Active-SWIR Signatures for Long-Range Night/Day Human Detection and Identification

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ABSTRACT

The capability to detect, observe, and positively identify people at a distance is important to numerous security and defense applications. Traditional solutions for human detection and observation include long-range visible imagers for daytime and thermal infrared imagers for night-time use. Positive identification, through computer face recognition, requires facial imagery that can be repeatably matched to a database of visible facial signatures (i.e. mug shots). Night-time identification at large distance is not possible with visible imagers, due to lack of light, or with thermal infrared imagers, due to poor correlation with visible facial imagery. An active-SWIR imaging system was developed that is both eye-safe and invisible, capable of producing close-up facial imagery at distances of several hundred meters, even in total darkness. The SWIR facial signatures correlate well to visible signatures, allowing for biometric face recognition night or day. Night-time face recognition results for several distances will be presented. Human detection and observation results at larger distances will also be presented. Example signatures will be presented and discussed.

Keywords: Face Recognition, SWIR, Night Vision, Surveillance, Biometrics, Active Imaging

1. INTRODUCTION

The ability to detect and identify humans covertly at long distances, during both night and day, has many applications for defense, law enforcement, and private security. Signatures acquired can give the user a tool to better assess the threat level of a target of interest. Operators can monitor large areas 24 hours a day without giving any indication of their actions or location. By making positive identification of known individuals of interest, the operator could then take the appropriate course of action from a safe distance. Existing imaging systems allow users to take advantage of daylight or local lighting paired with high powered optics to manually identify people at a distance if they are either familiar to the subject or referring to a short watch list of mug shots. Automated person identification at long range is not yet available. At night, or low/no light situations, no technology currently exists to identify individuals at long range whether it is manual or automatic. Also, where conventional thermal infrared has proven to be very successful in human detection, its facial imagery suffers dramatically from feature loss and inconsistencies making it a poor candidate for facial recognition. To address these technology gaps, the West Virginia High Technology Consortium Foundation (WVHTCF), under a research contract from the Office of Naval Research (ONR), is in current development of the Tactical Imager for Night/Day Extended Range Surveillance (TINDERS). This imaging system actively illuminates targets with short-wave infrared (SWIR) radiation that is completely covert to both the naked eye and conventional silicon imagers while maintaining complete eye safety. TINDERS aims to function in all lighting conditions, provide human detection and tracking at distances up to 3 kilometers, acquire recognizable human imagery to a distance of 800 meters, and identify through computer facial recognition at distances up to 400 meters. The final TINDERS unit will be portable and easy to set up. It will have the ability to automatically detect, track, zoom in on, image a moving person, and identify them via computer face recognition. The result will be a system that generates many signatures that differ from conventional visible band or thermal infrared imaging yet still produces facial imagery that correlates well for face recognition.

2. SYSTEM DESCRIPTION

2.1 System Overview

TINDERS began in 2009 as a laboratory prototype to provide proof of concept. This first phase unit was then mobilized and successfully demonstrated long range person detection and identification in complete darkness in 2010. The current second generation unit was designed to decrease system size and weight while improving usability.
The current system is now a mobile platform that can be assembled by a single user within 30 minutes. This system is typically deployed on a small tripod. Other configurations include vehicle mounting and tower implementation. Figure 1 illustrates both the tripod and tower deployments.

![Figure 1. TINDERS Second Generation System. (a) Typical TINDERS system deployment via tripod mount. (b) Optional mast-mounted configuration.](image)

TINDERS can be tasked by other sensors to slew to a target’s location or the operator can scan the system and manually point the system at a target. Once a person of interest is within the field of view, the system tries to acquire facial imagery. These images are then sent for face recognition to attempt to find a positive identification of a target. If a high confidence match is made by the system or by the operator, a status update or track can be sent to a centralized server.

### 2.2 SWIR Illumination

The TINDERS system is actively illuminated. The SWIR illuminator runs at constant power but changes the divergence angle to only produce a spot slightly larger than the imager’s field of view. The optical source is an erbium-doped fiber amplifier seeded by a fiber-coupled, superluminescent LED. The illumination spectrum is a narrow band at a common telecom wavelength greater than 1400 nm and is eye safe. The safety classification of the system is Class 1 M at the system output and Class 1 at the target as defined by the ANSI Z136 and IEC 60825 laser eye safety standards. TINDERS has a great advantage using this wavelength in that it is completely covert to the human eye and conventional silicon based imaging equipment including night vision goggles. Also at this wavelength, the light is fully absorbed before it hits the retina, resulting in a maximum eye-safe exposure level that is 65 times higher than at 800 nm, which allows the TINDERS illuminator to be that much more powerful than a near infrared, 800-nm, illuminator of the same size.

