Optical Engineering

OpticalEngineering.SPIEDigitalLibrary.org

Multispectral index for the remote detection of human skin signatures

Gladimir V. G. Baranoski
Tenn F. Chen

SPIE.

Multispectral index for the remote detection of human skin signatures

Gladimir V. G. Baranoski* **and Tenn F. Chen**
University of Waterloo, School of Computer Science, Natural Phenomena Simulation Group, 200 University Avenue, Waterloo, Ontario N2L 3G1, Canada

Abstract. We propose a multispectral index to assist the detection of human signatures in complex natural environments. Differently from previously proposed indices, it takes into account the spectral responses of human skin not only in the near infrared, but also in the visible region of the light spectrum. As a result, it can contribute to mitigate the chances of false alarms during time-critical search and rescue operations carried out in such environments. Our investigation is supported by the use of reflectance data measured for different skin specimens and natural materials such as sand, ocean water, melting snow, and forest vegetation. We believe that the observations reported in this work can be incorporated into the design of more effective procedures and devices for the differentiation of human targets from background materials commonly found in nature. [DOI: 10.1117/1.OE.54.7.070502]

Keywords: skin reflectance; human signatures; remote detection; remote differentiation.

Paper 150568L received May 2, 2015; accepted for publication Jun. 16, 2015; published online Jul. 14, 2015.

1 Introduction

Every year, search and rescue operations are employed to save numerous lives worldwide. In order to achieve this goal, the agencies responsible for these operations strive to reduce the time to find people who are lost or in distress. This is a challenging task, particularly when the search is performed on vast and complex environments such as open ocean waters, deserts, mountains, forests, and flooded regions. It usually involves visual screenings primarily performed by personnel onboard low-flying aircrafts.[1] During long airborne searches, the performance of the human operators may degrade due to fatigue, which may cause vital target clues to be missed.

The fundamental importance of reducing search time and increasing the probability of successful rescues has motivated the development of sophisticated airborne detection systems equipped with multispectral and hyperspectral sensors.[2] Despite recent advances in this area, however, the effective detection of human targets remains an open problem, notably in environments composed of background materials characterized by spectral features that pose limited contrast with skin spectral signatures. Such limited contrast may result in false positives, or false alarms, during time-critical search and rescue operations. These situations may hinder the chances of survival of a lost individual, especially under adverse environmental conditions, since valuable time may be unduly employed to investigate them. Accordingly, more comprehensive spectral differentiation techniques based on an expanded spectral coverage are required to mitigate these situations and improve the performance of current detection systems.[3]

In order to address these requirements, researchers started to look for insights in an area where similar issues have been extensively studied, namely the remote sensing of vegetation. More specifically, inspired by the normalized difference vegetation index, Nunez and Mendenhall[4] proposed an index for the detection of human skin signatures. This index, termed normalized difference skin index and henceforth referred to as NDSI_8, employs reflectance (ρ) values captured at two near-infrared (NIR) wavelengths (1100 and 1400 nm), and it is computed as

$$\mathrm{NDSI}_8 = \frac{\rho(1100) - \rho(1400)}{\rho(1100) + \rho(1400)}. \tag{1}$$

Subsequently, Nunez et al.[5] proposed a modified version of this index, henceforth referred to as NDSI_9, in which the NIR reflectances at 1100 and 1400 nm were replaced by NIR reflectances captured at 1080 and 1580 nm, respectively.

Since the indices proposed by Nunez et al.[4,5] employ two NIR reflectance values, they can effectively detect human targets when the background materials have a light absorption and reflection behavior markedly distinct from the light absorption and reflection behavior of human skin in this region of the light spectrum. Noteworthy examples include man-made and inorganic materials typically found in urban settings.

There are background materials, however, whose interactions with light can result in spectral features similar to skin spectral features in a particular spectral range. These include materials and material combinations typically found in nature such as melting snow and vegetation. Hence, to reduce the possibility of false alarms in the search for human targets in complex natural environments, it may be necessary to use multiple probes covering relevant spectral regions in which skin signatures are marked by characteristic features. Accordingly, in this work we propose a multispectral index, henceforth referred to as multispectral skin detection index (MSDI), for the remote detection of human skin signatures based on this premise.

