Optics Communications 283 (2010) 4274–4282

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Optical technique for classification, recognition and identification of obscured objects

Yevgeny Beiderman [a], Mina Teicher [b], Javier Garcia [c], Vicente Mico [c], Zeev Zalevsky [a,*]

[a] School of Engineering, Bar-Ilan University, Ramat-Gan, 52900, Israel
[b] Dept. of Mathematics, Bar-Ilan University, Ramat-Gan 52900, Israel
[c] Departamento de Óptica, Universitat de València, c/Dr. Moliner, 50, 46100 Burjassot, Spain

ARTICLE INFO

Article history:
Received 20 January 2010
Accepted 18 June 2010

Keywords:
Fourier transform optics
Optical sensing
Pattern recognition

ABSTRACT

The capability to classify, recognize and to identify objects from spatially low resolution images has high significance in security related applications especially in a case that recognition of camouflaged object is required.

In this paper we present a novel approach in which the scenery containing obscured objects which we wish to classify, recognize or identify is illuminated by spatially coherent beam (e.g. laser) and therefore secondary speckles pattern is reflected from the objects. By special image processing algorithm developed for this research and which is basically based upon temporal tracking of the random speckle pattern one may extract the temporal signature of the object. And right after, to use it for its classification (e.g. its separation from the other objects in the scenery), its recognition and identification even in a case that the imager provides poor spatial resolution that by itself does not allow doing the specified detection related operations.

1. Introduction

Speckles are randomly generated self interference patterns [1]. There are two types of speckle patterns: primarily and secondary. The primarily speckle pattern is generated by self interference when the object is illuminated through a diffuser which scatters the light and creates spatially random distribution. Secondary speckles are not projected but rather created due to the diffusive reflection from the rough surface of the object. In the case of secondary speckles the object is not illuminated through a diffuser but rather just illuminated with spatially coherent beam.

Electronic speckles interferometry (ESPI) is a known approach for detecting defects, deformations and for displacement measurements as vibration analysis [2–8]. Such measurement can be performed for instance by subtracting the speckle pattern before the deformation has occurred (due to change in loading, change in temperature, etc.) from the pattern after loading has occurred. This procedure produces correlation fringes that correspond to the object's local surface displacements between two exposures.

Hyper spectral sensing is becoming a very applicable field of research that is commonly used for security applications of identification and classification [9] as well as for environmental monitoring [10–13], for biomedical applications [14], detection of chemical threats [15] and for identification of liquids and food [16,17]. In this field in addition to the spatial information of the captured image, the observer obtains additional dimension related to the spectral distribution of the target and this dimension can be used as the signature of the inspected object and later on applied for its identification and classification [9,18].

In this paper we suggest to use a novel configuration and approach that resembles hyper spectral imaging but the additional dimension is not related to the reflectivity of various wavelengths but rather it is the temporal variation of the secondary speckles pattern reflected from the object. We illuminate the relevant items with spatially coherent beam and observe the generated speckle pattern on top of each object. We track the temporal shifts and movements of the random pattern of each object by correlation following the recently introduced configuration and algorithm that were detailed in Refs. [19,20]. This tracking allows determining both the magnitude and the direction of the object's local surface displacement when properly adapting the optics of the imager as well as the image processing algorithm. In Ref. [20] we were able to demonstrate that each object has its unique spectral signature and therefore by using this signature we can separate one object from the other as well as being able to know if the object is static (e.g. motor off) or not.

The main application proposed in this research is to use this unique extracted signature for classification of vehicles and their identification, detection of camouflaged or obscured objects [21] and other security related manipulations. The real advantage of the proposed approach is that the identification, classification, etc. can be obtained for cases where

* Corresponding author. Tel.: +972 3 5317055; fax: +972 3 7384051.
E-mail address: zalevsz@eng.biu.ac.il (Z. Zalevsky).

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doi:10.1016/j.optcom.2010.06.059

the spatially captured image has low resolution that does not allow by itself to do the above mentioned operations.

Note that the novelty presented in this paper is not only related to the experimental verification of the technique of Ref. [20] while being applied for the classification and the identification of obscured objects. The novelty is also related to the development of proper image processing algorithm allowing filtering out the temporal movement of the speckles coming due to the unique signature of the camouflaged object and the undesired reflection of the light coming from the camouflage itself which is having its own movement.

In Section 2 we describe the proposed approach and perform preliminary experimental investigation related to vehicles identification, inspection of remote air-conditioners and detection of camouflaged or obscured objects. The paper is concluded in Section 3.

2. Technical description and experimenting

The proposed approach is based upon capturing a time sequence of the secondary speckle pattern. This can be done by a fast digital camera. In our experiments we used a camera called PixelLink that is capable of reaching a rate of 8000 frames/s for a region of interest of 16 by 16 pixels (and slower rates for larger regions of interest).

