# RULE-BASED TARGET DIFFERENTIATION AND POSITION ESTIMATION FOR INDOOR MOBILE ROBOTICS APPLICATIONS

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## ABSTRACT

This study investigates the use of low-cost infrared sensors in the differentiation and localization of commonly encountered target primitives in indoor environments, such as planes, corners, edges, and cylinders. The intensity readings from such sensors are highly dependent on target location and properties in a way which cannot be represented in a simple manner, making the differentiation process difficult. In this paper, we propose the use of angular intensity scans from two infrared sensors and present a rule-based algorithm to process them. The algorithm can achieve position-invariant target differentiation without relying on the absolute return signal intensities of the infrared sensors. The method is verified experimentally. Planes, 90° corners, 90° edges, and cylinders are differentiated with correct rates of 90%, 100%, 82.5% and 92.5%, respectively. Targets are localized with average absolute range and azimuth errors of 0.55 cm and 1.03°. The method demonstrated shows that simple infrared sensors, when coupled with appropriate processing, can be used to extract a significantly greater amount of information than that which they are commonly employed for.

## 1. INTRODUCTION

Target differentiation and localization is of importance in robotics applications where there is need to identify targets and their positions for autonomous operation. In this paper, we consider the use of infrared sensors for this purpose. Infrared sensors are inexpensive, practical and widely available devices. Simple range estimates obtained with infrared sensors are not reliable because the return signal intensity depends both on the geometry and the surface properties of the target. On the other hand, from single intensity measurements, it is not possible to deduce the geometry and surface properties of the target without knowing its distance and angular location. In this study, we propose a scanning mechanism and a rule-based algorithm based on two infrared sensors to differentiate targets independent of their locations. The proposed method has the advantage that it does not require storage of any reference templates since the information necessary to differentiate the targets are completely embodied in the decision rules.

Application areas of infrared sensing include robotics and automation, process control, remote sensing, and safety and security systems. More specifically, infrared sensors have been used in simple object and proximity detection, floor sensing, position control [Butkiewicz, 1997], obstacle/collision avoidance [Lumelsky and Cheung, 1993; Lopez et al., 2001], and machine vision systems [Everett, 1995]. Infrared sensors are used in door detection [Beccari et al., 1998], mapping of openings in walls [Warszawski et al., 1996], as well as monitoring doors/windows of buildings and vehicles, and "light curtains" for protecting an area. In [Lopez et al., 2001], an automated guided vehicle detects unknown obstacles by means of an "electronic stick" consisting of infrared sensors, using a strategy similar to that adopted by a blind person. In [Flynn, 1998], infrared sensors are employed to locate edges of doorways in a complementary manner with sonar sensors for mobile robot navigation. Other researchers have also dealt with the fusion of information from infrared and sonar sensors [Barberá et al., 2000; Sabatini et al., 1995]. In [Barberá et al., 2000], data from infrared and sonar sensors are fused using neural networks and the results are compared with [Flynn, 1998]. In [Cheung and Lumelsky, 1989], system and implementation issues in infrared proximity sensing for robot arm motion planning are discussed. Following this work, Lumelsky and Cheung (1993) describe a teleoperated whole-sensitive robot arm completely covered with an infrared skin sensor to detect nearby objects. Processing the data from the artificial infrared skin by motion planning algorithms, real-time collision avoidance for the entire arm body is achieved in an unknown or dynamic environment. In another study [Novotny and Ferrier, 1999], the properties of a planar surface at a known distance have been determined using the Phong illumination model, and using this information, the infrared sensor employed has been modeled as a range finder for surfaces at short ranges (3–25 cm). Andò and Graziani (2001) also deal with determining the range of a planar surface. By incorporating the optimal amount of additive noise in the system, the authors were able to improve the system sensitivity and extend the operating range of the system from 17 cm to 24 cm. A number of commercially available infrared sensors are evaluated in [Korba et al., 1994] for space applications. Hashimoto et al. (2000) and Yoshiike et al. (1999) describe a passive infrared sensing system which identifies the number, locations and activities of the people in a room. Infrared sensors have also been used for automated sorting of waste objects made of different materials [Groot et al., 2000; Scott, 1995]. However, to the best of our knowledge, no attempt has been made to differentiate several kinds of targets and estimate their positions using infrared sensors.

