The Imaging Issue in an Automatic Face/Disguise Detection System

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Abstract

Automatic face recognition systems have made great strides in the past 10 years. They still, however, cannot cope with changes due to lighting and cannot detect disguises. Both of these issues are critical for the employment of face recognition systems in high security applications, such as embassy perimeters, federal plazas, and the like. We propose novel imaging solutions that address these difficult problems. We demonstrate with theoretical and experimental arguments that a dual-band fusion system in the near infrared can segment human faces much more accurately than traditional visible band face detection systems. Face detection is useful by itself as an early warning method in certain surveillance applications. Accurate face delineation can also improve the performance of face recognition systems in certain difficult scenarios, particularly in outside environments. We also demonstrate with theoretical and experimental arguments that the upper band of the near infrared (1.4 – 2.4 μm) is particularly advantageous for disguise detection purposes. This is attributable to the unique and universal properties of the human skin in this sub-band. We conclude the paper with a description of our ongoing and future efforts.

1 Introduction

Face Recognition technology is rapidly maturing [1][2][3][4][5] and its application potential is ever expanding. Today, there are face recognition systems that perform relatively reliably under controlled illumination conditions and under certain other restrictions (e.g. orientation of the face comparatively to the camera). It is still very challenging to perform face recognition in outside environments with little or no control over illumination. It is also very difficult to detect disguised faces, something of particular interest in high-end security applications (e.g. embassy perimeter surveillance, airport security, etc).

A significant factor for the current deficiencies of face recognition systems is due to the fact they operate exclusively in the visible spectrum. Figure 1 shows the entire Electro-Magnetic (EM) spectrum. The visible spectrum is only a small portion of the EM spectrum and one can argue that there are plenty of alternatives. Nevertheless, nature constrains our choices below the visible spectrum, since gamma rays, X-rays and, ultraviolet radiation are harmful to the human body. Therefore, the typically active systems in these ranges cannot be employed for face/disguise detection applications. Technology constrains our choices beyond the infrared region, since millimeter wave and radio wave imaging sensors are very expensive, bulky and, with insufficient resolution [6]. Still, the visible plus the infrared range is a huge area of the EM spectrum and we have to identify narrow bands within this area that are appropriate for the face/disguise detection task.

In general, current detection and recognition technologies usually place heavy emphasis on the algorithmic aspect of the problem and almost neglect its imaging aspect. We argue there are three equally important aspects to every computer vision problem:

- ***(a)*** ***Imaging Aspect.*** This aspect should be addressed first since everything else depends on it.

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- ***(b) Algorithmic Aspect.*** This aspect should be addressed second. The algorithmic aspect provides the automation component. Its success relies partially on a good imaging solution.
- (c) ***Engineering Aspect.*** This aspect should be addressed third. The previous two aspects can demonstrate the feasibility of an approach. The engineering aspect is what makes a feasible approach also practical. The engineering aspect includes user interface, speed, and packaging issues among others.

In the present paper, we focus our attention to the problems of face and disguise detection. We address the problem of face recognition only to the extend that relates to the former two. We concentrate on the imaging aspect of the problems. Specifically, we first describe in Section 2 the relative advantages and disadvantages of the visible spectrum for the purpose of face and disguise detection applications. In Section 3 we outline the relative advantages and disadvantages of the thermal infrared band for the same applications. Then, in Section 4 we describe in detail a novel set of methods we propose in the near-infrared that produce superior results for face/disguise detection applications. We conclude the paper in Section 5.

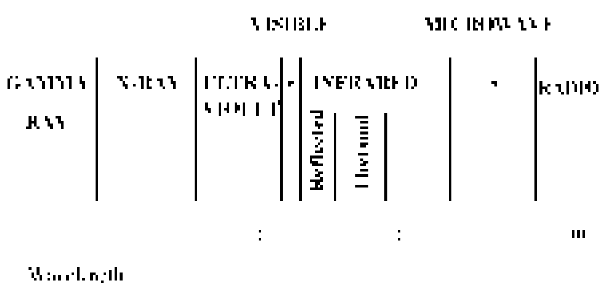

Figure 1. The Electro-Magnetic (EM) spectrum.

2 The visible spectrum for face/disguise detection applications

2.1 Face detection

Most face recognition systems operate in the visible spectrum. There are a number of advantages to this approach:

- (a) Federal and State mug shot databases are all in the visible band.
- (b) The visible spectrum imaging sensors are cheap, reliable and, they can attain high resolution.
- (c) Human faces in the visible band feature a non-uniform phenomenology that facilitates discrimination from person to person.

