EXTRACTION OF TARGET FEATURES USING INFRARED INTENSITY SIGNALS

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ABSTRACT

We propose the use of angular intensity signals obtained with low-cost infrared (IR) sensors and present an algorithm to simultaneously extract the geometry and surface properties of commonly encountered features or targets in indoor environments. The method is verified experimentally with planes, 90° corners, and 90° edges covered with aluminum, white cloth, and Styrofoam packaging material. An average correct classification rate of 80% of both geometry and surface over all target types is achieved and targets are localized within absolute range and azimuth errors of 1.5 cm and 1.1°, respectively. Taken separately, the geometry and surface type of targets can be correctly classified with rates of 99% and 81%, respectively, which shows that the geometrical properties of the targets are more distinctive than their surface properties, and surface determination is the limiting factor. The method demonstrated shows that simple IR sensors, when coupled with appropriate signal processing, can be used to extract substantially more information than such devices are commonly employed for.

1. INTRODUCTION

Target differentiation and localization is of considerable interest for intelligent systems where it is necessary to identify targets and their positions for autonomous operation. Differentiation is also important in industrial applications where different materials must be identified and separated. In this paper, we consider the use of a simple IR sensing system consisting of one emitter and one detector for the purpose of differentiation and localization. These devices are inexpensive, practical, and widely available. The emitted light is reflected from the target and its intensity is measured at the detector. However, it is often not possible to make reliable distance estimates based on the value of a single intensity return because the return depends on both the geometry and surface properties of the reflecting target. Likewise, the properties of the target cannot be deduced from simple intensity returns without knowing its distance and angular location. In this paper, we propose a scanning technique and an algorithm that can simultaneously determine the geometry and the surface type of the target, in a manner that is invariant to its location.

IR sensors are used in robotics and automation, process control, remote sensing, and safety and security systems. More specifically, they have been used in simple object and proximity detection, counting, distance and depth monitoring, floor sensing, position measurement and control, obstacle/collision avoidance, and map building. IR sensors are

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

In this approach, we compare the intensity scan of the observed target with the nine reference scans by computing their LS differences after aligning their centers with each other. The mean-square difference between the observed scan and the nine scans is computed as follows:

$$e_j = \frac{1}{n} \sum_{i=1}^{n} [I_i(\alpha_i) - \alpha_{\text{align}}] - I_j(\alpha_i)]^2$$

where $I_j, j = 1, \ldots, 9$, denotes the nine scans. Here, $\alpha_{\text{align}}$ is the angular shift that is necessary to align both patterns. The geometry-surface combination resulting in the smallest value of $e_j$ is declared as the observed target. Once the geometry and surface type are determined, the range can be estimated by using linear interpolation on the appropriate curve in Fig. 4 so that the accuracy of the method is not limited by the 2.5 cm spacing used in collecting the reference scans.

2.2 Matched Filtering (MF) Approach

As an alternative, we also considered the use of MF to compare the observed and reference scans. The output of the matched filter is the cross-correlation between the observed intensity pattern and the $j$th reference scan normalized by the square root of its total energy:

$$y_j(l) = \frac{\sum_{k=1}^{9} I_k(\alpha_k) I_j(\alpha_{k-l})}{\sqrt{\sum_{k=1}^{9} [I_k(\alpha_k)]^2}}$$

where $l = 1, \ldots, 2n - 1$ and $j = 1, \ldots, 9$. The geometry-surface combination corresponding to the maximum cross-correlation peak is declared as the correct target type, and the angular position of the correlation peak directly provides an estimate of $\theta$. Then, the distance is estimated by using
linear interpolation on the appropriate curve in Fig. 4 using the intensity value at the $\theta$ estimate.

2.3 Saturated Scans

If saturation is detected in the observed scan, special treatment is necessary. Comparisons are made between the observed scan and all the saturated reference scans. The range estimate of the target is taken as the distance corresponding to the scan resulting in the minimum mean-square difference in the LS approach and the distance corresponding to the best matching scan for the MF approach.

3. EXPERIMENTAL VERIFICATION AND DISCUSSION

In this section, we experimentally verify the proposed method by situating targets at randomly selected distances $r$ and azimuth angles $\theta$ and collecting a total of 194 test scans. The targets are randomly located at azimuth angles varying from $-45^\circ$ to $45^\circ$ from their nearest to their maximum observable ranges in Fig. 3.