The applied algorithm includes taking a set of random patterns and by correlating them we tracked the position of the correlation peak. Out of the 2D trajectory of the position of the correlation peak we extract temporal signature. The extraction of the temporal signature can be done even in a noisy environment. Basically the idea is to subtract from the overall 2D trajectory of the position of the peak the low pass version of the trajectory. Then we compute the following radius radial coordinate of the trajectory: $R = \sqrt{X^2 + Y^2}$ where X and Y are the horizontal and the vertical coordinates of the resulted trajectory. The spectrogram of the resulted time varying radius R is computed and its low frequency components as well as components that do not have temporal periodicity are filtered out. In order to perform the identification of a specific object we perform a 2D correlation between the reference spectrogram of the signature of that object with the processed spectrogram. In case that high correlation coefficient is obtained, identification may be declared. Note that the spectrogram of a recorded signal can be represented as [22]:

$$\text{Spectrogram}(t,\omega) = |STFT(t,\omega)|^2 \tag{1}$$

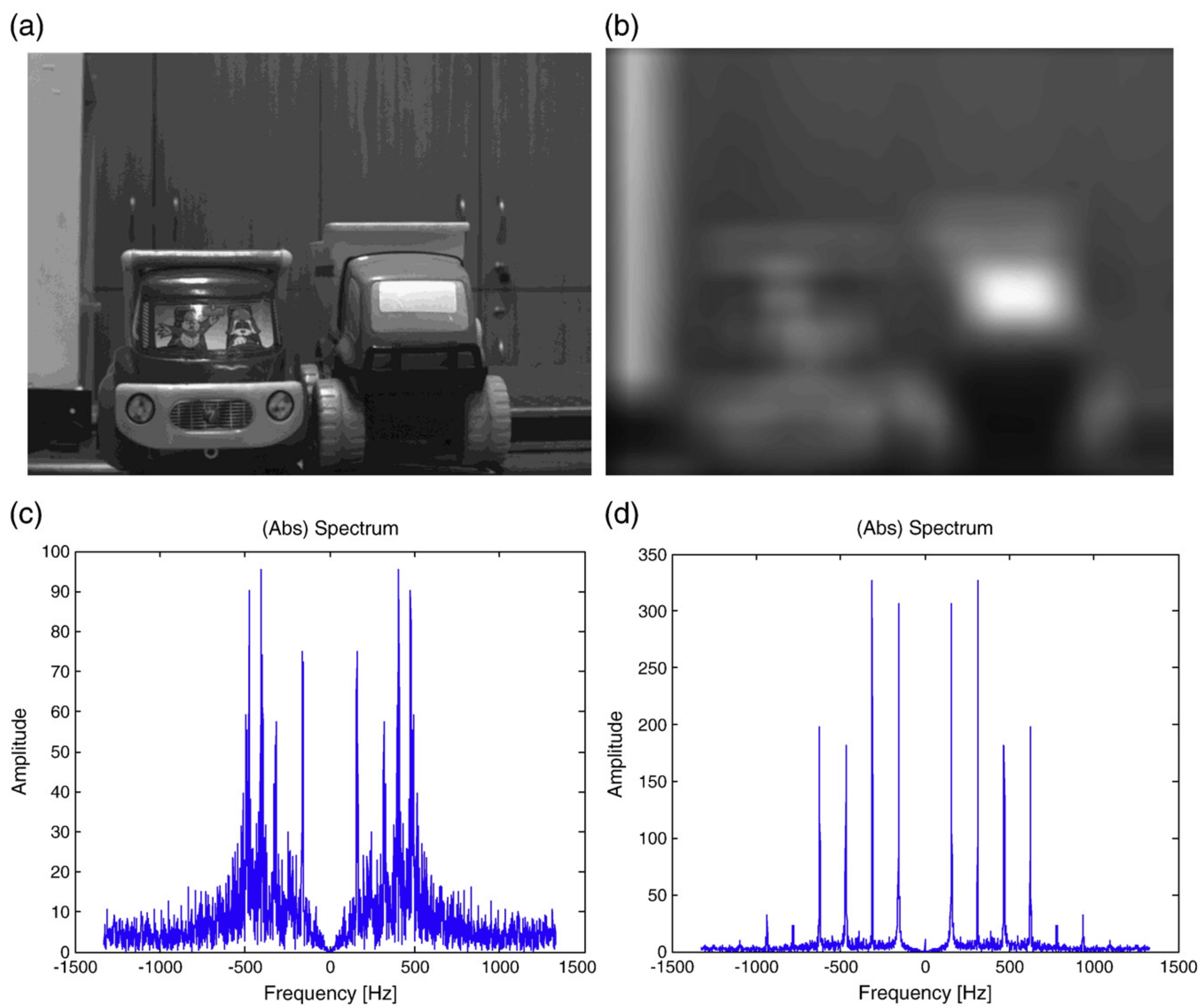

Fig. 1. Identification experiment with low resolution images: two different vehicles were positioned side by side. (a). High resolution image of the vehicles. (b). Low resolution of the two vehicles (due to defocusing). (c). The spectrum of the left vehicle [DC removed]. (d). The spectrum of the right vehicle [DC removed].