SWIR imagery offers the advantage relative to thermal infrared that facial landmarks closely resemble those appearing in visual-spectrum facial imagery, while thermal infrared facial imagery suffers from a lack of discernible features. Also, thermal facial signatures vary with changes in environment and body conditions. This lack of consistency makes facial pattern matching very difficult with thermal IR. Adomeit discusses the need to develop a distinction between friend and foe. He shows that if a positive identification cannot be made using any other means, in our case face recognition, object detection can be the next step in deciding threat level. TINDERS SWIR imagery is an excellent candidate to make use of both person identification using facial recognition and also threat determination using object association and situational observations.

### 2.3 Hardware

The complete system is comprised of three units. All optics are contained within the weather-tight, climate-controlled optical head; this includes the laser range finder for acquisition of target distance, illumination optics, imaging optics, SWIR focal plane array, and zoom mechanisms. The optical head is mounted on a pan/tilt stage and tripod unit. All associated electronics are packaged in a weatherized and thermoelectrically controlled equipment enclosure. A computer is necessary to run the TINDERS software and can be collocated with the system hardware or located at a distance equivalent to the allowable length of Ethernet communication. Figure 2 illustrates the packaging of these components including the control computer.
2.4 Imager Control and Messaging Software

The current TINDERS system is manually operated and requires a user to be present at all times. Normal operation includes scanning for targets of interest or allowing other sensors to task TINDERS to slew to a specified target location. Once a target is acquired manual tracking is initiated. The user can follow the target by the use of on screen controls or game pad interface. Once the target gives an opportunity for a facial capture, the operator can zoom in on the face and adjust any settings necessary for the best facial imagery.

From this interface, the user has control over the focusing distance and zoom levels. The user is presented with other information including the target’s location, the target’s distance, system bearing, and system location. The user can interact with other networked systems. For instance, TINDERS can receive tasking messages and slew the system to the location of interest. The user can then make use of TINDERS messaging features to send the resulting information to other systems or a central server.

2.5 Facial Recognition

The TINDERS system is designed to match the acquired SWIR images against a pre-populated database of visible-spectrum facial images, called the “gallery”. As it will be shown in section 3.1, SWIR facial images differ in some ways from the visible spectrum imagery that one is accustomed to seeing.

The TINDERS face recognition software was developed by Identix, now MorphoTrust USA. It is based on their commercially available ABIS® System FaceExaminer® package. The normal matching algorithms, designed to match visible-spectrum images against other visible-spectrum images, are combined with custom pre-processing that is performed on the SWIR probe images to improve the matching performance.

The TINDERS system submits a user-defined number of SWIR images, called probe images, to the face recognition software. The software will first search for eyes in the probe images. If none are found, or they are displayed on the image in the wrong location, the user can input the correct locations. Once the eyes are marked, whether manually or automatically, the probe images are compared one by one against the supplied gallery images, and each gallery image is given a match score. The search results for all of the probe images are then fused by keeping only the highest matching score for each gallery image. The highest-scoring gallery images are then displayed in rank order based upon the fused score. Using the maximum score and ignoring all others has led at times to introduction of spurious high score anomalies. For example, if one gallery image ranks the highest in four out of five probe searches, with a maximum score of 1.4, and one gallery image is highly ranked in only 1 probe search, but has a score of 1.45, the second image will be ranked first in the fused results. This has led to the development of an alternative fusion method that is currently being implemented and improved upon. Because TINDERS is acquiring video at a rate of 30 frames per second, the user can continue to submit new probe images as long as a single person is being tracked. By fusing the results of many
probe images acquired over time, high-confidence identification can be accomplished, even when the single-frame face recognition confidence is low.

3. RESULTS

While the primary goal of TINDERS is to detect and identify people, the unique signatures produced in its imagery can offer the user a valuable tool in accessing and averting threats. There are many signatures that differ from the visible and thermal infrared bands. A few of these along with facial recognition statistics will be presented in the following sections.

Two data collections have been conducted by the WVHTCF. Both the first and second generation systems were used in these collections. Also, TINDERS has been successfully demonstrated at multiple offsite exercises. This has allowed for the observation of many interesting characteristics of the imagery produced by the system.