2 Definition and Effectiveness Assessment

The proposed index takes into account the distinct spectral features of human skin in the visible and NIR regions (Fig. 1), in which light absorption within the cutaneous tissues is dominated by melanin and water, respectively. Accordingly, it employs reflectance (ρ) values captured at four wavelengths, with two in the visible (450 and 650 nm) and two in the NIR (1450 and 1650 nm) region, being computed as

$$\mathrm{MSDI} = \frac{\rho(650) - \rho(450)}{\rho(650) + \rho(450)} \times \frac{\rho(1650) - \rho(1450)}{\rho(1650) + \rho(1450)}. \tag{2}$$

*Address all correspondence to: Gladimir V. G. Baranoski, E-mail: gvgbaran@cs.uwaterloo.ca

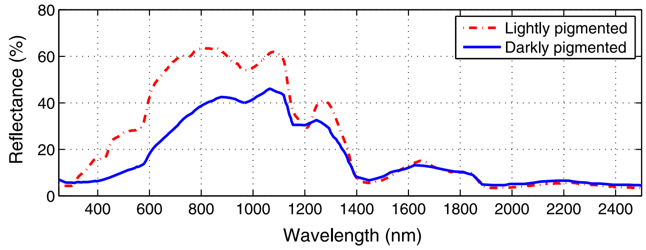

Fig. 1 Reflectance spectra for lightly and darkly pigmented skin specimens provided by Cooksey and Allen[6] and Jacquez et al.,[7,8] respectively.

One might argue that the multiplication operator could be replaced by another less-expensive arithmetic operator in Eq. (2). However, it is important to note that there are materials and material combinations in nature (e.g., water and soil mixtures found in rivers, particularly during flooding situations) that are characterized by spectral profiles qualitatively similar to the spectral profiles of human skin in the 450–650 and 1450–1650 nm ranges. The use of the multiplication operator reduces the chances of false alarms in these cases by highlighting the quantitative differences between the spectral profiles of these materials and human skin.

In order to assess the effectiveness of the proposed index, we computed MSDI, $NDSI_8$, and $NDSI_9$ values (Table 1) for skin specimens with markedly distinct levels of pigmentation (Fig. 1). We then computed their values for different materials found in natural environments to determine whether false alarms can occur based on their respective skin detection intervals depicted in Table 1. These computations are performed using actual measured reflectance values available for these materials in the literature. Since these datasets were obtained through distinct data acquisition initiatives,[6–10] one should expect variations in their respective measurement conditions. We note, however, that similar variations are also expected to occur during actual search and rescue operations.

It is worth noting that the existing indices, $NDSI_8$ and $NDSI_9$, were originally evaluated using reflectance values. These were derived from radiance values collected with a camera (using images).[4,5] The conversion from radiance to reflectance values was performed using the empirical lime method.[4] It is well-understood that images are obtained from the convolution of the illuminant spectral power distribution spectrum, the spectral reflectance of the target materials, and the broad spectral response of the human photoreceptors, or in the case of a charge-coupled device camera, its sensor sensitivity. Accordingly, reflectance data derived from images may be subjected to errors introduced by conversion algorithms as well as limitations with respect to the specification of illumination conditions and sensors' sensitivity.[11] Hence, for consistency with the evaluation employed by the related works and to mitigate biases associated with external confounding factors, we resorted to a direct use of experimentally measured reflectance data in our investigation.

Table 1 Computed MDSI, $NDSI_8$, and $NDSI_9$ values for a lightly and a darkly pigmented skin specimen.

Skin specimens	MSDI	$NDSI_8$	$NDSI_9$
Lightly pigmented	0.1815	0.7760	0.6776
Darkly pigmented	0.1588	0.6875	0.5981

3 Results and Discussion

Although one cannot assess the effectiveness of detection indices with respect to all materials and material combinations found in nature, we note that we have tested MSDI, $NDSI_8$, and $NDSI_9$ on the wide variety of natural materials available in the databases mentioned above, with no false alarms being attributed to the use of the proposed index. For conciseness, we primarily included in this section selected examples that illustrate representative cases.