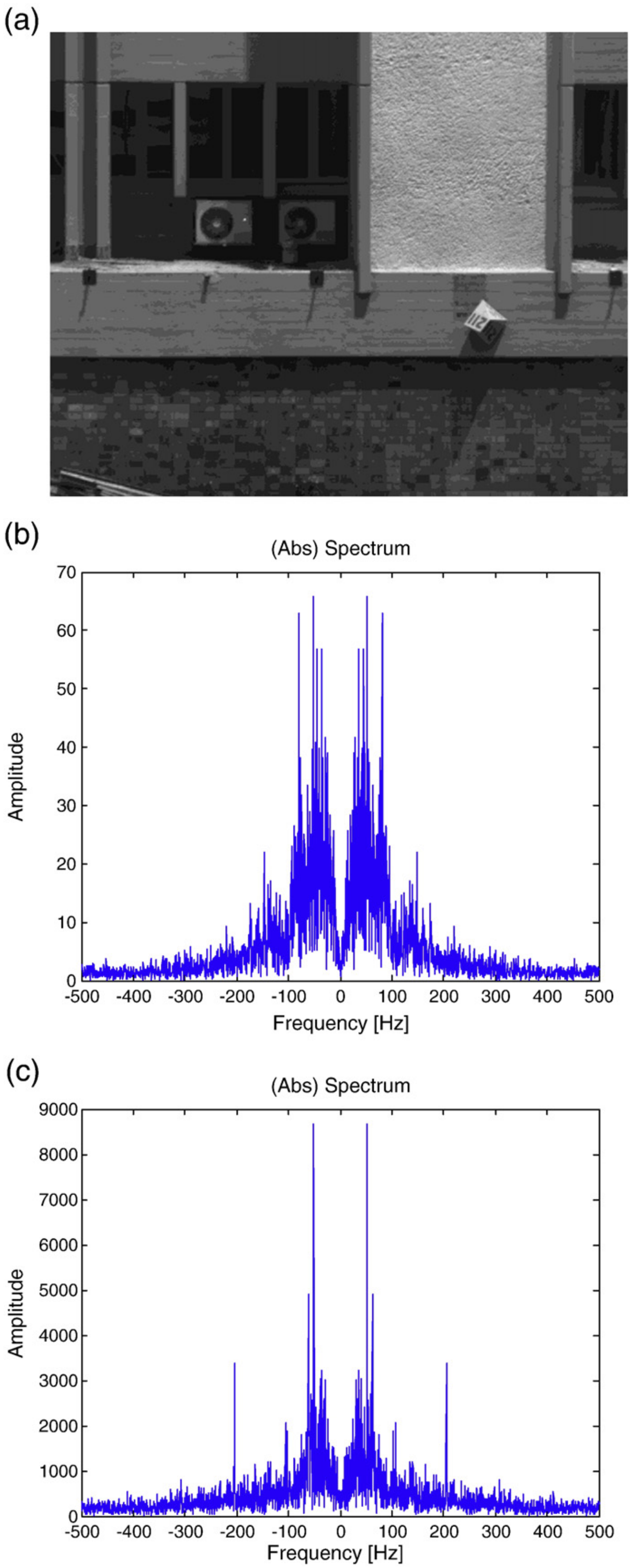

Fig. 2. Identification of operational air-conditioners. Experiment was performed at a range of 100 m. (a). Image of the experimental scenario. (b). Spectrum of the non operational air-conditioner. (c). The spectrum of the operational air-conditioner. One may see spectral spike at 200 Hz.

where t is the temporal coordinate and ω is the radial frequency coordinate. STFT stands for short time Fourier transform which is defined as:

$$STFT(t,\omega) = \int_{-\infty}^{\infty} s(\tau)W(\tau - t)\exp(-i\omega\tau)d\tau \quad (2)$$

$s(t)$ denotes our temporal signal and $W(t)$ is a window function. For the discrete case the definition is:

$$STFT(m,\omega) = \sum_{n=-\infty}^{\infty} s[m]W[n-m]\exp(-i\omega n) \quad (3)$$

where m is the index of the temporal sample.

In the experiment described in Fig. 1 we took two toy vehicles and placed them side by side. Each toy had its motor turned on. Each motor was different in its vibration modes. We projected the laser beam on both toys. The range to the objects was about 3 m. The image of Fig. 1(a) presents the experimental scenario. The images that were captured in the time sequence were of low resolution (see Fig. 1(b)). The resolution was so low (due to defocusing) that visual identification or classification of the two objects was impossible.

We have monitored the speckle patterns of each vehicle and extracted their temporal signatures. The obtained result is seen in Fig. 1(c) and (d). In Fig. 1(c) one may see the signature of the left toy car and in Fig. 1(d) the signature of the right one. One may easily see the unique spectral signature of each vehicle (each has different spectral peaks, while the DC is removed) and thus to identify and to classify them spatially despite the fact that in the image of the low resolution of Fig. 1(b) one can neither identify the cars nor separate them spatially.