3.1 Facial Signatures

In the summer through winter of 2012, in conjunction with a research group at West Virginia University (WVU), the WVHTCF acquired a set of imagery data for 104 individuals. Each person participated in at least four scenes at three distances of 100, 200, and 350 meters outdoors in complete darkness. Figure 3 illustrates imagery acquired from this data collection.

Figure 3. TINDERS SWIR Facial Images. Target ranges of 100, 200, and 350 meters in complete darkness followed by their associated visible-spectrum mug shots.

3.2 Full Body Signatures

At distances greater than 400 meters, the imagery is not suitable for facial recognition. At this greater range, however, there is sufficient data for person detection, tracking, and manual object recognition. Figure 4 illustrates this point with data acquired in fall 2012 at Camp Roberts, California. All three images are taken in complete darkness at three target distances of 1,000, 1,700, and 3,000 meters. The first image shows that some facial patterns are still recognizable such as the target’s mustache and glasses. It can also be seen that he is holding an automatic assault rifle. While there is decreasing resolution in the following two images, considerable information still remains for video surveillance purposes.
Figure 4. TINDERS human imagery. All images were taken under complete darkness at ranges of (a) 1,000 meters (b) 1,700 meters (c) 3,000 meters.

3.3 Water Signatures

Water has a unique characteristic in the SWIR band in that its absorption coefficient is three orders of magnitude higher than in the visible band. Figure 5 shows this effect. The snow pile, shown first in the visible spectrum, appears completely black in the SWIR image. This may be useful in situations where objects or people were placed in white camouflage but left uncovered of snow, or in situations where a person in wet clothing stands out as dark against a bright background.

Figure 5. SWIR Snow Signature. (a) Visible Spectrum image of snow pile. (b) SWIR imagery of snow pile.

3.4 Clothing Signatures

Clothing fabrics have a somewhat unique signature in TINDERS images. Clothing color, well outside of the SWIR band, has no influence on the imaged intensity. Three images are shown in Figure 6. The first two are the same image of a black, 100% cotton pullover sweatshirt with two different contrast levels. The second contrast level matches that of the third image. The shirt here is a synthetic blend. As can be seen, the intensity level of the cotton shirt has a stark contrast to the vegetation background.

Figure 6. SWIR Clothing Signature. (a) Black, 100% cotton sweatshirt (b) Same image as “a” but with contrast level to match “c” (c) Synthetic blend t-shirt
One application of this is detecting a person in camouflage. While thermal infrared has been proven to be a valuable tool for person detection, TINDERS reveals more detailed features from the target. Figure 7 shows a simulated sniper crawling into position at a distance of 393 meters. Even though the person would be very difficult to pick out of visible imagery, the target is very distinctive. It can also be clearly seen that the person is carrying a two-way radio.

![Image](image_url)

**Figure 7.** Simulated sniper crawling into position in total darkness at a distance of 393 m.

### 3.5 Retro Reflection

Snipers go to great lengths to conceal themselves in order to reach their firing position. Typically they cover themselves in native foliage or wear ghillie suits. Figure 8 shows a simulated sniper wearing a typical ghillie suit. As discussed above, the difference in SWIR reflectivity between the fabric and the background gives a much larger contrast than in the visible spectrum. Another advantage that TINDERS has over passive systems is a byproduct of using an active illumination source. The incident light causes a retro reflection from the sniper’s optics. Figure 8 illustrates the resulting reflection from a gun scope and small set of binoculars acquired at a range of 1,815 meters in total darkness. This totally saturates the pixels making it very simple to distinguish it from the background.

![Image](image_url)

**Figure 8.** (a) Target with sniper rifle and wearing ghillie suit. (b) Target wearing ghillie suit in prone position behind tree looking at TINDERS with rifle scope at a distance of 1,815 meters in total darkness. (c) Target with binoculars and wearing ghillie suit. (d) Target wearing ghillie suit standing beside tree looking at TINDERS with binoculars at a distance of 1,815 meters in total darkness.

### 3.6 Facial Recognition Data Analysis

As previously mentioned, two data collections have been conducted by the WVHTCF. The first set was imaged with the original prototype system. Facial imagery was acquired at distances of 50 and 106 meters indoors in a darkened hallway. The second dataset was already discussed as containing 104 individuals at three distances of 100, 200, and 350 meters outdoors in complete darkness.

