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Multi-Wavelength Laser Scanning Architecture for Object Discrimination

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Abstract—A novel method for identifying and discriminating various objects using five different lasers is described. This method uses a laser combination module that allows five laser diodes of different wavelengths to sequentially emit identically polarized light beams through a common aperture, along one optical path. Each laser beam enters a custom-made curved optical cavity for multi-beam spot generation through internal partial beam reflection. The intensity of the reflected light beams from each spot is detected by a high-speed area scan image sensor. Object discrimination based on analyzing the Gaussian profile of reflected laser light at distinguishing wavelengths is demonstrated.

Index Terms—Laser spectroscopy, remote sensing, laser sensors, laser scanning and data processing

I. INTRODUCTION

OVER the last decade, there has been a strong research effort towards advanced laser scanning methods employed for discrimination in various fields like perimeter security, defense, agriculture, transportation, surveying and the geosciences. By using more wavelengths at points in the spectrum where different objects show different optical characteristics, more precise discrimination can be accomplished.

A laser scanning technique with moving parts has been tested in the British Home Office - Police Scientific Development Branch (PSDB) in 2004 [1]. However, laser scanning with moving parts is much more sensitive to vibration than a multi-beam stationary optic approach [2]. Mirror device scanners are slow, bulky and expensive [3] and being inherently mechanical they wear out as a result of acceleration,

cause deflection errors and require regular calibration [4].

This paper describes and demonstrates the concept of a laser scanning architecture that does not have any moving parts and it is more robust and reliable when compared to the light deflection methods used in the current laser scanner architectures deployed for perimeter security.

Fig. 1. Typical reflectance spectrum of leather obtained by using visible and infrared spectrometers. Variations in the reflectance between 450nm and 950nm can be used to identify and discriminate leather from other objects.

II. LASER SCANNING ARCHITECTURE AND DISCRIMINATION METHOD

The laser scanning architecture is composed of a multi-laser module, an optical cavity as a multi-beam generator and a high-speed area imager. Figure 2 shows a schematic diagram of the laser scanning system.

Fig. 2. Schematic diagram for laser scanning system.

A. Laser combination module

The laser module contains five lasers of different wavelengths appropriately aligned with four free-space beam combiners, as shown in Fig. 3. This laser arrangement produces five collimated and overlapped laser beams with a same polarization angles. The output beam diameter of each laser is 4mm. The laser diode sequencing is controlled by an ON/OFF switchboard and can be easily automated by using multi channel digital output device interfaced to a computer or microcontroller. The sequencing frequency of the lasers can be controlled and the optical output power of each diode can be adjusted by the laser driver.

Fig. 3. Laser combination module with five wavelengths and free spacing beam combiners.

B. Multi-beam generator

The output optical signal from the laser combination module passes through a custom fabricated curved optical cavity for sample illumination as illustrated in Fig. 4.

Fig. 4. Optical cavity structure

A custom-made optical cavity was used to resolve the problem from diffracting the laser beams of different wavelengths onto a spot array [5, 6]. This cavity was made of BK-7 glass with 45° curvature and inner and outer interface radii of R_1 and R_2 , respectively. The rear side of the glass was coated with highly reflective ($R \geq 99.5\%$) multilayer thin film structure. The front side of the cavity is coated with partial transmission ($T \geq 13\%$) multilayer thin films. An uncoated 10mm entrance and exit windows were used at both ends of the rear side of the cavity. Hence, an input collimated optical beam experienced multiple reflections within the optical cavity, and every time it hit the front surface a small fraction (around 13%) of its optical power was transmitted, thus projecting a laser spot array onto an object sample.

The cavity could generate 20 spots from one laser source when an incident beam was injected through the entrance window. Note that the number of outgoing beams depends on the incident angle of laser beam and the cavity length.

Fig. 5. Distribution of the output optical power for all five lasers after passing through the optical cavity.

