People counter based on fusion of reflected light intensities from an infrared sensor array

Heinrich Ruser, Vladislav Pavlov

Institut für Mess- und Automatisierungstechnik (IMA)
Universität der Bundeswehr München
Werner-Heisenberg-Weg 39
D-85577 Neubiberg
heinrich.ruser@unibw.de
vladislav.pavlov@unibw.de

Abstract: An effective low-cost solution to determine characteristic features of objects from a simple infrared diode array, working on the reflection light scanner principle and using the fusion of amplitude information to detect and characterize objects, has been designed. Essentially, two arrays of several emitter-receiver pairs are mounted on opposite sides of the area of observation (e.g. a conveyer, doorway etc.), enabling the estimation of the size of a moving object in different dimensions and its reflection coefficient. The results show that from simple light intensity measurements, a variety of objects can be reliably recognised. As an example, the problem of determining the number of persons traversing doorways is addressed. With the proposed array processing, people can be recognised correctly and are well separable from other echoes (motion of hands etc.), making the performance far more reliable than that of ordinary light barriers.

1 Introduction

For presence detection and counting systems, numerous technical solutions based on a variety of principles (mechanical, ultrasound, radar, thermal, optical, capacitive etc.) are available and still refined (e.g. [1-4]). A frequent task is to count the number of persons getting into or out of a room. Contrary to common impression, this is not at all a simple task. As the experience shows, commonly used double-beam light barriers do not perform very well (see Section 4). Incidental errors cumulated over time make such devices almost useless for certain applications (like occupancy-driven heating in low-energy homes). The described sensor consists of small infrared (IR) diode arrays working on a reflection light scanner principle. Their non-linear behaviour and high dependence on the reflectivity on the sensed object has prevented their application as range sensors. Based on a fusion of the light intensities measured at the different receiver locations in the array and making use of the Phong illumination model [5,6], these limitations are overcome. Object properties like size, location, material, velocity of motion can be classified and the number of people in the area of observation is reliably determined.

2 Infrared array

A sensor array consists of N pairs of a highly directional IR emitter diode and a shielded sensitive phototransistor, located close to one another. For the described application, a configuration with two arrays of N=3 pairs mounted vertically face-to-face at a doorway has been examined, see Fig. 1. The pairs are inclined outwards in order to enlarge the (nearly horizontal) area of observation. The required range d_{max} to cover the distance between both arrays is approx. 40 cm what is still challenging for the detection of dark and ribbed materials. Pulsed IR emitter diodes SFH 415-U (Siemens, 930-970 nm) with a 12° 3dB beam angle and photo diodes TSL-252R (TAOS Corp., 950 nm) with integrated preamplifier were chosen. The emitters are driven at successive instances, excluding mutual influence. In Fig. 2, the emitted and received pulses are shown for one and all six sensors. The pulse length is 8 s, charging the emitter diode to maximum. Due to receiver delays, the amplitude of the received pulse is detected approx. 1 s after the emitter pulse ends. The period between two emitting pulses is 36 s. The impulse forming and processing is performed on a 8bit PIC microcontroller.

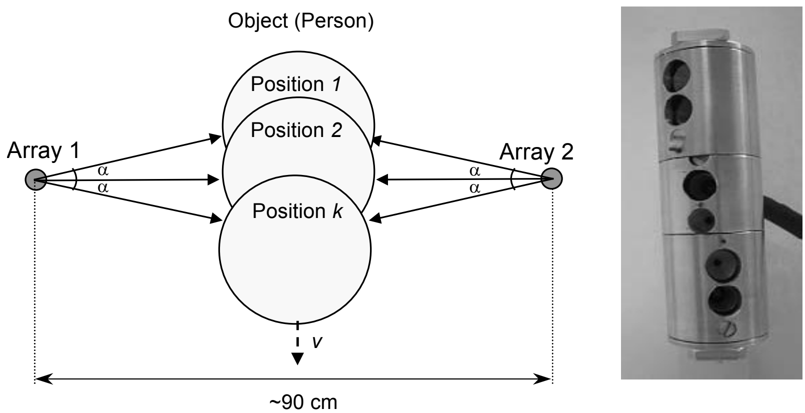

Figure 1: Basic configuration of the detector (top view) and view of a sensor array consisting of three emitter/receiver diode pairs

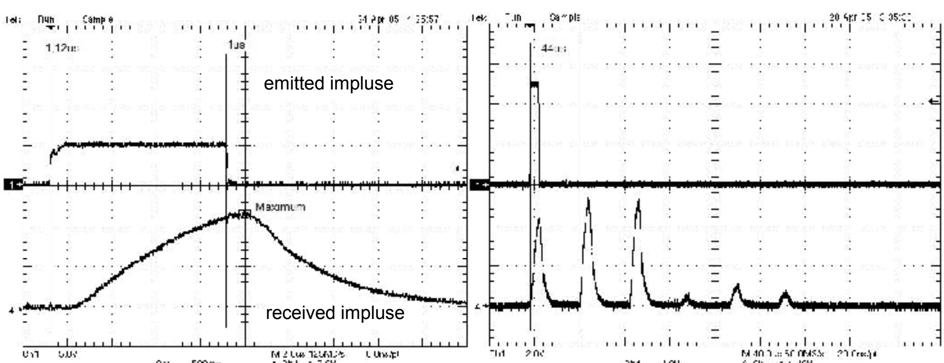

Figure 2: Transmitted pulse and received pulses for 1 sensor (left) and for 6 sensors (right).