The first dataset was shared with two research groups at WVU to test face recognition algorithms they were working on independently from the WVHTCF. Kalka describes the method of applying a pre-processing algorithm to the SWIR
images before submitting them to match against the visible database using MorphoTrust USA’s FaceIt G8. 90% rank 1 success was achieved for the 50 meter TINDERS images and 80% for the 106 meter distance. Zuo describes fusing the FaceIt G8 results with their own algorithm. With a false acceptance rate of 0.1%, a correct response rate of 85% at 50 meters and 74% at 106 meters was achieved.

Likewise, this dataset was given to MorphoTrust USA to develop a plug-in specially designed to preprocess TINDERS SWIR imagery. Figure 9 illustrates the resulting receiver operating characteristics (ROC) of their results at 50 and 106 meters. Here they fused 9 images of each person, including 3 frontal, neutral expression images, 2 images with the subject speaking, and 4 images with a 10° pose angle. These images were matched against the complete database of 56 visible-spectrum mug shots. With a false acceptance rate of 1%, they achieved a correct acceptance rate of approximately 70% for both the 50 and 100 meter images.

Due to the recent acquisition of the second dataset, only a preliminary evaluation has been conducted. Figure 10 is a set of two screen shots of successful face recognition via the TINDERS GUI with integrated face-recognition software. These were acquired at 200 and 350 meters and matched against a visible-spectrum database of over 1,600 people. To perform these tests, the operator played back the recorded video from the data collection and submitted 11 images to the facial recognition portion of the software. TINDERS automatically decides whether each submitted image is suitable and of good quality to be matched against the gallery. For the 200 meter case, 8 of the 11 images were deemed to be acceptable and the eyes were automatically marked. 9 of the 11 faces were detected for the 350 meter case and the eyes were automatically marked. These images are then submitted for matching against the 1,600 person visible-spectrum gallery. The top match is displayed in the large image window with the top 20 other possible but lower ranking matches below it.
Figure 10. Example screen shots showing TINDERS face recognition from video under dark nighttime conditions at distances of (left) 200 m and (right) 350 m. In both cases, the correct individual was chosen from a database containing visible-spectrum images of more than 1600 people.

A preliminary examination of the 100 meter images was conducted halfway through the recent collection. The most relevant evaluation method to this study was the generation of Cumulative Match Characteristics (CMC). Each probe image has a corresponding visible-spectrum gallery image contained within the database. This is called a closed-set database. For this exercise, because the data collection was not yet complete, TINDERS imagery of 42 people was evaluated at a distance of 100 meters. Five probe images, with three different contrast level adjustments, were then submitted to the face recognition software for evaluation. The score and rank data were then recorded. This process was repeated for each person in the database.

Figure 11 shows a cumulative match characteristic (CMC) for the 42 people. The y axis shows the probability that the correct gallery image will be ranked equal to or better than the rank specified on the x axis. Of the 42 people tested, 63% matched the correct gallery image at Rank 1, while 90% of the correct gallery images ranked within the top 7.
4. DISCUSSION

Where current technology such as visible-spectrum, high resolution imaging and thermal infrared show weaknesses in night time operation and feature preservation respectively, the TINDERS system has demonstrated the ability to bridge this gap. Although matching SWIR facial imagery to a database of visible-spectrum mug shots has produced challenges, the TINDERS system achieves repeatable results to distances of 400 meters. The TINDERS system also supplies images with many unique characteristics due to its operation in the SWIR band. These signatures can be exploited by the operator to gather data on a target of interest and take appropriate action on the situation.

Currently the TINDERS team is improving the usability of the system. Whereas tracking is presently manually controlled, the process is being automated. The system will detect any movement and decide whether it is human activity. The system would then zoom in on the head and check for a high quality face for recognition. These images will then be matched against the gallery and the user will be alerted if a high confidence match has been made. The implementation of these features will minimize the user’s involvement in the system’s activity freeing him/her to tend to more important tasks. The second dataset was also recently given to MorphoTrust USA to further improve their TINDERS plugin.

In summary the WVHTCF has developed a man-portable, active-SWIR imaging system capable of producing high quality facial imagery, whether day or night. The images with target distances of up to 400 meters are matched against a visible-spectrum database. Three independent research groups have used TINDERS imagery and produced successful match rates of 70% at a range of 106 meters in total darkness. The unique active-SWIR imagery acquired by the TINDERS system produces signatures that can be used by an operator to better detect targets and make high confidence identification.

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