Note also that the signature indicates that, although static, both vehicles have their motors turned on and therefore they are real objects and not a camouflage made out of carton. Actually the proposed approach can be used for classification in classical problems of blind source separation where spatially both images are mixed but due to their temporal signature they may still be separable and identifiable.

In the next experiment we projected our laser beam on a wall of a building positioned about 100 m away and tried to identify which of the air-conditioning systems installed on the wall are operating. The image of the experimental scenario is seen in Fig. 2(a). There one may see two air-conditioning systems installed side by side while the left one was not operating and the right one was turned on. The spectrum of the left air-conditioner (extracted from the tracking of the speckles in the projected laser beam) is seen in Fig. 2(b). We have filtered the frequencies below 100 Hz in order to remove noises. In Fig. 2(c) one may see the spectrum of the air-conditioner that was turned on.

One may clearly see the spectral peak at 200 Hz identifying its operational mode, which is approximately two orders of magnitude higher than any other peak appearing in its turned off state (one should disregard the peak at 50 Hz appearing due to electricity line).

The next experiment was aimed to demonstrate the camouflage application (detection of obscured objects). The tested object was a toy truck. We have prepared real branches to be used for the camouflage. In one case the toy was hidden behind the branches (Fig. 3(a)) and in the other case there was no toy (Fig. 3(b)).

The position of the hidden truck is marked by the laser spot in Fig. 3(a). In Fig. 3(c) we present the toy that was used as our object (upper left side) and the image of the camouflaged scenery as it is being seen with low resolution imaging system (a defocused image) that was used for the experiment. Despite the fact that the image is of low resolution we will demonstrate not only that we can identify the object but also to see if it is indeed hidden in the camouflaged scenery.

The results of the experiment are seen in Fig. 3(d)–(f) where we present the extracted spectrogram for the case of working engine