Initially, we compared the performance of the indices with respect to natural materials whose reflectance profile is characterized by the absence of prominent spectral features at the NIR wavelengths of interest (Fig. 2). As expected, since the reflectance of human skin is marked by noticeable features in this region (Fig. 1), all computed index values (Table 2) were outside their corresponding skin detection interval (Table 1), suggesting that these indices can effectively differentiate these materials from human targets.

In our next round of comparisons, we considered natural materials with a reflectance profile marked by the presence of prominent spectral features at the NIR wavelengths of

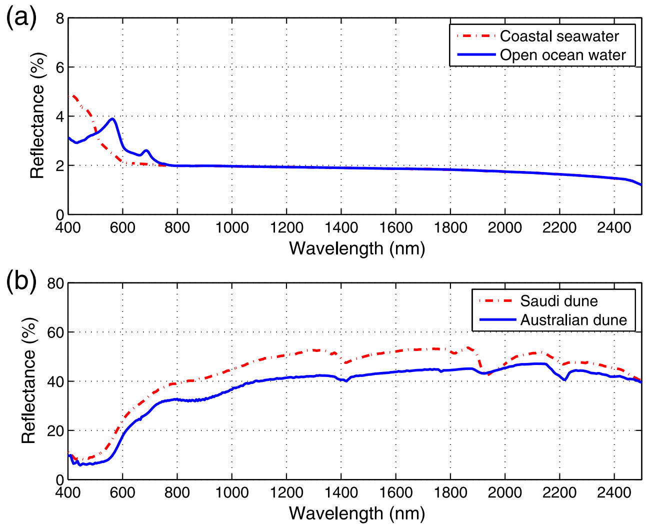

Fig. 2 Reflectance spectra for sample materials characterized by the absence of prominent features at the near-infrared (NIR) wavelengths of interest. (a) Ocean water samples.[9] (b) Desert (dune) sand samples.[10]

Table 2 Computed MDSI, $NDSI_8$, and $NDSI_9$ values for samples of ocean water (from Atlantic Ocean)[9] and desert sand (from Saudi and Australian dune fields).[10]

Sample materials	MSDI	$NDSI_8$	$NDSI_9$
Sand (Saudi dune)	0.0206	−0.0068	−0.0381
Sand (Australian dune)	0.0146	−0.0078	−0.0476
Coastal seawater	0.0008	0.0104	0.0236
Open ocean water	−0.0039	0.0104	0.0236

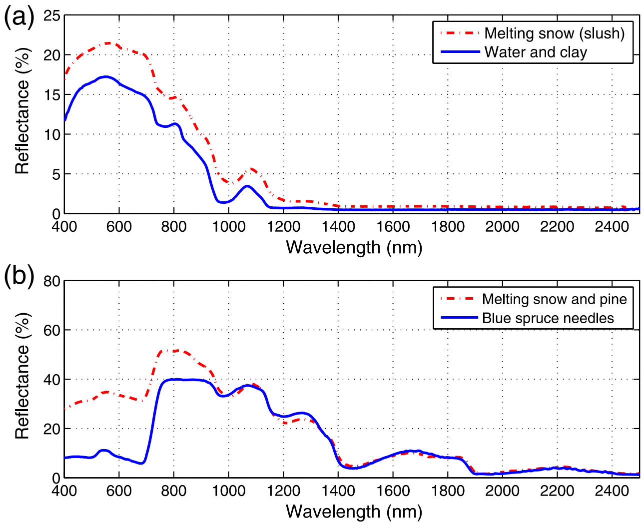

Fig. 3 Reflectance spectra[9] for sample materials characterized by the presence of prominent features at the NIR wavelengths of interest. (a) Melting snow (slush) and water mixed with clay (1.67 g/L). (b) Melting snow mixed with forest vegetation (pinyon pine), and fresh blue spruce needles.

