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Arrayed laser image contrast evaluation (Alice) for human body detection

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Abstract

Human body detection is an important research area with potential for numerous applications, including search and rescue missions, safe driving, surveillance, and security. Here, we propose and experimentally validate a novel concept named 'arrayed laser image contrast evaluation' (Alice) to detect the human body, based on the unique optical properties of human skin. In the Alice system, an NIR dot array laser is used for illumination, and the irradiated area is detected using a near infrared (NIR) camera. Human skin has the characteristic optical properties of relatively low light absorption and high light scattering in the NIR region. When human skin is illuminated with focused laser dots, the NIR light penetrates deeply. Light is scattered multiple times inside the skin before it is re-emitted. The light intensity distribution of the reflected light tends to be diffuse. Human skin can be easily identified using arrayed laser image contrasts, calculated from the reflected light intensity distribution. With the Alice system, an almost entirely hidden person can be successfully detected using information from even a tiny patch of skin. The Alice human body detection system thus has potential for use in a wide range of applications.

Introduction

Human body detection is the key to many applications, such as victim rescue during large-scale disasters [1], safe driving in advanced driver assistance systems (ADAS) [2]-[5] and auto-driving, surveillance and security [6]. It is often crucial for victims of large-scale disasters to be detected and rescued as soon as possible. In the automotive field, ADAS require fast and robust methods for detecting pedestrians. The identification of humans in surveillance videos has a wide range of applications, including unusual event tracking, person-counting in dense crowds, detection of human presence, etc. Since human body detection is anticipated to be useful in numerous applications, various methods have been proposed: for example, pattern recognition with visible cameras or near infrared (NIR) cameras [3], far infrared (FIR) cameras [4] and multispectral/hyperspectral imaging systems [1], [5]. Although a vision-based approach with visible or NIR cameras provides high image resolution, it requires complex image processing to permit human recognition. The complex image processing causes longer processing time, the difficulty of detecting hidden individuals, and the risk of misdetection and/or false detection. In a FIR imaging system, the radiation from a human body can be rapidly detected without any needs for additional illumination; however, FIR imaging systems fail to detect the human body in high temperature environments, human bodies with a low body temperature, or dead bodies. The property of reflection spectra from human skin is used in multi-spectral camera systems. The drawbacks of multi-spectral systems are low image resolution, high system cost and a high false detection ratio.

To overcome these problems, we are developing a novel human body detection method based on the optical properties of human skin in an NIR range that should allow stable and reliable human body detection. It is often necessary to detect persons who have deliberately concealed themselves, for example, suspected law-breakers after observation by surveillance cameras, or the locations of people trapped under wreckage after large-scale disasters. In this study, we explore the feasibility and potential applications of this novel Alice technology.

Basic concept

Human tissues have the characteristic optical properties of relatively low light absorption and high light scattering in the red and NIR spectral range in the wavelength from 650 - 1000 nm. This spectral range is known as the "tissue optical window." In this optical window, the transport scattering coefficient (μ'_s) of human tissue is much greater than the absorption coefficient (μ_a). The typical value for μ'_s is around 1 mm^{-1}, whereas μ_a lies in the range of 0.005 - 0.02 mm^{-1}. In biological tissues, scattering is the dominant light-tissue interaction and the penetrating light is rapidly diffused due to the high μ'_s of tissue.

The basic concept of the Alice system is sensing the diffuse reflectance, rather than direct reflectance, from the skin. The total reflectance consists of direct reflection from the surface and diffuse reflection from the inside. Usually the direct and diffuse reflectance is measured simultaneously, making it difficult to separate the components. However, the use of an arrayed spot laser light source allows the direct reflection component to be separated from total reflection using the light intensity distribution. Since the ratio of diffuse reflectance to the surface reflectance from human skin is higher than that from other materials, it is easy to distinguish a human body from other materials.