3 Object characterization

The intensities of the light reflected to each sensor in the array depend on the distance and direction of the light source from the reflector and its surface characteristics such as colour and reflectance properties. Light striking an object's surface is partly absorbed and reflected (diffuse reflection and specular reflection). A simple model for the illumination intensity I is [7]

$$I = I_a k_a + \frac{1}{d^n} I_p k_d \cos \vartheta \tag{1}$$

where I_a - ambient light intensity, k_a - ambient light reflected, d - distance to the light source, n – loss factor, depending on the surface size and roughness: n = 2..4 (n=2 for a large surface, n=4 for a point reflector), I_p - point light source intensity, k_d - surface reflection coefficient ($0 \le k_d \le 1$), φ - angle between direction of incidence of light and the surface normal. The relationship $I = I_p k_d \cos \vartheta$ applies due to *Lambert's cosine law* meaning the reflected intensity depends on the light source's orientation relative to the surface but is independent of the viewing direction.

In order to establish models for the functions *I(d)* and *I(ϑ),* the intensities of the received signals have been measured for a variety of materials with different colours and surfaces. In Fig. 3, material-dependent intensities as a function of distance are given, as well as measured intensities as a function of the positions of the reflecting surface relative to the receiving photo diodes sensor of an array.

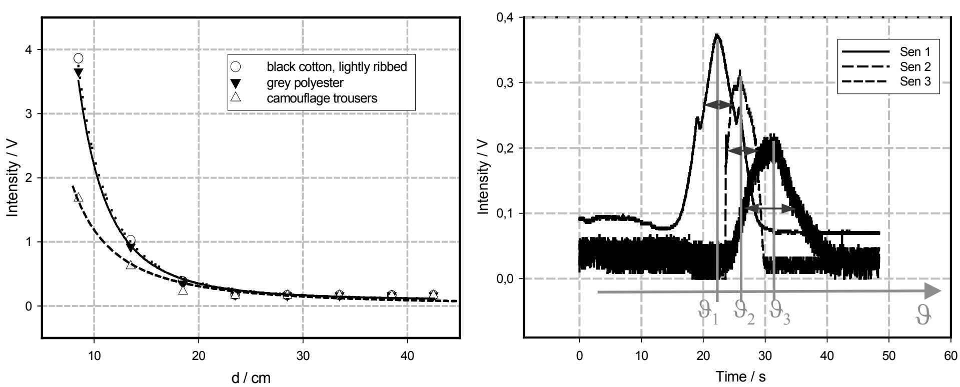

Figure 3: Intensities as a function of object distance from the light source for different materials (left) and as a function of the angles of incidence corresponding to the time instants in case of a reflector moving across the detector array with constant velocity (right)

Before classification, some reasonable assumptions about the objects of interest have to be made. For a person detector, such assumption will be that in the horizontal plain the object will be roughly a circle with a radius R. In order to obtain the size and the reflection coefficient of an observed object, the received intensities I_j from all sensors j from the array can be modelled as

$$I_j = I_j(x, y, \overline{R}, k_d) \quad , j = 1..6 \tag{2}$$

with (x, y) - central point of the circle, $\overline{R}$ - mean radius. Hence, from the 6 intensities $I_1,...,I_6$, a system of 6 equations is obtained, from which the unknown parameters x, y, $\overline{R}$ and k_d can be calculated. Later, an additional parameter, e.g. the form coefficient *a,* can also be determined from this set of equations. (For the regular circle, *a* is set to 1 for all sensors.) Hence, yet another property of the object can be deduced from the same measurements.

Simulations using (2) were carried out to calculate the expected amplitudes depending on the object's location towards every sensor in the array. In Fig. 4, examples of light intensities reflected from the object's surface at intersections with the light beams along a given trajectory are shown. From the combined processing of these amplitudes as a function o time the properties of the object are evaluated.