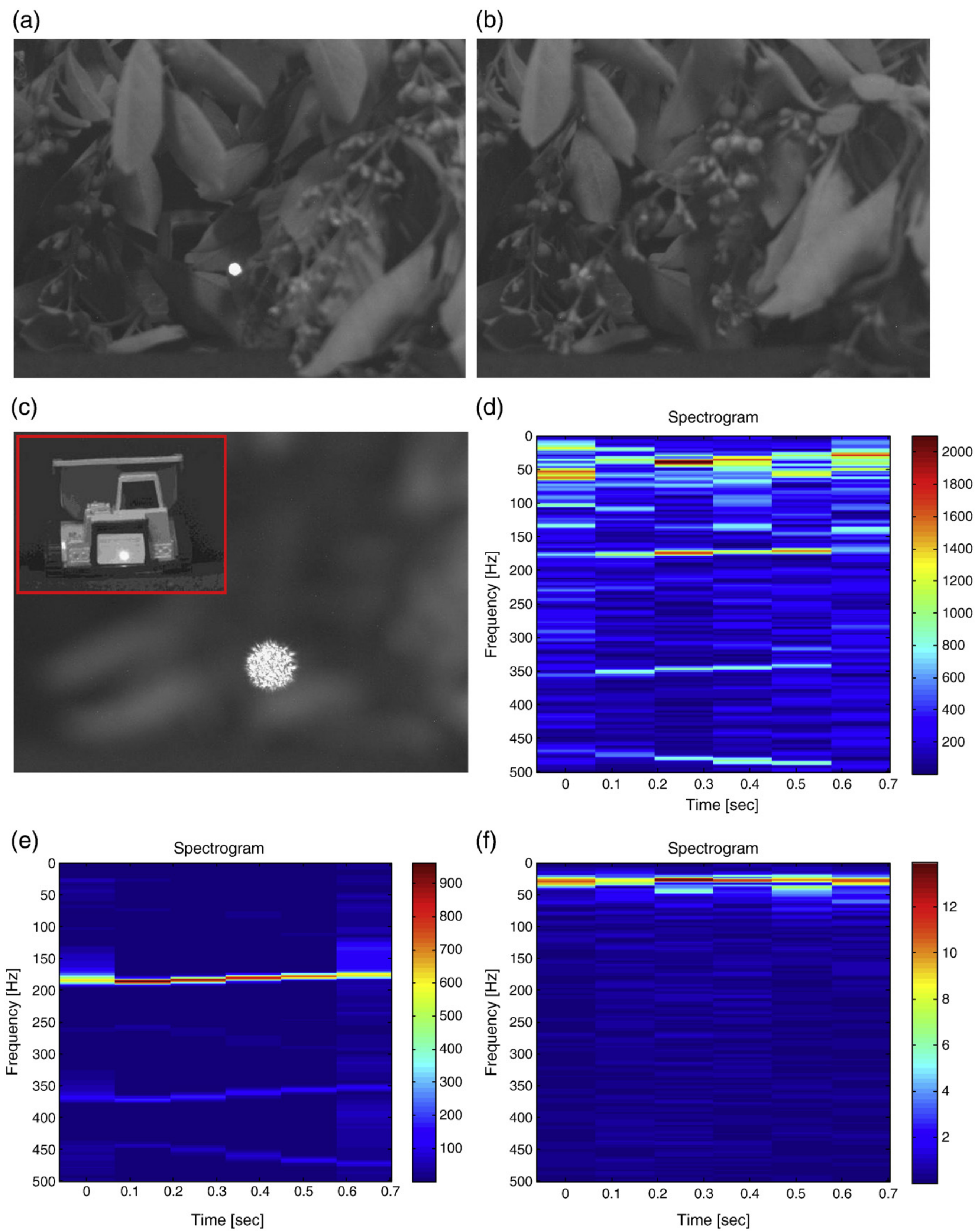

Fig. 3. Identifying of camouflaged object. (a). Camouflaged object. (b). Camouflage without the object. (c). The object (upper left part) and the low resolution camouflaged scenery. (d). The spectrogram of the camouflaged object with its engine turned on. (e). The spectrogram of the object with its engine turned on and without the camouflage. (f). The spectrogram of the camouflaged object without turning on its engine.

Fig. 4. Experimental setup.

with camouflage (Fig. 3(d)), working engine without camouflage (Fig. 3(e)) and non working engine with camouflage (Fig. 3(f)). One may see that the unique signature of the truck that contains spectral peaks at around 190 Hz, 380 Hz and 460 Hz exists in Fig. 3(d) as well as in Fig. 3(e) (with and without the camouflage). Due to the addition of the camouflage some low frequency noises were generated as well (frequencies below 100 Hz due to electricity line). In Fig. 3(f) where the engine was turned off the unique signature of frequencies above 100 Hz does not appear and thus despite the camouflage the object can easily be identified as well as classified.

In Fig. 4 we tried to apply the proposed approach in order to obtain detection of camouflaged objects behind visually blocking fence while we generated some small holes to allow penetration of light. Such experimental conditions simulate the scenario where the camouflaging item is hiding the object visually but allows some portion of the light to go through.

The experimental setup included a vibrating object (toy car) positioned behind a Bristol board with small holes (see Fig. 4). The distance from the camera to the object was 3 m, the distance from the camouflaging board to the object was 5 cm. The width of the Bristol was 2 mm. The spot of the illuminating laser was 2.5 cm. We made 9 holes in the board while the pitch between holes was 4 mm and the diameter of each hole was 3 mm. We worked with a frame rate of 953 fps at our camera.

The obtained results are presented in Figs. 5–7. In Fig. 5(a)–(c) we present a stable object without vibration and without camouflage. Fig. 5(a) is the measured spectrogram, Fig. 5(b) is the extracted temporal signal and in Fig. 5(c) one may see the power spectrum of the temporal signal. In Fig. 5(d)–(f) we observed the vibrating object without camouflage. Once again one may see in Fig. 5(d) the measured spectrogram, in Fig. 5(e) the extracted temporal signal and in Fig. 5(f) one may see the power spectrum of the temporal signal. The vibrating object has unique signature expressed as peaks at frequencies of 230 Hz and 470 Hz.

In Fig. 6(a)–(d) we measured the camouflaged and non vibrating object. One may see in Fig. 6(a) the measured spectrogram, in Fig. 6(b) the log display of the spectrogram (in dB units), in Fig. 6(c) the extracted temporal signal and in Fig. 6(d) one may see the power spectrum of the temporal signal. In this case the unique spectral signature does not exist.

The last experiment included the measurement performed for the vibrating and camouflaged object. One may see in Fig. 7(a) the measured spectrogram, in Fig. 7(b) the log display of the spectrogram (in dB units), in Fig. 7(c) the extracted temporal signal and in Fig. 7(d) one may see the power spectrum of the temporal signal. In this case the unique spectral signature which we saw also in Fig. 5(d) and (f) is well visible in Fig. 7(a), (b) and (d). Thus, although camouflaged the vibrating object can be detected as well as recognized due to the reconstruction of its unique spectral signature.

In Fig. 8 we have demonstrated the proposed approach for people being camouflaged behind a bush. In Fig. 8(a) we present the scenario (the lower part shows the subject standing in front of a window, while his chest is illuminated by a laser beam. In the upper part the subject is hiding behind bushes in front of a window, while the camouflage is illuminated by a laser beam). The range was 40 m. Exposure time of 0.6 ms and frame rate of 770 Hz were used in our camera.

In Fig. 8(b) we show two recordings extracted using the optical system of Ref. [20]. The lower recording is without the camouflage and the upper one is with it (it corresponds to the images of Fig. 8(a). From Fig. 8(b) one may see the similarity of the heart beats pattern for the subject with or without being camouflaged. One may also see that in both cases the heart beats pattern is repeating itself every 0.55 s (the subject was tested after performing some physical exercises).

3. Conclusions

In this paper we have demonstrated the usage of a technology in which the secondary speckle pattern is monitored versus time, in order to extract the temporal/spectral signature of objects. Special image processing algorithm allows the extraction of a unique signature that can be used in order to classify, recognize and identify objects even in a case that the spatial quality of the imaging is very low. The approach can also be used in order to detect and to then recognize camouflaged or obscured objects.