System description

As shown in Fig. 1(a), the Alice system comprises a dot array laser source emitting at a wavelength of 830 nm, an NIR camera, and a computer to process the images. A pseudorandom dot pattern is projected using an 830-nm laser diode and a diffractive optical element (DOE). The laser light source projects a rectangular area with angles of 57 x 43 degrees on the vertical and horizontal axes. The total dot number of the laser spots was 34815. The reflected NIR images from objects including human skin were captured using two types of cameras. For the initial evaluation, we used a low-resolution VGA (640 x 480-pixel) NIR camera which outputs RAW format images at 8 bits per pixel. For obtaining images with high resolution and wide dynamic range, a commercially-available digital camera (Panasonic Lumix GH4) was used. The camera has a 16-M (4608 x 3456 pixels) four-thirds format CMOS sensor and the option to output 12-bit RAW data. The ultraviolet (UV) and NIR cut-off filter was removed from the camera to permit images in the NIR spectrum to be taken. A quartz glass plate with an

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equivalent optical path was placed in front of the image sensor to substitute for the removed UV/NIR cut-off filter and maintain the focal position of the camera.

Because of the specific optical properties of human skin, each illuminated laser spot spreads out in human tissues due to multiple scattering. The image contrast of the laser spots on the skin is therefore much lower than that on other materials. This is illustrated in Fig. 1(b). To detect the human body, the image contrast of the laser spots, not the image contrast of the objects, is calculated. Figure 2(a) shows an image of the projected pseudorandom dot pattern on a wall. Figure 2(b) shows the NIR image of a hand on cloth. The laser spot image contrast on the cloth is much higher than that on the hand.

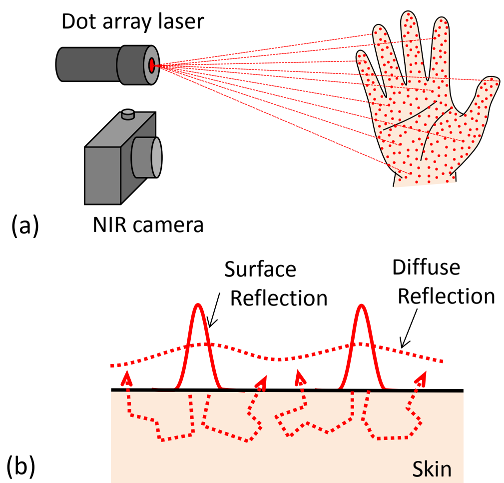

Figure 1. Alice System. (a) schematic illustration of the system; (b) surface and diffuse reflectance from skin.

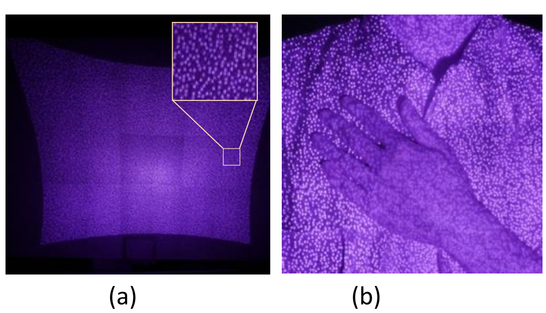

Figure 2. Projected dot array pattern. (a) NIR image projected on a wall, (b) NIR image of hand on cloth.

Image processing

To detect the human body, we calculated a laser spot contrast (LSC) from the captured NIR images. To utilize the data of every 16-Mpixel image received, we used RAW format data at 12 bits per pixel. The sensor RAW data were read from the camera file into Matlab using Adobe DNG Converter [7], [8]. We then processed the RAW image data to detect the human body using a Matlab program (MathWorks). The camera contains a normal color image sensor with Bayer color filters. On removing the UV/IR cut-off filter, all color pixels for red, green and blue gain NIR sensitivity. Since each color pixel has a slightly different NIR sensitivity, the data from the green pixels were used for image processing.

Figure 3 shows the data processing process for human body detection used in the Alice system. The object was a sticky paper label attached to the palm of a hand. The color image was taken using a visible-light camera and the NIR image was taken with a VGA-NIR camera under illumination with the NIR dot array laser source. The image difference between the paper and palm regions could be clearly observed in the NIR image. Bright spots corresponding to the illuminated laser spots could be plainly observed on the paper. On the other hand, the laser image contrast on the palm was weak because of the diffuse reflectance in the palm. Light that has reflected from human skin has two main components: surface reflection and diffuse reflection, as shown in Fig. 1. It should be noted that the NIR diffuse reflectance from human skin has a relatively high value of around 70% [9]. Approximately only 5 - 7% of the light incident on the skin is directly reflected back to the environment at the skin-air interface. The remaining portion is transmitted into the skin. Light is scattered multiple times inside the skin before it is re-emitted from the surface. Since the spatial distribution of the scattered light rapidly becomes diffuse, the reflected light distribution from skin is very broad. From this distribution, human skin can be identified because of the low image contrast it shows with laser spots.