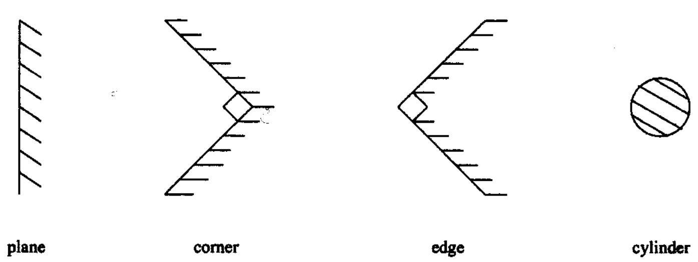



Figure 1: Target primitives used in the experiment.

## 2. TARGET DIFFERENTIATION and LOCALIZATION

The infrared sensor [Matrix Elektronik] used in this study works with 20–28 V DC input voltage and provides an analog output voltage proportional to the measured intensity. The detector window is covered with an infrared filter to minimize the effect of ambient light on the intensity measurements. The sensitivity of the device can be adjusted with a potentiometer to set the operating range of the system. Range, azimuth, geometry, and surface parameters of the target affect the intensity readings of the infrared sensors.

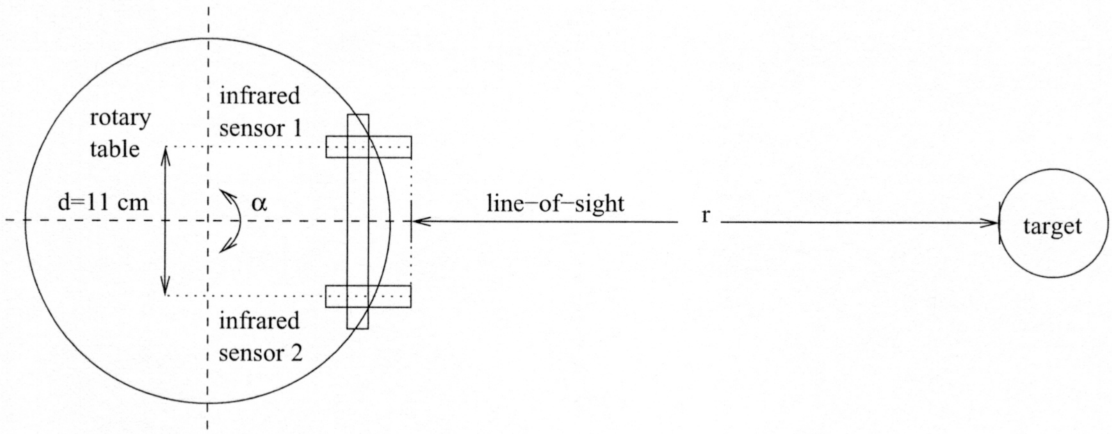
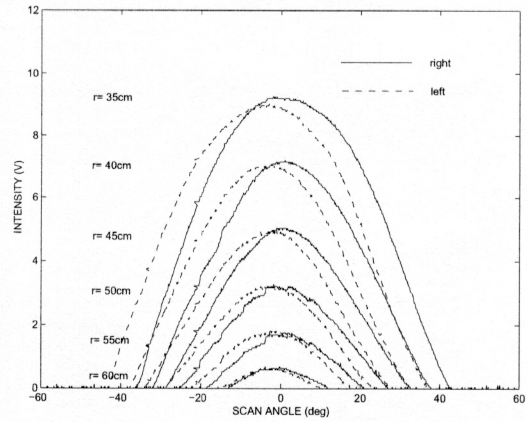
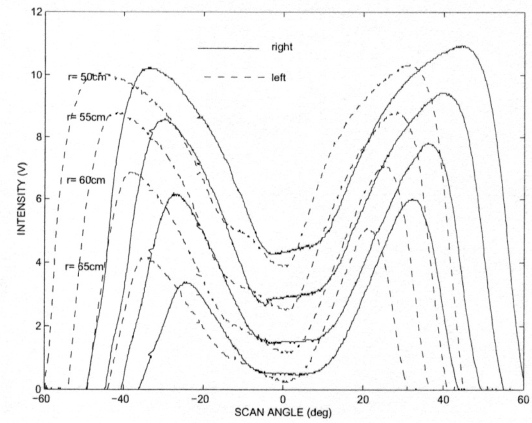



Figure 2: The experimental setup. Both the scan angle $\alpha$ and the target azimuth $\theta$ are measured counter-clockwise from the horizontal axis.