A full-fledged face recognition system requires the existence of a face detection sub-system. The premise is very simple: faces cannot be recognized if they cannot first be detected. Today, state-of-the-art face recognition/detection systems operate relatively robustly in indoor environments with controlled lighting conditions. In outdoor environments, however, the performance of these systems degrades substantially, mainly due to uncontrolled lighting effects. The face detection sub-system is usually the first that fails, sealing the fate of the entire face recognition process.

In general, the visible spectrum has certain advantages for ***face recognition*** purposes indoors but it may be particularly bad for ***face detection*** purposes outdoors. The primary reasons are:

- (a) It is very difficult to enhance an outdoor scene with artificial visible lighting when human beings are involved. The human eye is sensitive to the visible spectrum and is distracted when is hit by direct visible light. This distraction can be fatal in case of a vehicle driver or simply annoying in case of a pedestrian.
- (b) Human faces from different ethnic groups have different reflectance characteristics. This high variability coupled with the variability induced from the uncontrolled lighting conditions make detection problematic.

2.2 Disguise detection

Disguises are meant to cheat the human eye. Therefore, the various disguise materials and methods that have been developed over the years are impossible or very difficult to be detected in the visible spectrum. In general, there are two methods for altering the facial characteristics of a person:

- ***(a) Artificial Materials.*** The individual alters his/her facial appearance through the addition/application of fake nose, make-up, wig, artificial eyelashes and the like. Professional actors routinely use this method for the needs of their acting roles. A well-done disguise by this technique is very difficult or impossible to be detected in the visible spectrum. Figure 2 (a) depicts a Caucasian male undisguised. Figure 2 (b) depicts the same Caucasian male disguised with a fake nose and a wig. The face has been touched with a make-up material to integrate smoothly the fake nose. Although, the disguise is very simplistic, the facial appearance of the person changes substantially. There is no way to visually detect the deception without apriori knowledge.

(b) ***Surgical Alteration.*** The individual alters his/her facial appearance via plastic surgery. An extended facial reconstruction is impossible to be detected in the visible spectrum without apriori knowledge.

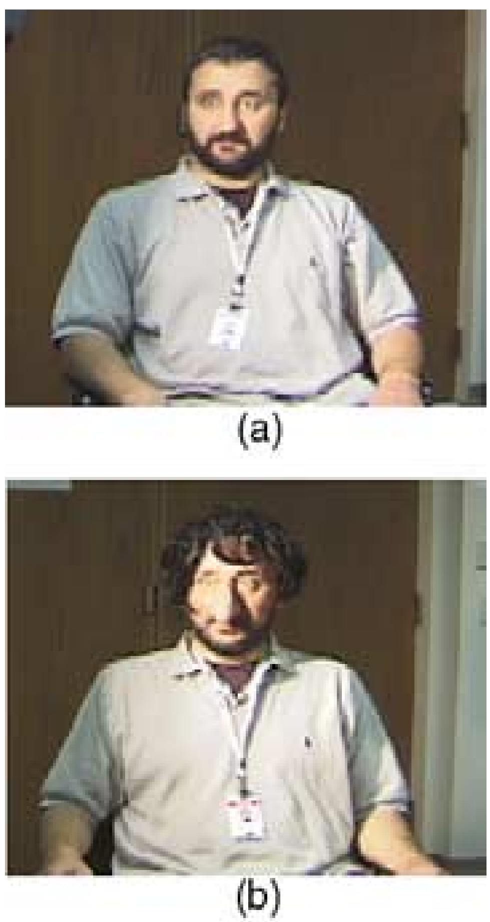

Figure 2. (a) Caucasian male undisguised. (b) Caucasian male disguised with a wig, a fake nose, and make-up.

3 The thermal infrared spectrum for face/disguise detection applications

3.1 Face detection

The thermal infrared spectrum comprises two bands: the mid-infrared (3.0 – 5.0 μm) and the far-infrared (8.0 – 14.0 μm) band. The thermal infrared spectrum is associated with the thermal properties of materials. The human body emits thermal radiation in both bands of the thermal infrared. The thermal infrared wavebands have a number of advantages for face detection purposes:

(a) There is no need for an external illumination source since the human face/body is an emitter of thermal energy. The passive nature of the thermal infrared systems lowers their complexity and increases their reliability.

(b) The human face/body maintains a constant average temperature of about 36^0 C providing a consistent thermal signature. In most cases the thermal signature of the face is distinct from the thermal signature of the environment and facilitates robust segmentation. This is in contrast to the segmentation difficulties encountered often in the visible spectrum due to physical diversity coupled with lighting, color, and shadow effects.