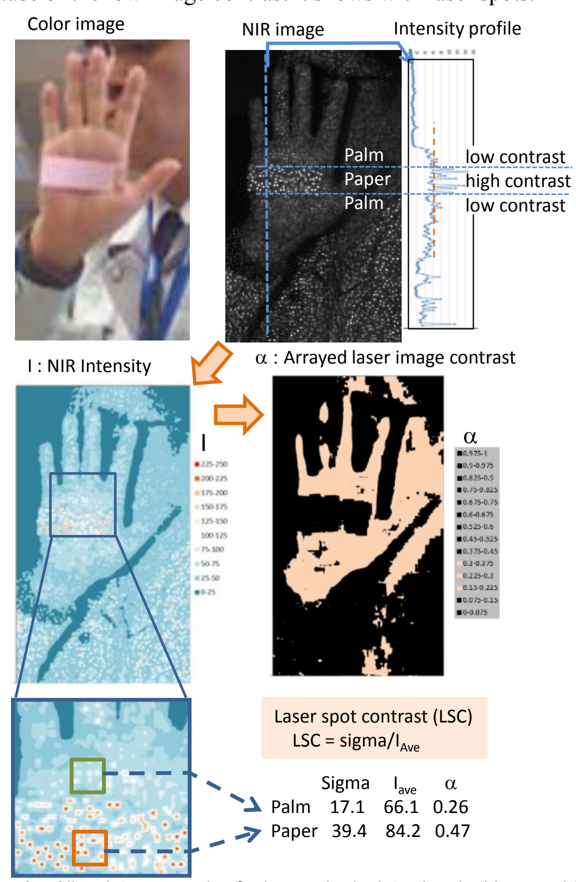

Figure 3. Alice data processing for human body detection. In this case, LSC (α) was calculated in 7x7 pixel frames. Hand and face were successfully detected through image processing.

The human body was separately identified by signal processing based on the difference in the arrayed laser image

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contrast. Because of the diffuse reflectance of the palm, the arrayed laser image contrast was much lower than that for the paper. The arrayed laser image contrast (denoted as α) is defined as the ratio of the standard deviation, σ to the average intensity, $\bar{I}$. In case of Fig. 3, the calculated area was the 7x7 pixel frames.

$$\alpha = \frac{\sigma}{\bar{I}} \qquad (1)$$

Since the value of α depends on the ratio of scattering coefficient to absorption coefficient, the human body can be easily identified based on the α values. The α values were calculated pixel by pixel over the entire area of the NIR image. The detected body area where the α values ranged in 0.15 to 0.375 was painted in skin-color after removing small objects using a morphological opening function in Matlab.

The palm and face were successfully detected, allowing palm and sticky paper to be clearly distinguished from each other. The high diffuse reflectance from human skin reduced the image contrast of the laser spot, which resulted in a small α value. In this paper, the calculated pixel area and threshold α values were changed to match the output image resolution and the zoom lens magnification of the camera.

Results and discussion

The detection performance of the Alice system depending on the distance was validated. We captured images of a sitting person on a chair in front of a Macbeth chart board at distances of 1.0, 1.5, 2.0, and 3.0 m. In Fig. 4, the left-hand photos show the 16M-NIR images illuminated with the dot array laser source and the right side shows the detected body area. The detected body areas were displayed in skin color. The human body could be detected from a short distance of 1 m to a longer distance of 3 m without changing the magnification of the camera lens. We could observe the flare in the same position at the bottom right corner of the captured NIR images. The flare was generated by the configuration of the laser light source and camera: it generated false positive detection in the right-hand figures, requiring us to re-configure the camera and laser to eliminate the flare. In the detected images, noise increased with increased distance. The reflected light intensity and the density of the laser spots on the skin decreased with increasing distance. The pedestrian detection system for ADAS must work over a large range of distances, at least 25 m [2]. The current detection capability does not have sufficient range and resolution for ADAS application. To extend the detection range, a laser source with higher power and higher spot density needs to be adopted.

We confirmed the capability to discriminate between human body and other materials. A hand was detected against a wide variety of materials. Figure 5(a) shows various types of kitchenware, such as a drainer case, paper towels, scissors, bottles of cleaning liquids, plastic bags, a wooden rack, microwave oven, plant, foamed polystyrene box, and drawer in front of a wall and a glass window. Some of the objects are semi-translucent. A hand was positioned above the scene, as shown in Fig. 5(b). The figure was the captured 16M-NIR image illuminated with the dot array laser source. After image processing, the hand was successfully distinguished from the other materials, as shown in Fig. 5(c). The flare and the lid of the drainer case generated false positives. The drainer lid was translucent and was positioned aslant to the camera. Oblique surfaces tend to generate false positives.