Preliminary experimental validation was demonstrated for identification and classification of several objects out of their low resolution image. We have demonstrated recognition of operating air-conditioning systems positioned on a wall of a remote building, a toy truck camouflaged with real branches and imaged at low resolution imaging system and a human subject hiding behind real bushes.

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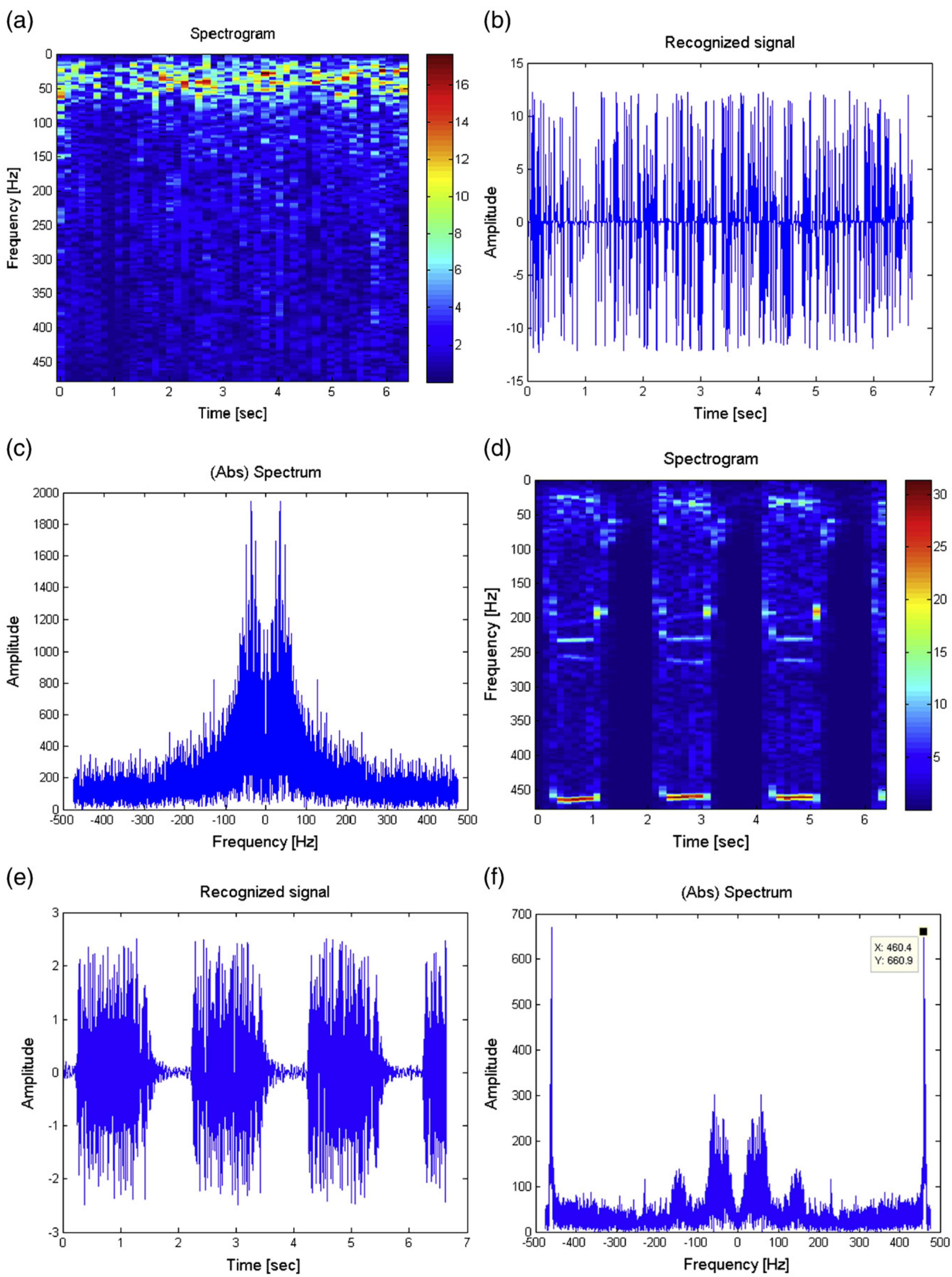

Fig. 5. (a)–(c) Non vibrating and non camouflaged object, (a) the spectrogram, (b) the temporal signal and (c) its power spectrum. (d)–(f) Vibrating and non camouflaged object, (d) the spectrogram, (e) the temporal signal and (f) its power spectrum.