Unfortunately, there are also quite a few disadvantages associated with the thermal imaging approach [7]:

(a) The bulk of thermal radiation cannot transmit through glass. Therefore, it is very difficult to detect vehicle occupants in the thermal infrared spectrum. Figure 3 (a) shows a side view of a vehicle moving at slow speed. The waveband of the camera used was in the mid-infrared (3.0 – 5.0 μm). The vehicle's occupant face is clearly visible. Figure 3 (b) shows a frontal view of a vehicle moving at slow speed. We used the same mid-infrared camera as for the image of Figure 3 (a). This time although an occupant exists (observe his arm protruding out of the window), his face cannot be seen. The windshield appears to be opaque to the mid-infrared range. Figure 4 shows the transmittance diagram of a typical side window. It is evident that thermal radiation can transmit through the side window well into the mid-infrared range (up to 4.8 μm) which explains the clear view of the occupant's silhouette in Figure 3 (a). Figure 5 shows the transmittance diagram of a typical windshield. It is evident that radiation transmittance drops to nil at about 2.8 μm which explains the opacity of the windshield at the mid-infrared.

(b) The speed (exposure time) of most commercially available thermal infrared cameras is not satisfactory. The result is blurry images for vehicles moving faster than 20 mph. The effect of slow camera speeds is compounded by the fact that we can image only the side view of the vehicle. From the side, the vehicle remains for less time in the field of view of the camera.

(c) Thermal cameras are still very expensive.

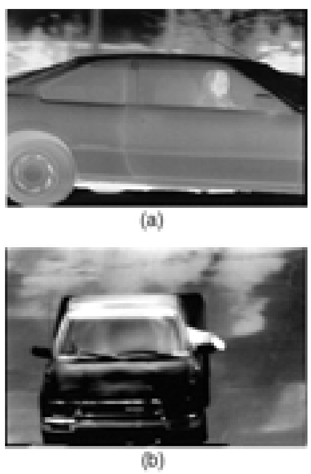

Figure 3. Snapshots of vehicles moving at low speeds (up to 15 mph) (a) Side view of a vehicle in the mid-infrared. (b) Frontal view of a vehicle in the mid-infrared.

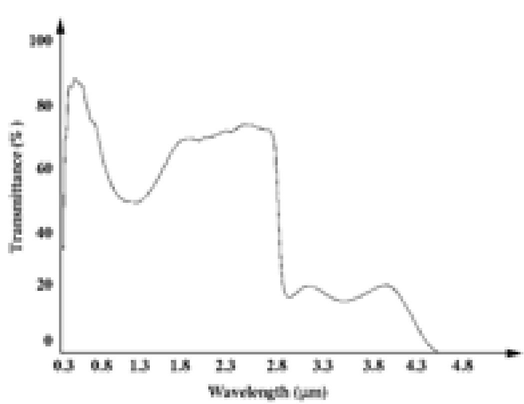

Figure 4. Transmittance diagram of a typical side window.

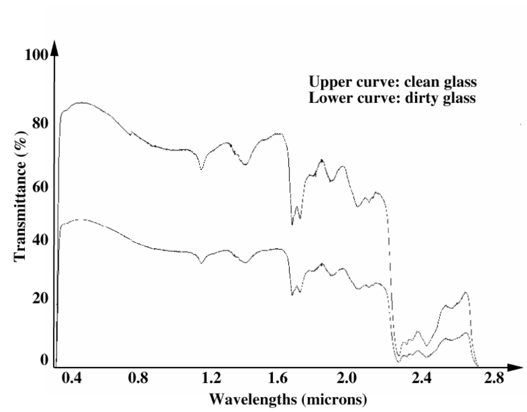

Figure 5. Transmittance diagram of a typical windshield.

3.2 Disguise detection

Thermal infrared may provide valuable clues in an automatic disguise detection system. The reason is that various artificial materials that are used in a typical disguise are reducing the thermal signature of the face [8]. This is an abnormality that can be easily detected in the thermal imagery. As we will see in the next Section, however, these types of disguises can be detected even better in the near-infrared band. The truly unique advantage of the thermal infrared is its ability to uncover facial disguises through surgical alterations (plastic surgery). Plastic surgery may add or subtract skin tissue, redistribute fat, add silicone, create or remove scars. Any one or combination of such procedures would probably cheat a visible spectrum identification system, but would generally be detectable in the thermal infrared. Surgical incisions cause alteration of blood vessel flow, which appear as distinct ***cold spots*** in the thermal imagery.