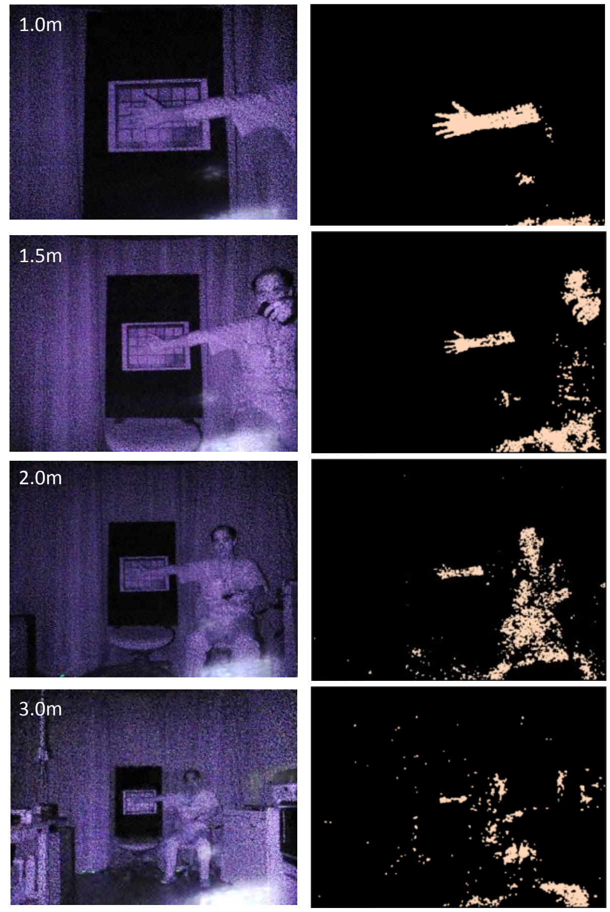

Figure 4.   Human body detection performance of the Alice system as a function of distance between target and camera.

To validate the practical usefulness of the Alice system, we took two scenes to be assumed applications: detection of suspicious persons and the search for disaster victims. Figure 6 shows the results of a detection test of a person hiding behind boxes. In this scene, we assumed that the surveillance camera was being used to detect suspicious persons. It is not easy to find the person in the color image shown in Fig. 6(a). Detection in the NIR image shown in Fig. 6(b) is much more difficult. The detected areas after data processing are shown in skin color. The hidden person can be successfully detected, as shown in Fig. 6(d). In this experiment, the room was illuminated with a fluorescent lamp. Since the Alice system uses NIR laser illumination, we can detect a suspicious presence in a dark room.

The other scenario we modeled was the search for victims after a disaster. There is increasing interest in sending robots into dangerous situations such as buildings that are on fire or which have collapsed after an earthquake. It is important for search and rescue robots to be able to find victims under debris as quickly as possible. In these situations, people can be partially or almost totally hidden by the wreckage. It is both difficult and important to detect partially covered persons. In Fig. 7(a), a subject is hiding under a desk with only his fingertips visible. It was difficult to visually distinguish the fingers from other objects. The fingertips could be seen only with difficulty in the NIR photo shown in Fig. 7(b). After image processing, however, the fingertips were

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successfully detected, as shown in Fig. 7(c). False detection areas remained. In this case, drawers arranged obliquely to the camera and a rounded spray can was also detected. There is a tendency to generate false positives from oblique surfaces. The image analysis of the NIR photography shows that the density of the laser spots varied on oblique and curved surfaces. Currently, we detect human body parts using a simple equation (1) in which a constant density of laser spots is implicitly assumed. An algorithm for correcting the spot density might be effective in removing false positives generated by oblique surfaces.

