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Target differentiation with simple infrared sensors using statistical pattern recognition techniques

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Abstract

This study compares the performances of various statistical pattern recognition techniques for the differentiation of commonly encountered features in indoor environments, possibly with different surface properties, using simple infrared (IR) sensors. The intensity measurements obtained from such sensors are highly dependent on the location, geometry, and surface properties of the reflecting feature in a way that cannot be represented by a simple analytical relationship, therefore complicating the differentiation process. We construct feature vectors based on the parameters of angular IR intensity scans from different targets to determine their geometry and/or surface type. Mixture of normals classifier with three components correctly differentiates three types of geometries with different surface properties, resulting in the best performance (100%) in geometry differentiation. Parametric differentiation correctly identifies six different surface types of the same planar geometry, resulting in the best surface differentiation rate (100%). However, this rate is not maintained with the inclusion of more surfaces. The results indicate that the geometrical properties of the targets are more distinctive than their surface properties, and surface recognition is the limiting factor in differentiation. The results demonstrate that simple IR sensors, when coupled with appropriate processing and recognition techniques, can be used to extract substantially more information than such devices are commonly employed for.

Keywords: Target differentiation; Geometry differentiation; Surface differentiation; Statistical pattern recognition; Feature extraction; Infrared sensors; Optical sensing

1. Introduction

Target differentiation is of considerable interest for intelligent systems that need to interact with and operate in their environment autonomously. Such systems rely on sensor modules which are often their only available source of information. Since the resources of such systems are limited, the available resources should be used in the best way possible. It is desirable to maximally exploit the capabilities of lower cost sensors before more costly and sophisticated sensors with higher resolution and higher resource requirements are employed. This can be achieved by employing better characterization and physical modeling of these sensors.

Although ultrasonic sensors have been widely used for object detection and ranging, they are limited by their large beam width and the difficulty of interpreting their readings due to specular, higher-order, and multiple reflections from surfaces. Furthermore, many readily available ultrasonic systems cannot detect objects up to 0.5 m which corresponds to their blank-out zone. Therefore, in performing tasks at short distances from objects, use of inexpensive and widely available sensors such as simple infrared detectors are preferable to employing ultrasonic sensors or more costly laser and vision systems. Furthermore, in a sensor-fusion framework, IR sensors would be perfectly complementary to these systems which are not suitable for close-range detection. Infrared detectors offer faster response times and better angular resolution than ultrasonic sensors and provide intensity readings at nearby ranges (typically from a few centimeters up to a meter). The intensity versus range characteristics are nonlinear and dependent on the properties of the surface and environmental conditions. Consequently, a major problem with the use of simple IR detectors is that it is often not possible to make accurate and reliable range estimates

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based on the value of a single intensity return because the return depends on both the geometry and surface properties of the encountered object. Likewise, the surface properties and the geometry of the target cannot be deduced from simple intensity returns without knowing its position and orientation.

Due to single intensity readings not providing much information about the target properties, recognition capabilities of IR sensors have been underestimated and underused in most work. To achieve accurate results with these sensors, their nonlinear characteristics should be analyzed and modeled based on experimental data. Armed with such characterization and modeling, their potential can be more fully exploited and their usage can be extended beyond simple tasks such as counting and proximity detection. The aim of this study is to maximally realize the potential of these simple sensors so that they can be used in more complicated tasks such as differentiation, recognition, clustering, docking, perception of the environment and surroundings, and map building. For this purpose, we employ various statistical pattern recognition techniques (parametric density estimation, mixture of normals, kernel estimator, k-nearest neighbor (k-NN), artificial neural network, and support vector machine classifiers) to classify targets with different geometries, different surface properties, and the combination of the two. With the approaches considered in this paper, we can differentiate a moderate number of targets and/or surfaces commonly encountered in indoor environments, using a simple IR system consisting of one emitter and one detector. We provide a comparison of these approaches based on real data acquired from simple IR sensors. The results indicate that if the data acquired from such simple IR sensors are processed effectively through the use of suitable techniques, substantially more information about the environment can be extracted than is commonly achieved with conventional usage.

This paper is organized as follows: In Section 2, we make an introduction to IR sensing and introduce the IR sensor and the experimental set up used in this study. Section 3 summarizes our earlier work on target differentiation with IR sensors. Section 4 provides differentiation of planar surfaces based on parametric modeling of the IR intensity scans. In Section 5, statistical pattern recognition techniques based on the parameterized model are employed for geometry/surface-type determination. A comparison of the different techniques considered is provided in Section 6 together with a discussion. Concluding remarks are made and directions for future research are provided in the same section.

2. Infrared (IR) sensing

Most work on pattern recognition involving infrared deals with the recognition or detection of features or targets in conventional two-dimensional (2D) images. Examples of work in this category include face identification [1], automatic vehicle detection [2], automatic target recognition [3] and tracking [4], detection and identification of targets in background clutter [5], remote sensing, and automated terrain analysis [6]. We note that the differentiation techniques employed in this paper are different from such operations performed on conventional images [7] in that here we work not on direct "photographic" images of the targets obtained by some kind of imaging system, but rather on angular intensity scans obtained by rotating a point sensor. The targets we differentiate are not patterns in a 2D image, but rather objects in space, exhibiting depth, at different positions with respect to the sensing system.

Simple IR sensors are used in robotics and automation, process control, remote sensing, and safety and security systems. More specifically, they have been used in object and proximity detection [8], counting [9], distance and depth monitoring, floor sensing, position measurement and control [10], obstacle/collision avoidance [11], and map building [12]. Other applications include door detection and mapping of openings in walls [13], as well as monitoring doors/windows of buildings and vehicles, and "light curtains" for protecting an area. IR sensors have also been used for automated sorting of waste objects made of different materials [14].

In earlier work [15], we developed a novel range estimation technique which is independent of surface type since it is based on the position of the maximum intensity value instead of surface-dependent absolute intensity values. An intelligent feature of the system is that its operating range is made adaptive based on the maximum intensity of the detected signal.

The IR sensor [16] used in this study is employed in the active mode and consists of an emitter and detector and works with 20–28 V DC input voltage. The emitted light is back-scattered from the target and an analog output voltage, proportional to the reflected light, is measured at the detector. The detector window is covered with an IR filter to minimize the effect of ambient light on the intensity measurements. Indeed, when the emitter is turned off, the detector reading is essentially zero. The sensitivity of the device can be adjusted with a potentiometer to set the operating range of the system. The maximum range of operation of the sensor is about 60 cm. The IR sensor (see Fig. 1(a)) is mounted on a 12 in rotary table [17] to obtain angular intensity scans from the targets. A photograph of the experimental setup and its schematics can be seen in Figs. 1(b) and 2, respectively. Basically, the IR sensor, rotating on the platform, acquires angular scans from targets positioned differently. The different target types are a plane, a 90° corner, a 90° edge, and a cylinder of radius 4.8 cm, each with a height of 120 cm and with cross-sections given in Fig. 3. All targets are made of unpolished oak wood. The horizontal extent of all targets other than the cylinder is large enough that they can be considered infinite and thus edge effects can be ignored. Some example angular intensity scans acquired from these targets are provided in Fig. 4.

3. Review of our earlier work on differentiation with infrared

3.1. Rule-based target differentiation

As a first attempt in differentiation of targets with simple IR sensors, we employed a rule-based approach which is based on