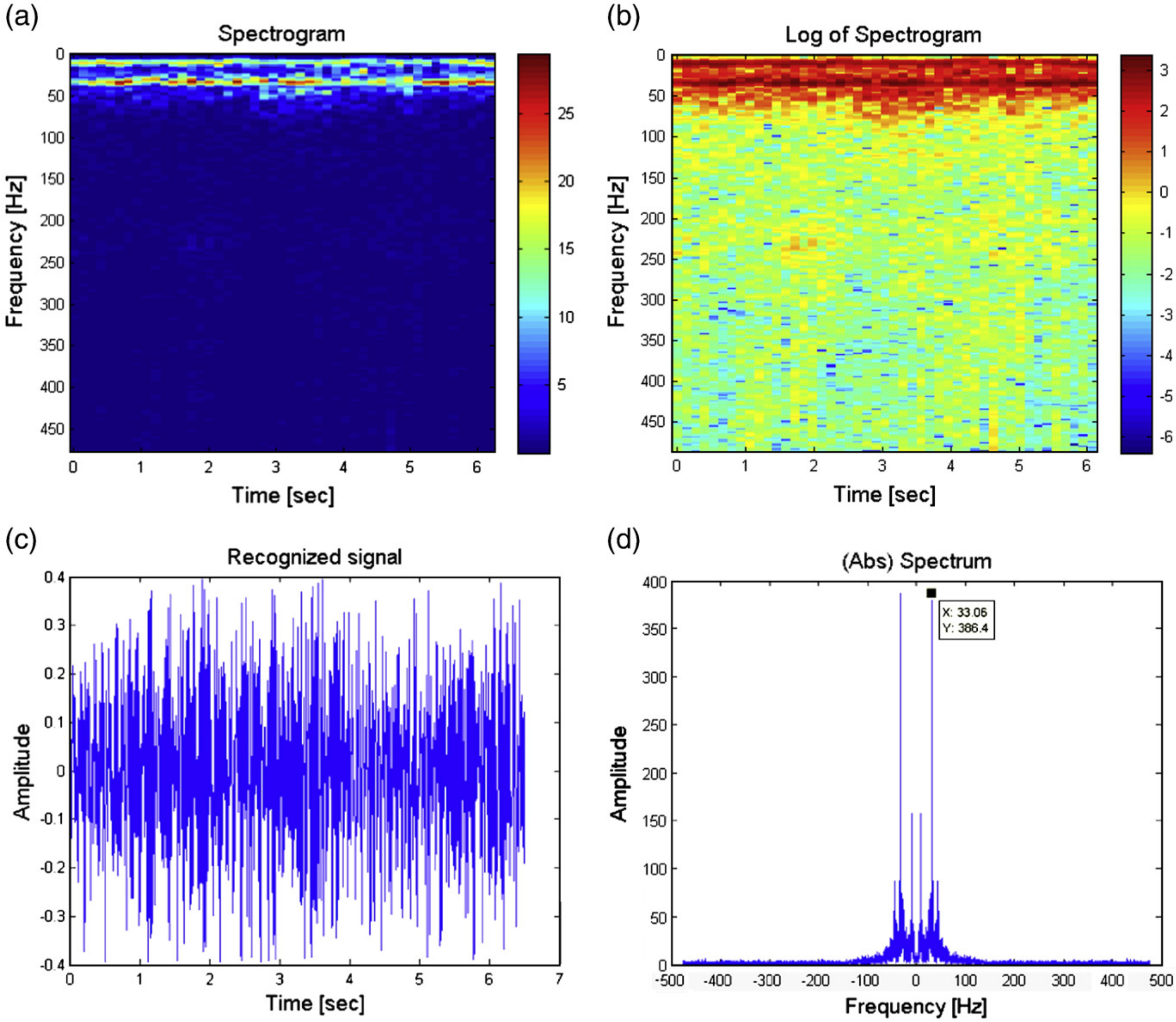

Fig. 6. Camouflaged and non vibrating object. (a) The spectrogram, (b) the log of the spectrogram, (c) the temporal signal and (d) its power spectrum.