The results of LS based target differentiation are displayed in Table 1, which gives the results obtained using the maximum intensity (or the middle-of-two-maxima intensity for corner) values (numbers before the parentheses) and those obtained using the intensity value at the COG of the scans (numbers in the parentheses). 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 trials (194). The same average correct classification rate is achieved by using the maximum and the COG variations of the LS approach, which is 77%.

MF differentiation results are presented in Table 2. The average accuracy of differentiation over all target types is 80%, which is better than that obtained with the LS approach.

Planes and corners covered with aluminum are correctly classified with all the approaches employed due to their distinctive features. Planes of different surface properties are better classified than the others, with a correct differentiation rate of 91% for the MF approach. For corners, the highest correct differentiation rate of 83% is achieved with the COG variation of the LS approach. The greatest difficulty is encountered in the differentiation of edges of different surfaces, which have the most similar intensity patterns. The highest correct differentiation rate of 60% for edges is achieved with the maximum intensity variation of the LS approach. Taken separately, the geometry and surface type of targets can be correctly classified with rates of 99% and 81%, which shows that the geometrical properties of the targets are more distinctive than their surface properties, and surface determination is the limiting factor.

The average absolute position estimation errors for the different approaches are presented in Table 3 for all test targets. Using the maximum and COG variations of the LS approach, the target ranges are estimated with average absolute range errors of 1.8 and 1.7 cm, respectively. MF results in an average absolute range error of 1.5 cm, which is better than the LS approach. The greatest contribution to the range errors comes from targets which are incorrectly differentiated and/or whose intensity scans are saturated. If we average over only correctly differentiated targets (regardless of whether they lead to saturation), the average absolute range errors are reduced to 1.2, 1.0, and 0.7 cm for the maximum and COG variations of the LS and the MF approaches, respectively. As for azimuth estimation, the respective average absolute errors for the maximum and COG variations of the LS and the MF approaches are 1.6°, 1.5°, and 1.1°, with MF resulting in the smallest error. When we average over only correctly differentiated targets, these errors are reduced to 1.5°, 1.2°, and 0.9°.

To explore the boundaries of system performance and to assess the robustness of the system, we also tested the system with targets of either unfamiliar geometry, unfamiliar surface, or both, whose scans are not included in the reference data sets. Therefore, these targets are new to the system. First, tests were done for planes, corners, and edges covered with five new surfaces: brown, violet, black, and white paper, and wood. Planes are classified as planes 100% of the time using both variations of the LS method and 99.3% of the time using the MF approach. Corners are classified as corners 100% of the time using any of the three approaches. Edges are correctly classified 89.1% of the time using the maximum variation of the LS approach, 88.2% of the time using the COG variation of the LS approach, and 87.3% of the time using the MF approach. In these tests, no target type is mistakenly classified as a corner due to the unique characteristics of the corner scans. Similarly, corners of the preceding type are correctly classified as corners 98% of the time using the maximum variation of the LS approach, 94% of the time using the COG variation of the LS approach, and 98% of the time using the MF approach.
In this study, differentiation and localization of commonly encountered indoor features or targets such as planes, corners, and edges with different surfaces was achieved using an inexpensive IR sensor. Different approaches were compared in terms of differentiation and localization accuracy. The MF approach in general gave better results for both tasks. The robustness of the methods was investigated by presenting the system with targets of either unfamiliar geometry, unfamiliar surface type, or both.

Current and future work involves designing a more intelligent system whose operating range is adjustable based on the return signal intensity. This will eliminate saturation and allow the system to accurately and faster differentiate and localize targets over a wider operating range. We are also working on the differentiation of targets through the use of artificial neural networks in order to improve the accuracy.

Parametric modeling and representation of intensity scans of different geometries (such as corner, edge, and cylinder) as in [8] is also being considered to employ the proposed approach in the simultaneous determination of the geometry and the surface type of targets.

4. CONCLUSION

In this study, differentiation and localization of commonly encountered indoor features or targets such as planes, corners, and edges with different surfaces was achieved using an inexpensive IR sensor. Different approaches were compared in terms of differentiation and localization accuracy. The MF approach in general gave better results for both tasks. The robustness of the methods was investigated by presenting the system with targets of either unfamiliar geometry, unfamiliar surface type, or both.

REFERENCES