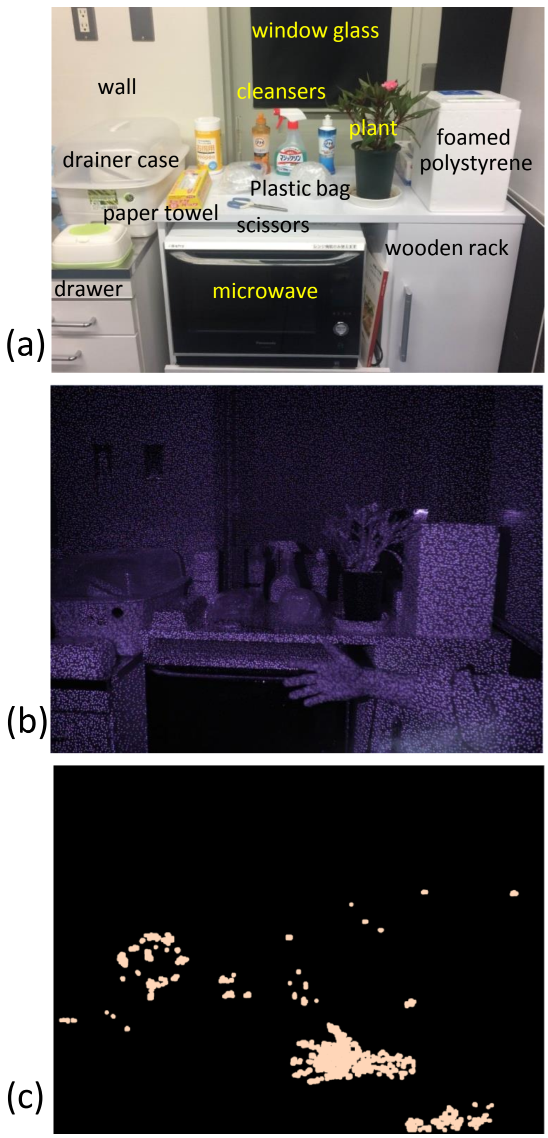

Figure 5. Human body detection from a scene including various materials.

Vision-based approaches to pedestrian detection have been intensively investigated, and significant progress has been made in this field. However, most vision-based strategies work best when people are fully visible and appear in poses such as standing or walking. It is especially difficult to find partially occluded persons who might show a wide range of other poses [4]. On many occasions there is a need to detect human bodies even though they are heavily occluded in recorded images. Typical examples include criminal suspects captured by surveillance cameras and the detection of people trapped under wreckage after a large-scale disaster. Using the Alice system, heavily occluded humans could be detected using information from a tiny part of the human body. In recent years, multi-sensor fusion is proposed as a solution to the problems of vision based detection systems. The fusion of different sensing devices helps to overcome the limitation of each sensing technology, providing accurate detections. The Alice system detects a human body by employing the optical properties of human skin and does not rely on any clues from visual shapes. Sensor fusion of a visual camera and the Alice system might be effective. The strengths and weaknesses of different sensors can be complemented to improve the system's detection performance.

Some sensors use detection mechanisms that are not vision-based, such as FIR cameras and multispectral cameras. FIR cameras capture images corresponding to the temperature and can directly detect heat-emitting targets, providing simple and rapid human detection. However, they suffer several disadvantages, including a lower spatial resolution, a lower dynamic range and false detection of warm objects in addition to actual human bodies. Moreover, FIR imaging systems fail to detect human bodies in hot environments, individuals with hypothermia, and dead bodies. These situations are common when large-scale disasters strike. Multispectral cameras [4] and hyperspectral cameras [1] were developed to detect human skin. These cameras interpret the property of reflection spectra from human skin. The drawbacks of multispectral cameras are the influence of variations in illumination and a high system cost due to the need for special imaging devices that can detect NIR wavelengths over 1000 nm. It was concluded that the Alice system is the optimum detection method for the sensor fusion with a visual camera.

Conclusion and future studies

We have developed a novel human body detection system, 'Alice,' that interprets the specific optical properties of human skin in the tissue optical window. The Alice human detection system has a potential impact in a wide range of applications where it is necessary to detect persons partially hidden behind objects, including victim rescue, pedestrian detection and the detection of suspicious persons.

We intend to improve detection algorithms of the human body detection system for the higher accuracy and the faster speed of the system. The improvement would allow us to design a real-time system detecting human bodies from video.

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Author biography

Hisashi Watanabe received his BS degree and his MS degree in Nuclear Engineering from Osaka University, Japan, in 1982 and in 1984, respectively. He joined Matsushita Electric Industrial Co., Ltd., (now Panasonic Corporation) of Osaka, Japan in 1984, where he conducted research and development on semiconductor lithography processes and image sensor devices. His current research interests include imaging devices and imaging systems. He is a member of the Japan Society of Applied Physics.