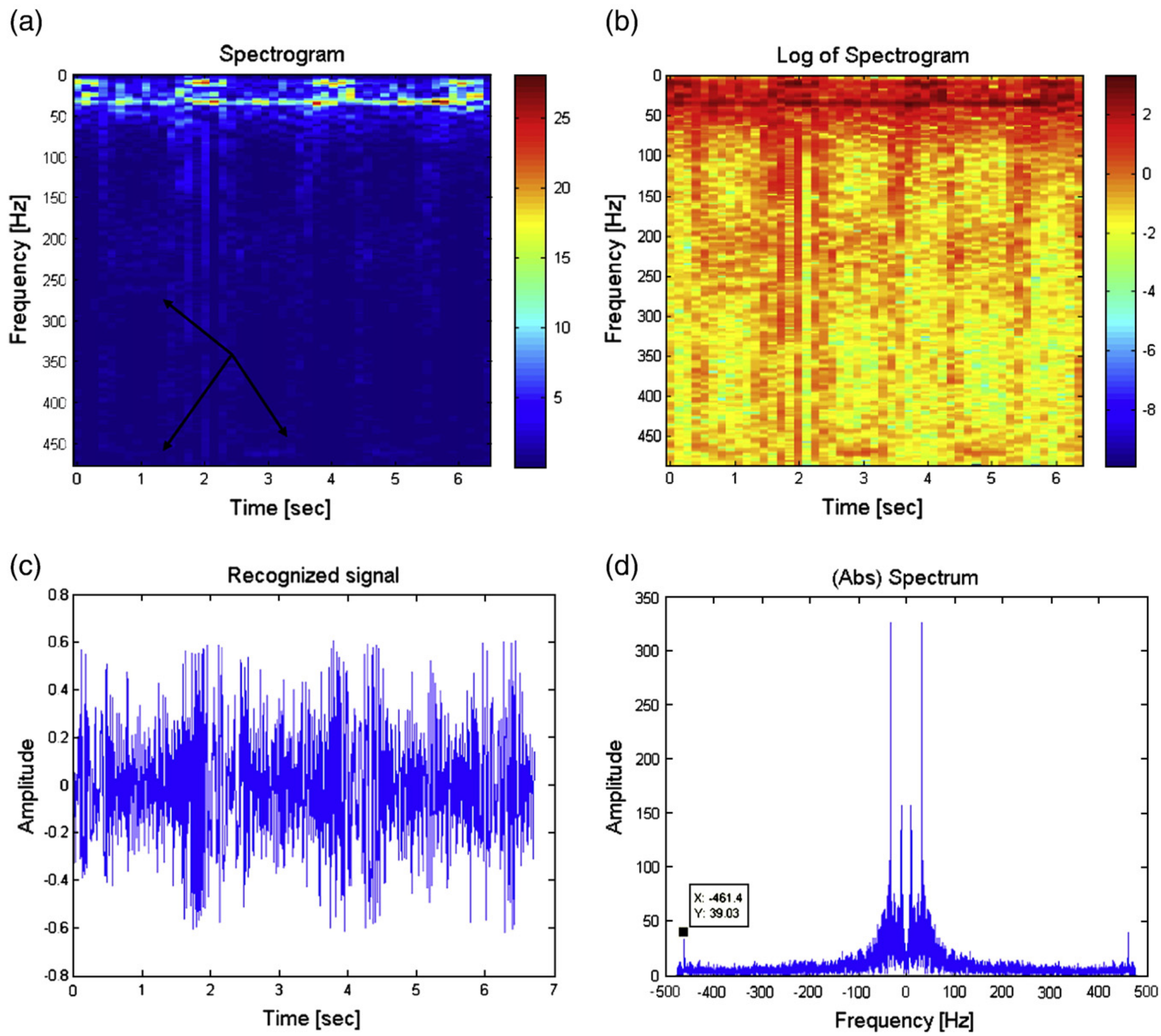

Fig. 7. Camouflaged vibrating object. (a) The spectrogram, (b) the log of the spectrogram, (c) the temporal signal and (d) its power spectrum.

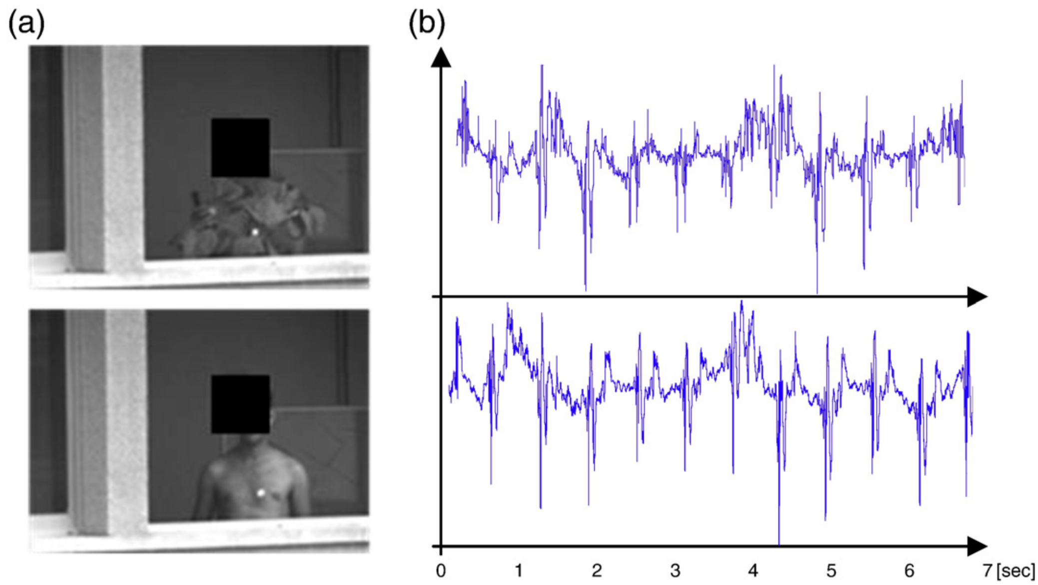

Fig. 8. Camouflaged subject. (a) The scenario of the experiment, (b) experimental results: upper recording is of the camouflaged subject. Lower recording is the same subject without the camouflage.