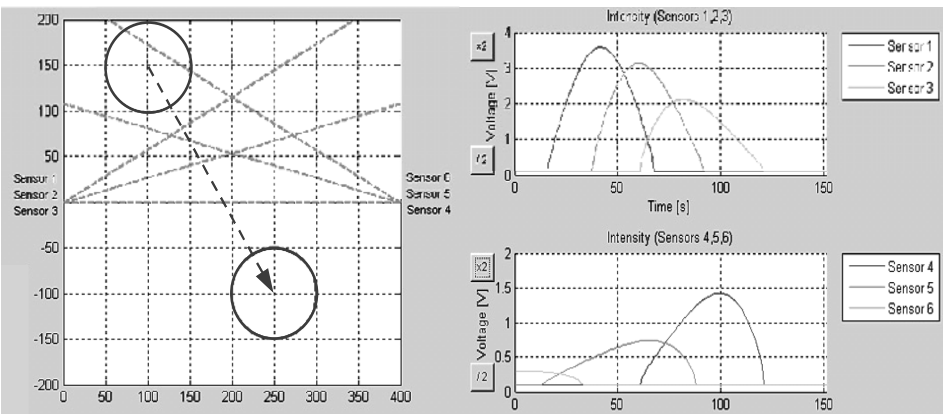

Figure 4: Trajectory of motion of a cylindrical object and light intensities reflected from the object's surface received at every sensor

4 Reliable person counter

The IR array has been mounted at the entrance of a room. The performance of the proposed device has been compared with a commercial IR double-light barrier (SICK W50) at the same doorway, see Fig. 5. The sensor-specific distance functions

$$d_j = f^{-1}(I_j) \quad , j = 1..6 \tag{3}$$

have been laid down in look-up tables for a fast assessing of the size of the reflecting objects. While the commercial sensor can be easily fooled (it shows numerous missed and double countings, esp. when a person moves his/her arms or turns around in the doorway), the described simple IR array showed no false reading.

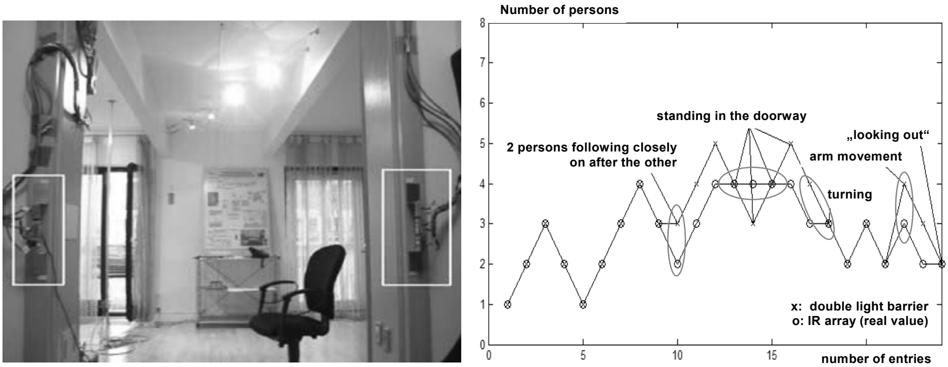

Figure 5: People counter mounted at a door and results compared with a double-beam light barrier

5 Conclusions

A solution for counting persons traversing doorways has been presented. A low-cost infrared array working on a reflection light scanner principle is used. The size, position and reflectivity of objects can be deduced just from a series of light intensities obtained by a number of active IR sensors when a person moves through the area of observation. The reliability has been shown to be far better than that of commonly used light barriers. With this ‘low-pixel image processing’ several other applications of reliable object recognition, e.g. in robotics can be addressed.

References

[1] Albiol, A., Mora, I., Naranjo V.: Real-time high-density people counter using morphological tools, IEEE Trans. Intell. Transportation, Vol. 2/4, 2001

[2] Korba, L., Elgazzar, S., Welch T.: “Active infrared sensors for mobile robots”, IEEE Trans. Instrum. Meas. 43/2, 1994

[3] A.M. Sabatini et al.: “A low-cost, composite proximity sensor array combining ultrasonic and infrared proximity sensors”, Proc. IEEE/RSJ Conf. on Intell. Robots and Systems (IROS’95), Pittsburgh, 1995

[4] Pavlov, V., Ruser, H., Tränkler, H.-R., Böttcher, J.: Multi-electrode capacitive person detector using wavelet denoising, IEEE Conference on Multisensor Fusion and Integration (MFI’06), 3.-6.Sept. 2006, Heidelberg

[5] Novotny, P.M., Ferreier, N.J.: Using infrared sensors and the Phong illuminations model to measure distances, IEEE Int. Conf. on Robotics and Automation, Detroit, 1999

[6] Aytac, T., Barshan, B.: “Differentiation and localization of target primitives using infrared sensors“, Proc. IROS’02, Lausanne, 2002

[7] Besl, P.J.: Active Optical Range Imaging Sensors. In: J. Sanz (Ed.): *Advances in Machine Vision*, New York: Springer, 1999