Naturally, the disguise detection potential in the thermal infrared is limited by the face detection ability in this spectrum. As we described in Section 3.1, face detection in the thermal infrared is handicapped for subjects inside vehicles and for subjects moving at high speeds. The cost of the technology is also quite substantial.

4 The near-infrared spectrum for face/disguise detection applications

4.1 Face detection

The reflected infrared spectrum ranges from 0.7 – 3.0 μm. The reflected infrared spectrum is associated with reflected solar radiation that contains no information about the thermal properties of materials. This radiation is for the most part invisible to the human eye. The reflected infrared sub-band that ranges from 0.7 – 2.4 μm is known as the near-infrared spectrum. The near-infrared spectrum provides unique advantages for a solution to the face detection problem. In particular we found that:

(a) A camera in this range can safely and effectively operate both day and night. During nighttime or in case of overcast days we would need a matching near-infrared illumination source to enhance the scene. Provided that the spectral signature of the illumination source is well into the near-infrared range, the light will be invisible to the human eye. Therefore, no danger of driver distraction or pedestrian annoyance exists [9]. This is in stark contrast with the case of the visible spectrum.

(b) A camera in this range can "see through" both the vehicle's windshield and its side windows. The transmittance of typical vehicle windows in the near infrared spectrum is at least 40% (see Figure 4 and Figure 5). This is in stark contrast with the case of the thermal infrared spectrum.

(c) There are commercially available near-infrared cameras that can freeze the motion of vehicles travelling at speeds greater than 20-mph [10].

(d) Near-infrared cameras although more expensive than visible spectrum cameras they are usually much more affordable than thermal infrared cameras.

(e) Detection of human skin (and consequently human faces) is very good in the near-infrared, particularly in the range 1.4 – 2.4 μm. We have also developed a near-infrared fusion method that not only performs exceptional face detection but also isolates the human face from the background irrespectively of the scene complexity. In the rest of this Subsection we will describe in some detail this fusion scheme.

Our face detection system is the only dual-band system in the near-infrared range [11]. Our method calls for two co-registered cameras (CAM 1 and CAM 2) with spectral sensitivity above (upper-band) and below (lower-band) the 1.4 μm threshold point respectively (see Figure 6**)**. Ideally, these bands should cover the following ranges:

- Upper-band: 0.8 – 1.4 μm,
- Lower-band: 1.4 – 2.2 μm.

Other, slightly shorter or longer ranges can also yield acceptable results. Also, the 1.4 μm should not be considered as an absolute threshold but only as an approximate demarcation point for the dual-band system. Therefore, the camera ranges can cross somewhat the 1.4 μm in either direction without diminishing the face detecting ability of the system. The quality of the imaging signal remains high even during overcast days and nighttime, because as we said earlier we can safely illuminate the scene with eye-safe near-infrared illuminators. Also, since the eye is not sensitive to the near-infrared spectrum the system remains stealthy all the time.

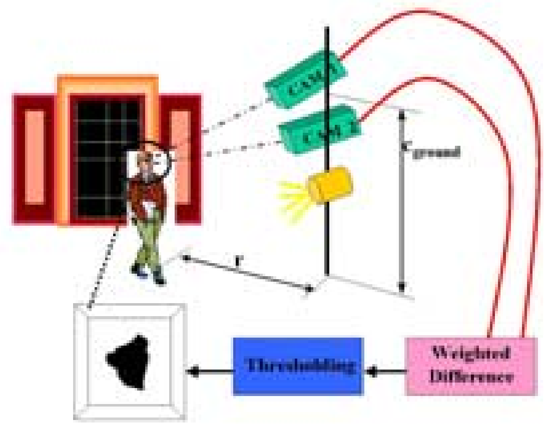

Figure 6. Architecture of the dual-band face detection system.

The crown jewel of the method is the fusion (weighted difference) of the co-registered imaging signals from the lower- and upper-band cameras. Because of the abrupt change in the reflectance for the human skin around 1.4 μm the fusion has as a result the intensification of the humans' face silhouettes and other exposed skin parts and the diminution of the background. It is remarkable that the human skin maintains this phenomenology across races (see Figure 8) [12]. The spectral radiance of the sun on the scene is approximately $f=3$ times bigger in the lower-band than in the upper-band. That means that the same scene will appear overall much brighter in the lower-band than in the upper-band. Therefore, for the image fusion to work properly, the weighted difference equation for the image pixel values should be as follows:

$$P(i,j)_{fused} = P(i,j)_{lower} - f*P(i,j)_{upper}, \qquad (4.1)$$

where, $P(i,j)_{lower}$ is the pixel value of the lower band image in position (i,j) of the corresponding image array, $P(i,j)_{upper}$ is the pixel value of the upper band image in position (i,j) of the corresponding image array, and $P(i,j)_{fused}$ is the resulting pixel value of the fused image in position (i,j) of the corresponding image array. The weighting factor ***f***=3 can be computed if we divide the results of the numerical integration along the lower and upper portions of the sun spectral radiance curve. The factor ***f*** counterbalances the overall difference in brightness between the images from the two bands. The weighting factor ***f*** could be different than 3 and still get acceptable fusion results, but it should remain close to the neighborhood of 3 for optimal results. In case of an artificial illumination source during nighttime, the weighting factor ***f*** should be estimated from the spectral distribution of the artificial source in a manner similar to the one we used in the case of solar illumination.

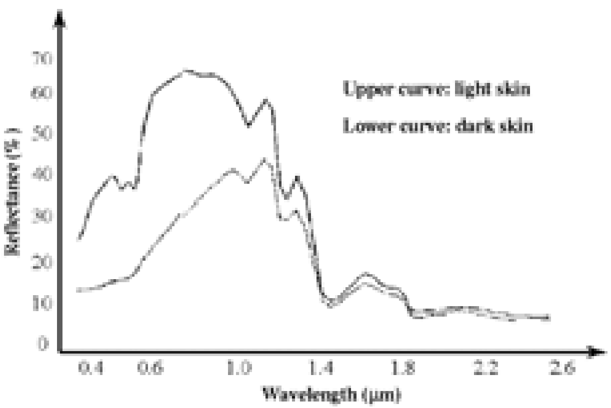

Figure 7. Reflectance diagram of Caucasian skin vesrus dark skin. Asian skin behaves in a similar way.

The increased contrast between the exposed human skin and the rest of the scene allows for perfect image segmentation through simple thresholding. We recommend the use of the Otsu thresholding algorithm [13], although, other thresholding algorithms will also produce acceptable results. In the final processed image only the exposed skin parts of the human body remain as binary blobs. The background is totally discounted. For a typically dressed individual the major portion of his/her exposed skin is of course in his/her face.

The dual-band near-infrared ***face detection*** method could be used in combination with a traditional visible spectrum ***face recognition*** method. Provided that the near-infrared cameras are co-registered with the visible band camera, the dual-band detector can cue the face recognition system as to the location and area of the faces in the scene. This approach will provide a much more accurate face segmentation result than a traditional visible band method. Although, in many cases the visible band recognizer would be unable to make use of the accurate detection information (e.g. nighttime, vehicle occupants), in other limit cases (e.g. overcast scene) may prove the necessary boost to perform successfully.

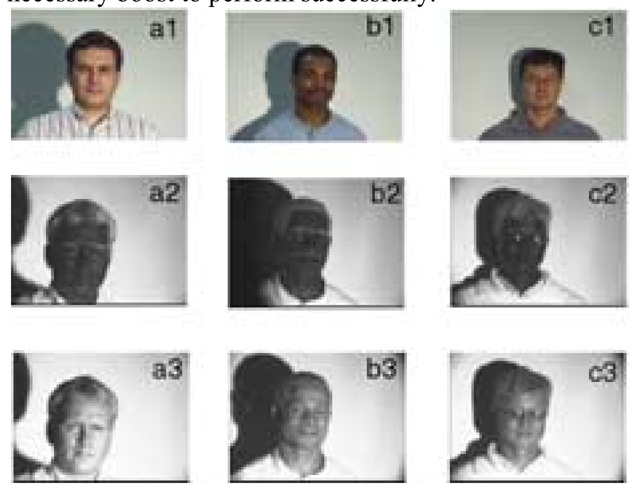

Figure 8. Three people with correspondingly different racial backgrounds (Caucasian, African, and Asian). The first row depicts images of the subjects in the visible band (high variability). The second row depicts the same subjects in the upper near-infrared band (all appear black). The third row depicts the subjects in the lower near-infrared band (all appear white).