C. High speed area imager

An area imager with 768(H) x 494(V) pixels and $8.4 \times 9.8 \mu\text{m}$ pixel size was used to detect the intensities of the light reflected from objects. This imager was interfaced to a PC using a Gigabit Ethernet connection. This particular imager exhibited high sensitivity over the wavelength range (470 – 785nm). An imaging lens was also used in conjunction with the imager in order to map the intensities of the beams scattered from the different laser spots into the imaging plane. The imaging data were measured in 12-bit digital form.

D. Discrimination method

Our method for discriminating between various objects is based on analyzing the slopes in the spectral response between the five wavelengths used. The five wavelengths can produce four different slope values [5,7-9]. The four slope values, S_1 , S_2 , S_3 and S_4 , are defined in equation (1) as:

$$S_1 = \frac{R_{473} - R_{532}}{\lambda_{532} - \lambda_{473}}, \quad S_2 = \frac{R_{635} - R_{532}}{\lambda_{635} - \lambda_{532}},$$

$$S_3 = \frac{R_{670} - R_{635}}{\lambda_{670} - \lambda_{635}} \quad \text{and} \quad S_4 = \frac{R_{785} - R_{670}}{\lambda_{785} - \lambda_{670}} \quad (1)$$

where λ_n is the wavelength of the laser diode in nanometers, $R_\lambda = I_\lambda / P_\lambda$ is the calculated reflectance, I_λ is the peak recorded intensity in arbitrary units and P_λ is the measured optical power for each spot generated by the cavity in watts. The values for I_λ can be obtained by applying Gaussian curve fitting to the recorded

intensity profile of the laser spot image and then calculating the peak intensity of the laser spot.

III. RESULTS AND DISCUSSION

Five different objects namely: brick, cement sheet, roof tile, cotton and leather were used to demonstrate the proof-of-concept. Each object was first characterized with two different commercially available (visible and near infrared) spectrometers. The experimental setup and measured reflectance spectrum for the selected objects are shown in Figure 6 and 7, respectively.

Fig. 6. Experimental setup for measuring the reflectance spectra for the sample objects.

Fig. 7. Typical measured spectral responses of sample objects used in the experiments.

To identify the above mentioned objects, specific wavelengths, namely 473nm, 532nm, 635nm, 670nm and 785nm, were selected for two main reasons. Firstly, the spectral reflectance slopes at the different wavelengths are significant and do not overlap simultaneously and secondly, these wavelengths are synthesized using commercially available lasers. The object samples were placed at 4m from the optical cavity and illuminated with an array of coplanar laser beams emitted through the multi-wavelength laser

scanner and the reflected intensities from these objects were measured as illustrated in Fig. 3.

Fig. 8. Calculated average slope values for five different objects.

Fig. 9. Average values with standard deviations for slopes S_1 , S_2 , S_3 and S_4 for five different objects placed at 4m from the optical cavity.

The slopes S_1 , S_2 , S_3 and S_4 of each sample object were calculated using Eq. (1) and the results are displayed in Figures 8 and 9. It is obvious from the latter figures that each object is distinguishable in at least one slope. The standard deviations for the calculated slope values for the objects placed at 4m reveal no simultaneous overlapping between slope values for different objects, making the discrimination of various natural objects possible. Note that the variability of the measurements was mainly due to fluctuations in the response of the area imager and the optical intensities of the laser diodes. The experimental results presented in Figures 8 and 9 demonstrate the concept of the novel multi-

wavelength laser scanning architecture for object discrimination.

IV. CONCLUSION AND FUTURE WORK

A novel five-waveband laser-based object discrimination has been proposed and experimentally demonstrated. Several sample objects have been tested, namely brick, cement sheet, roof tile, cotton and leather. Spectral signatures have been obtained using two different spectrometers and spectral analyses have demonstrated that lasers with 473nm, 532nm, 635nm, 670nm and 785nm wavelengths are the most appropriate wavelengths for object discrimination.

The reflectance properties of the objects have been measured and used to calculate the slope values at the selected wavelengths. Spectral slope measurements have shown no simultaneous overlapping between the slope values of the different objects, demonstrating object discrimination at 4m from the area imager.

Future development will focus on improving the precision of the object discrimination by stabilizing the output powers of the lasers and introducing additional wavelengths for discriminating a broader range of objects.

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