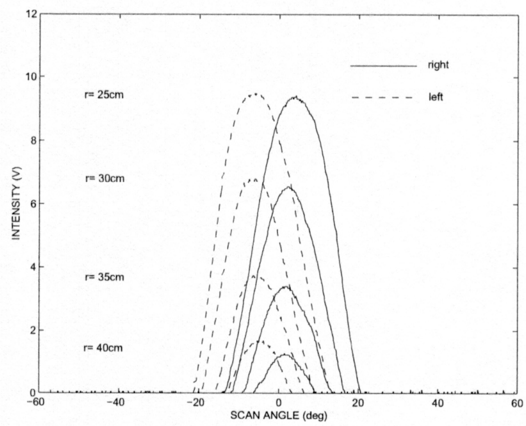
The target primitives employed in this study are a plane, a 90° corner, a 90° edge, and a cylinder of radius 4.8 cm, whose cross-sections are given in Figure 1. They are made of wood, each with a height of 120 cm. Our method is based on angularly scanning the target over a certain angular range. We use two infrared sensors horizontally mounted on a 12 inch rotary table [Arrick Robotics, 2002] with a center-to-center separation of 11 cm [Figure 2]. Targets are scanned from $-60°$ to $60°$ with $0.15°$ increments, and the mean of 100 samples are calculated at each position of the rotary table. The outputs of the infrared sensors are multiplexed to the input of an 8-bit microprocessor compatible A/D converter chip having a conversion time of 100 $\mu$sec.



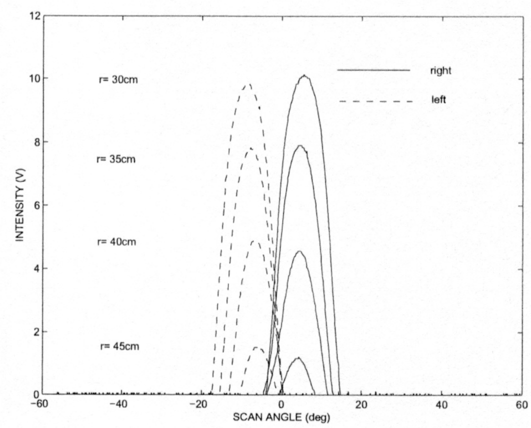

(a) plane




(b) corner




(c) edge




(d) cylinder

Figure 3: Intensity versus scan angle characteristics for various targets along the line-of-sight of the experimental setup.

Some sample scan patterns obtained from the targets are shown in Figure 3. Based on these patterns, it is observed that the return signal intensity patterns for a corner, which have two maxima and a single minimum (a double-humped pattern), differ significantly from those of other targets which have a single maximum [Figure 3(b)]. The double-humped pattern is a result of the two orthogonal planes constituting the corner. Because of these distinctive characteristics, the corner differentiation rule is employed first. We check if the scan pattern has two humps or not. If so, it is a corner. The average of the angular locations of the dips in the middle of the two humps for the left and right infrared sensors provides an estimate of the angular location of the corner.

If the target is found not to be a corner, we next check whether it is a plane or not. As seen in Figure 3(a), the difference between the angular locations of the maximum readings for the planar targets is significantly smaller than that of other targets. Planar targets are differentiated from other targets by comparing the absolute difference of the angle values at which the two intensity patterns have their maxima. If the difference between the two maxima is less than an empirically determined reference value, then the target is a plane, otherwise, it is either an edge or a cylinder. (In the experiments, we have used a reference value of 6.75°.) The azimuth estimation of planar targets is accomplished by averaging the angular locations of the maxima of the two scans associated with the two sensors.

Notice that the above (and following) rules are designed to be independent of those features of the scans which vary with range and azimuth, so as to enable position-invariant recognition of the targets. In addition, the proposed method has the advantage that it does not require storage of any reference templates since the information necessary to differentiate the targets are completely embodied in the decision rules.

If the target is not a plane either, we next check whether it is an edge or a cylinder. The intensity patterns for the edge and the cylinder are given in Figures 3(c) and (d). They have shapes similar to those of planar targets, but the intersection points of the intensity patterns differ significantly from those of planar targets. In the differentiation of edges and cylinders, the ratio of the intensity value at the intersection of the two scans corresponding to the two sensors, to the maximum intensity value of the scans is employed. (Because the maximum intensity values of the right and left infrared scans are very close, the maximum intensity reading of either infrared sensor or their average can be used in this computation.) This ratio is compared with an empirically determined reference value to determine whether the target is an edge or a cylinder. If the ratio is greater than the reference value, the target is an edge, otherwise, it is a cylinder. (In our experiments, the reference value was 0.65.) If the scan patterns from the two sensors do not intersect, the algorithm cannot distinguish between a cylinder and an edge. However, this never occurred in our experiments. The azimuth estimate of edges and cylinders is also obtained by averaging the angular locations of the maxima of the two scans. Having determined the target type and estimated its azimuth, its range can also be estimated by using linear interpolation between the central values of the individual intensity scans given in Figure 3.