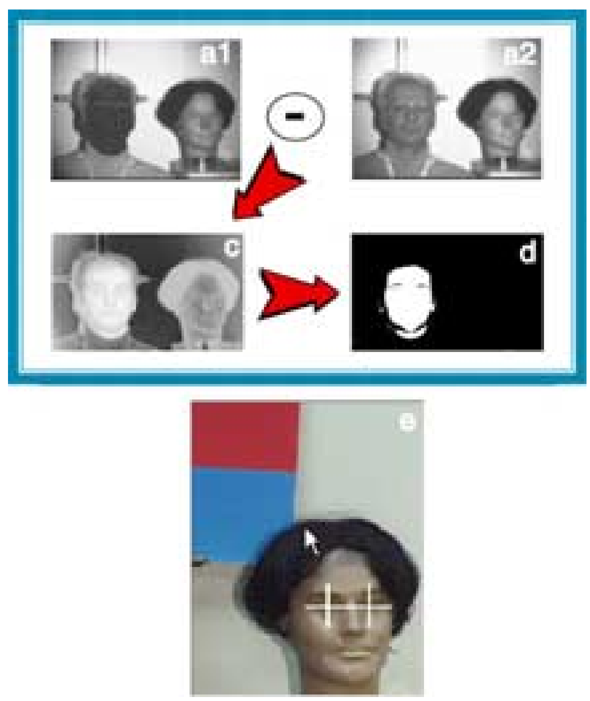

Figure 9. Image of a Caucasian male and a dummy head in (a1) the uper-band and (a2) the lower-band of the near-infrared. (c) The results of fusion between *a1* and *a2.* (d) The final thresholded result. (e) The result of the Visionics FaceIt *alignment* operation. FaceIt mistakenly identifies the dummy head as a real face and correctly detects (*aligns*) its eyes (white crosses).

A case in point about the potential value of our face detector in an overall visible band face recognition system is made in Figure 9 and Figure 10. Figure 9 demonstrates the effectiveness of the dual-band face detector indoor environments. Our face detector performs flawlessly. The interesting part is that it is not fooled by the dummy face, which is considered inanimate (as it is) and eliminated along with the rest of the background. FaceIt by Visionics, a state-of-the-art face detection and recognition system is fooled, and detects the fake face as if it were a true human face. Figure 10 demonstrates the effectiveness of the dual-band face detector in outdoor environments. We image a subject that is looking out the window of his car. The window is open (therefore is not a factor) and the car is stopped. This is a typical outdoor scene, and it could have taken place outside an embassy or other Government building. Our dual-band detector performs superbly and locates the subject's face with amazing accuracy. In contrast, the "alignment" module of FaceIt by Visionics [14] fails to locate the face, sealing the fate of the entire recognition process.

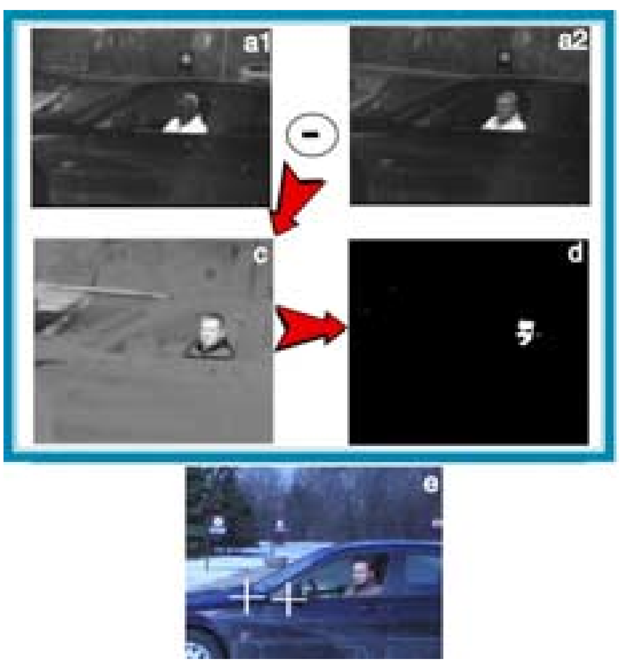

Figure 10. Image of a Caucasian male outdoors in (a1) the upper-band and (a2) the lower-band of the near-infrared. The vehicle's window is open and is not a factor. (c) The result of fusion between *a1* and *a2*. (d) The final thresholded result. (e) The Visionics FaceIt alignment operation fails to locate the face of the subject as evidenced by the location of the white crosses.

4.2 Disguise detection

As we discussed in Section 4.1, the human skin has extremely low reflectance in the upper-band of the near-infrared (1.4 – 2.4 μm) and therefore appears very dark in the respective imagery. Since almost everything else in a typical scene has higher reflectance in the upper-band, there is sharp and consistent contrast between the human face and the background. Moreover, because this skin reflectance property is universal across the human race we have an excellent measure of how should a natural human face look like in the near-infrared – pitch black. We also have established that the natural human hair features a universal reflectance property in the upper-band. In contrast to skin, human hair is highly reflective in the range 1.4 – 2.4 μm and appears always as a bright object in the respective imagery (see Figure 11).