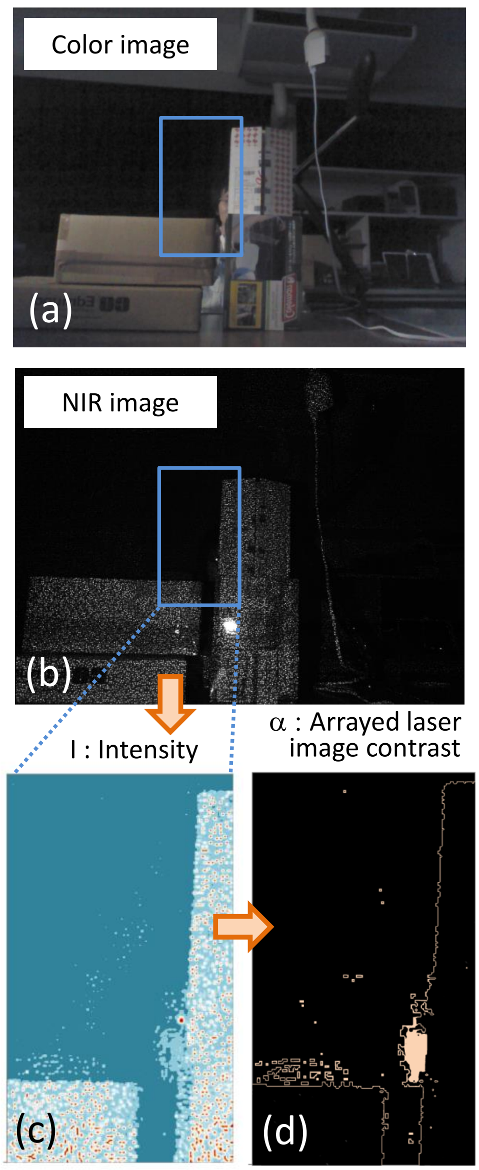

Figure 6. Detection of occluded human body. A person hiding behind boxes could be detected.

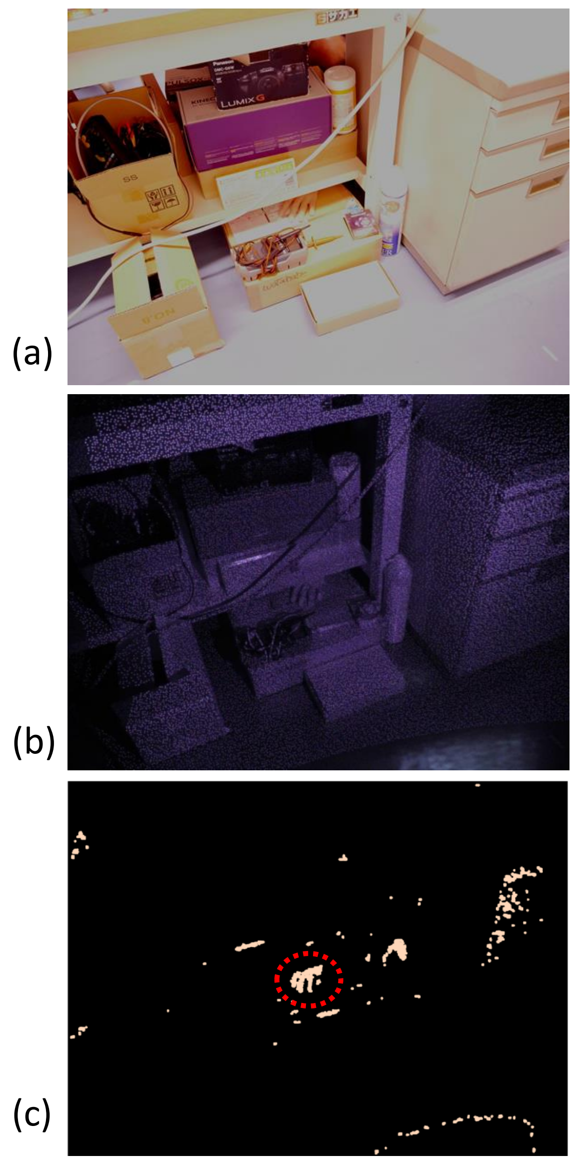

Figure 7. Detection of human body hidden under desk. Fingertips were successfully detected.