the circulation of people.

The technologies are self-illuminated and operate well with any external illumination. These properties are important for building surveillance systems capable of continuous operation undisturbed by factors such as temporary blackouts.

Given a specific surveillance problem it is possible to make a careful selection of the components to be used, totally adapted to requirements, e.g., range of distances, field of view, speed, etc.

To conclude, it is possible to say that spatial (i.e., distance) measurements can be an important aspect in designing effective and highly secure Safeguards systems. Indeed, it is based on the actual contents of the environment rather than on its visual appearance projected onto a CCD sensor. The complementarities of these two aspects can constitute a major improvement to today's Safeguards systems.

6. REFERENCES

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