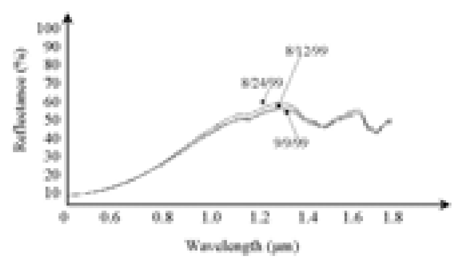

Figure 11. Reflectance diagram of natural human hair. A specimen of blond hair was cut from the scalp of a Caucasian individual. Three separate reflectance measurements on the specimen spaced several days apart produced identical results.

We have run a series of experiments that demonstrate that any prosthetic substance or device applied on the facial skin or the scalp alters to various detectable degrees the respective unique near-infrared signatures. Every disguise configuration we tried so far although can easily cheat the eye in the visible spectrum it is immediately apparent in the upper-band of the near-infrared. Figure 12 shows how an undisguised face appears both in the visible and the upper near-infrared band. One can observe the dark appearance of the facial skin and the bright appearance of the hair, which is characteristic in the upper band for the entire human species.

Figure 13 shows the case of a total facial disguise. The face of the subject was touched by make-up, a fake nose has been fitted, and the subject's scalp was covered with a wig. The make-up material alters radically the reflectivity of the facial skin. As a result, the facial skin appears very bright, an obvious abnormality in the upper near infrared band. In contrast, the artificial hair wig has much lower reflectivity than natural human hair in the upper near-infrared. As a result, the hair of the subject appears black in the image, an impossible phenomenology in this band.

Figure 12. Appearance of an undisguised Caucasian individual in: (a) the visible spectrum and (b) the sub-band 1.3 – 1.7 μm of the upper near-infrared.

From our experimentation so far, even sophisticated disguise materials like wigs made out of true human hair, leave a distinct signature in the upper near-infrared. Figure 15 shows a Caucasian individual wearing a toupee made out of true human hair. The toupee covers only the middle part of his head leaving exposed its sides. The subject's natural hair appears on the sides but it is indistinguishable in the visible spectrum image from the toupee's hair because they have the same color. Also, some of the subject's natural hair banks are exposed in the forehead area. These are also indistinguishable in the visible range image. In the upper near-infrared image, however, the exposed natural hair of the subject appears clearly brighter than the true human hair of the wig. Due to some slight chemical processing that the true human hair undergoes to be fitted in the toupee, its reflectance characteristics are totally altered. Figure 15 shows the reflectance diagram of the toupee in the visible and near-infrared spectrums. One can easily observe that the reflectance of the toupee is significantly lower than the subject's natural hair. This is the reason that the toupee appears much duller in the imagery of Figure 14 (b) than the subject's hair. Although, the difference is subtler when compared with the difference between natural and artificial hair (see Figure 13 (b)), it is still quite substantial and can be easily captured by a machine vision system.

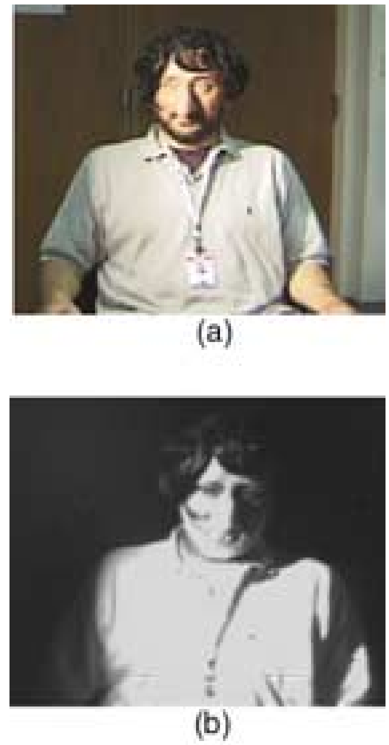

Figure 13. Appearance of a Caucasian individual wearing a total disguise in: (a) the visible spectrum and (b) the sub-band 1.3-1.7 μm of the upper near-infrared.

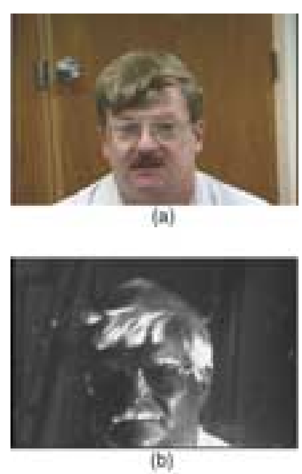

Figure 14. Appearance of a Caucasian individual wearing a true human hair toupee in: (a) the visible spectrum and (b) the sub-band 1.3-1.7 μm of the upper near-infrared.