## 3. EXPERIMENTAL VERIFICATION of the ALGORITHM

Using the experimental setup described in Section 2, the algorithm presented in the previous section is used to differentiate and estimate the position of a plane, a 90° corner, a 90° edge, and a cylinder of radius 4.8 cm.

Based on the results for 160 experimental test scans, the target confusion matrix shown in Table 1, which contains information about the actual and detected targets, is obtained. The average accuracy over all target types can be found by summing the correct decisions given along the diagonal of the confusion matrix and dividing this sum by the total number of test scans (160), resulting in an average accuracy of 91.3% over all target types. Targets are localized within absolute average range and azimuth errors of 0.55 cm and 1.03°, respectively. The percentage-wise accuracy and confusion rates are presented in Table 2. The second column of the table gives the percentage accuracy of correct differentiation of the target and the third column gives the percentage of cases when a certain target was mistaken for another. The fourth column gives the total percentage of other target types that were mistaken for a particular target type. For instance, for the planar target $(4+3)/43 = 16.3\%$, meaning that targets other than plane are incorrectly classified as planes with a rate of 16.3%.

Table 1: Target confusion matrix (P: plane, C: corner, E: edge, CY: cylinder).

| target | differentiation result | | | | total |
|---|---|---|---|---|---|
| | P | C | E | CY | |
| P | 36 | – | 4 | – | 40 |
| C | – | 40 | – | – | 40 |
| E | 4 | – | 33 | 3 | 40 |
| CY | 3 | – | – | 37 | 40 |
| total | 43 | 40 | 37 | 40 | 160 |

Table 2: Performance parameters of the algorithm (P: plane, C: corner, E: edge, CY: cylinder).

| actual target | correct diff. rate (%) | differen. error I (%) | differen. error II (%) |
|---|---|---|---|
| P | 90 | 10 | 16.3 |
| C | 100 | 0 | 0 |
| E | 82.5 | 17.5 | 10.8 |
| CY | 92.5 | 7.5 | 7.5 |
| overall | 91.25 | 8.75 | 8.65 |

Because the intensity pattern of a corner differs significantly from the rest of the targets, the algorithm differentiates corners accurately with a rate of 100%. A target is never classified as a corner if it is actually not a corner. Edges and cylinders are the most difficult targets to differentiate. It may be considered fortunate that edges and cylinders tend to be in general less common than planes and corners in typical indoor environments.

## 4. CONCLUSION

In this study, differentiation and localization of commonly encountered targets or features such as planes, corners, edges and cylinders is achieved using intensity measurements from inexpensive infrared sensors. We propose a scanning mechanism and a rule-based algorithm based on two infrared sensors to differentiate targets independent of their positions. We have shown that the resulting angular intensity scans contain sufficient information to identify several different target types and estimate their distance and azimuth. The algorithm is evaluated in terms of correct target differentiation rate, and range and azimuth estimation accuracy. A typical application of the demonstrated system would be in mobile robotics in surveying an unknown environment composed of such features or targets. Many artificial environments fall into this category. We plan to test and evaluate the developed system on a small mobile robot in our laboratory for map building in a test room composed of the primitive target types considered in this study.

The accomplishment of this study is that even though the intensity scan patterns are highly dependent on target location, and this dependence cannot be represented by a simple relationship, we achieve position-invariant target differentiation. By designing the decision rules so that they do not depend on those features of the scans which vary with range and azimuth, an average correct target differentiation rate of 91.3% over all target types is achieved and targets are localized within average absolute range and azimuth errors of 0.55 cm and 1.03°, respectively. The proposed method has the advantage that it does not require storage of any reference templates since the information necessary to differentiate the targets are completely embodied in the decision rules.

In this paper, we have demonstrated target differentiation using four basic target types having similar surface properties. Current work investigates the deduction of not only the geometry but also the surface properties of the target from its intensity scans without knowing its location.

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