Table 3 Computed MDSI, $NDSI_8$, and $NDSI_9$ values for samples of melting snow (slush), water mixed with clay (1.67 g/L), melting snow mixed with forest vegetation (pinyon pine), and fresh blue spruce needles. These samples were collected at different locations across North America.[9]

Sample materials	MDSI	$NDSI_8$	$NDSI_9$
Melting snow (slush)	0.0001	**0.6975**	0.7232
Water and clay	0.0000	**0.6883**	0.7540
Melting snow and pine	0.0086	0.6163	**0.6403**
Blue spruce needles	−0.0604	0.6811	**0.6268**

interest (Fig. 3). Since MSDI takes into account spectral features in both visible and NIR regions, it provides values (Table 3) outside its detection interval computed for the skin specimens considered in this work (Table 1). On the other hand, since the $NDSI_8$ and $NDSI_9$ consider only spectral features in the NIR region, they are more prone to result in false alarms when the natural background is composed by materials whose spectral signatures are characterized by spectral features similar to those found in the spectral signatures of human skin within this region. This can be verified by the $NDSI_8$ and $NDSI_9$ values depicted in boldface in Table 3, which are within the $NDSI_8$ and $NDSI_9$ detection intervals computed for the skin specimens considered in this work (Table 1). We note that the computed skin detection intervals presented in Table 1 should be viewed as relative references since some variation should be expected with respect to individuals characterized by more extreme pigmentation levels.

Clearly, comprehensive *in situ* tests are required to fully assess the capabilities of detection indices under different operation conditions. This would involve collecting data from real environments using the same equipment available to personnel involved in the detection of human targets. This equipment would include, for example, detection systems that still may not be affordable for general use. Nonetheless, as a proof of concept, the results of our investigation indicate that the proposed index can potentially mitigate the number of false alarms that may occur in search and rescue operations in complex natural environments.

4 Conclusion

Even though the MDSI requires the acquisition of reflectance values at four different wavelengths and within a spectral range broader than the usual range (e.g., 380–1100 nm) covered by the most widely used detection systems,[2] we believe that it can effectively contribute to the reduction of search time, and thus increase the survival chances of those who are lost. Moreover, as pointed out by Eismann et al.,[3] such systems were developed based on spectrometer hardware that were both reliable and relatively inexpensive at the time they were proposed. However, current hyperspectral technology continues to evolve, and devices such as the InGaAs detector arrays can provide low-cost solutions for extending the spectral coverage of existing detection systems up to 1700 nm per.[3]

Acknowledgement

This work was partially supported by the Natural Sciences and Research Council of Canada (NSERC) under grant 238337.

References

1. C. Leonard et al., "Performance of an EO/IR sensor system in marine search and rescue," *Proc. SPIE* **5787**, 122–133 (2005).
2. B. Stevenson et al., "The civil air patrol ARCHER hyperspectral sensor system," *Proc. SPIE* **5787**, 17–28 (2005).
3. M. Eismann, A. Stocker, and N. Nasrabadi, "Automated hyperspectral cueing for civilian search and rescue," *Proc. IEEE* **97**(6), 1031–1055 (2009).
4. A. Nunez and M. Mendenhall, "Detection of human skin in near infrared hyperspectral imagery," in *Proc. IEEE Int. Geoscience and Remote Sensing Symp., (IGARSS 2008)*, Vol. **2**, pp. II–621–II–624, Boston, Massachusetts (2008).
5. A. Nunez, M. Mendenhall, and K. Gross, "Melanosome level estimation in human skin from hyperspectral imagery," in *Proc. First Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing*, Grenoble, France (2009).
6. C. Cooksey and D. Allen, "Reflectance measurements of human skin from the ultraviolet to the shortwave infrared (250 nm to 2500 nm)," *Proc. SPIE* **8734**, 87340N (2013).
7. J. Jacquez et al., "Spectral reflectance of human skin in the region 235-700 mμ," *J. Appl. Physiol.* **8**, 212–214 (1955).
8. J. Jacquez et al., "Spectral reflectance of human skin in the region 0.7-2.6 μ," *J. Appl. Physiol.* **8**(3), 297–299 (1955).
9. R. Clark et al., "USGS Digital Spectral Library splib06a: U.S. Geological Survey," Digital Data Series 231, Denver, Colorado, http://speclab.cr.usgs.gov/spectral.lib06 (2007).
10. J. R. C. Breed, J. MCCauley, and P. Corl, "Remote Sensing Field Guide–desert," Technical Report ETL-0588, U.S. Army Topographic Engineering Center, Fort Belvoir, Virginia (1991).
11. P. Kakumanu, S. Makrogiannis, and N. Bourbakis, "A survey of skin-color modeling and detection methods," *Pattern Recognit.* **40**, 1106–1122 (2007).

Biographies for the authors are not available.