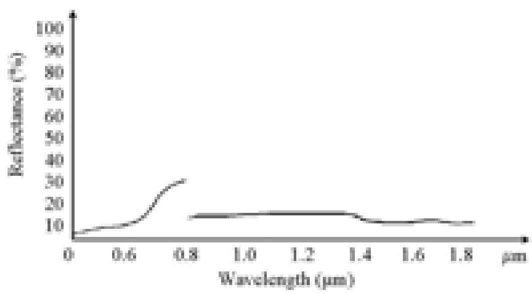

Figure 15. Reflectance diagram of the true human hair toupee shown in Figure 14.

5 Conclusion and future work

We have researched to a certain extend the imaging issue in a face and disguise detection sub-system. Such a sub-system could become an integral and important part of a face recognition system in the future. We argue that such a sub-system would be essential if it were for the face recognition technology to move from the constrained clerical indoor environments that is used today to unconstrained outdoor environments for the protection of high value targets.

We have demonstrated that a dual-band system in the near-infrared can achieve superior face detecting capability. The system fuses information from the upper- and lower-band of the near-infrared. The fusion mechanism capitalizes upon the abrupt change in reflectivity that the human skin features around the threshold wavelength of 1.4 μm. We have also demonstrated that an imaging system based just on the upper-band of the near-infrared provides superior disguise detecting ability. The method is based on the following facts:

(a) The human skin has very low reflectivity in the upper-band and always ranks amongst the darkest objects in the scene.

(b) Artificial facial disguise materials feature high reflectivity in the upper-band and always rank amongst the brightest objects in the scene. Therefore, when they are applied to natural face they alter totally its phenomenology and they facilitate easy detection in the imagery by a human observer or a machine vision system.

(c) The natural human hair has high reflectivity in the upper-band and always ranks amongst the brightest objects in the scene.

(d) Artificial hair or even true human hair wigs feature low reflectivity in the upper-band and always rank amongst the darkest objects in the scene. Therefore, when they are applied to the scalp or to the face (beard, mustache) they alter totally the expected phenomenology and they facilitate easy detection in the imagery by a human observer or a machine vision system.

The only deficiency of an upper near-infrared disguise detection system is that it cannot detect surgical face alterations. This is where a thermal infrared system would provide an advantage. Overall, however, the near–infrared system solution is superior because of its ability to transmit through glass, and the commercial availability of fast imaging sensors. In an ideal world where cost is not an issue, a robust face/disguise detection and recognition system would need to employ all three modalities: visible, near- and mid-infrared (see Figure 16). The dual-band near-infrared system would be primarily responsible for the face detection task. The upper near-infrared sub-system within the dual-band system would also be responsible for the disguise detection task (artificial materials). The thermal camera system would be primarily responsible for detecting surgical face alterations. Finally, the visible camera system would be primarily responsible for the face recognition task. A prerequisite for the success of the proposed fusion system is an accurate cross-registration system between all four modalities: visible, lower near-infrared, upper near-infrared and, thermal infrared.

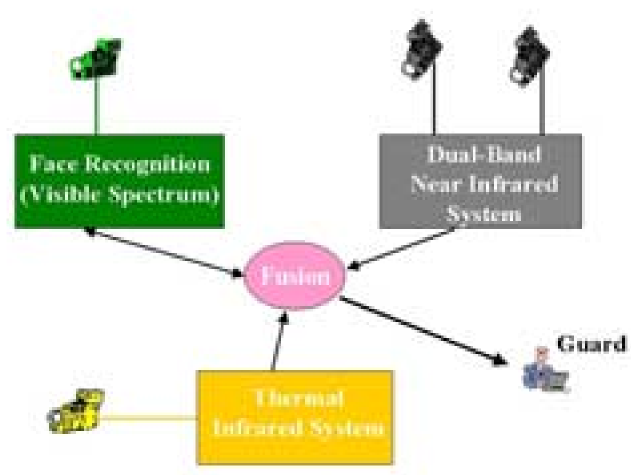

Figure 16. Architecture of a face/disguise detection and recognition system based on multi-band fusion.

We are currently working towards the conclusion of our feasibility study regarding a near-infrared disguise detection system. Our primary emphasis is in studying the reflectance properties of all the materials used in professional disguises. We prepare an exhaustive list of materials and relevant methods with the help of Antonio J. Mendez [15], a world-class expert in disguises. Once we study the phenomenology of all these materials, we plan on verifying our results with statistically significant populations of disguised individuals. We will draw our population sample across the human racial spectrum.

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