Assessment of laser-dazzling effects on TV-cameras by means of pattern recognition algorithms

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ABSTRACT

Imaging systems are widespread observation tools used to fulfil various functions such as detection, recognition, identification and video-tracking. These devices can be dazzled by using intensive light sources, e.g. lasers. In order to avoid such a disturbance, dazzling effects in TV-cameras must be better understood.

In this paper we studied the influence of laser-dazzling on the performance of pattern recognition algorithms. The experiments were performed using a black and white TV-CCD-camera, dazzled by a nanosecond frequency doubled Nd:YAG laser. The camera observed a scene comprising different geometrical forms which had to be recognized by the algorithm. Different dazzling conditions were studied by varying the laser repetition rate, the pulse energy and the position of the geometrical forms relative to the laser spot. The algorithm is based on edge detection and locates areas with forms similar to a reference symbol. As a measure of correspondence it computes the degree of correlation of the different areas. The experiments show that dazzling can highly affect the performance of the used pattern recognition algorithms by generating lots of spurious edges which mimic the reference symbol. As a consequence dazzling results in detrimental effects, since it not only prevents the recognizing of well defined symbols, but it also creates many false alarms.

Keywords: laser-dazzling, imaging system, CCD camera, pattern recognition

1. INTRODUCTION

Imaging systems are widespread observation tools used to fulfill various functions either for civilian or military purposes such as detection, recognition, identification and video-tracking. Low cost TV-cameras with 8-bit dynamic range are very sensitive to strong lighting, and their pixels can easily be saturated even by incoherent light sources such as lamps or flashes. More sophisticated devices like thermal imagers or 16-bit cameras are very often quite sensitive to strong light fluxes, as their sensitivity and resolution are increased. Moreover, all these devices can be dazzled by using coherent laser sources.

The studies of the sensitivity of cameras or focal plane arrays to laser blooming are very rare in the open literature. In 1997, a French team has studied and quantified the sensitivity to dazzling of a CCD camera operating in the visible and near infrared band. Still in 1997, another team in Israel has evaluated the blooming effects on an InSb focal plane array. More recently, in 2005, the dazzling effects of a femtosecond laser were demonstrated.

But many of these studies do not go further than giving qualitative results or simple demonstrations of very complex phenomena. A more comprehensive understanding of the physical phenomena leading to the dazzling effects on cameras is a necessary step on the way to quantifying these effects and establishing new figures of merit and performance criteria for imaging systems.

Quantifying the efficiency of dazzling effects is complex, as this efficiency depends on the very mission the dazzled device is designed to accomplish. High resolution imaging systems perform demanding missions and dazzling could easily prevent the imaging system from being operative. On the other hand, low resolution systems are less demanding and should be less annoyed by dazzling devices.
In this paper, dazzling experiments were performed on black and white TV-CCD-cameras using a pulsed nanosecond frequency doubled Nd:YAG laser. First, the different physical phenomena taking part in the dazzling effects were evidenced.

Next, pattern recognition algorithms were developed, and their efficiency assessed. These algorithms can provide appropriate benchmarks for the assessment of laser dazzling effects on cameras in the case of highly demanding missions such as target recognition.

2. METHODOLOGY

2.1 Experimental set-up

The experiments were performed using a black and white TV-CCD-camera, dazzled by a pulsed nanosecond frequency doubled Nd:YAG laser (Fig. 1).

The Nd:YAG laser is a solid state laser continuously pumped by laser-diodes (DPSS), so that the laser pulse repetition frequency (PRF) can be varied from very low PRF values (down to 10 Hz) to very high values (up to 100 kHz). The PRF tuning does not modify the beam profile emitted by the laser, neither the beam quality which is very good ($M^2 < 1.2$). To protect the laser from unwanted back-reflected light, an optical isolator is placed at the exit of the laser beam. The average power of the laser varies with the PRF, and reaches 20 W at the highest PRF. The energy per pulse varies from 4 mJ at low PRF to 0.2 mJ at highest PRF, and would be always higher than 1 mJ per pulse if the PRF does not exceed 20 kHz.

The Nd:YAG laser beam passes through a two-lens system (telescope) equivalent to a focusing lens with tunable focal length and is doubled in a nonlinear crystal of KTP. A special KTP crystal with "full resistance" to the high PRF has to be used. The efficiency of conversion in this crystal is around 30%, without optimizing the length of the crystal for doubling. Next, the green beam at 532 nm is separated from the fundamental beam using two beam splitters.

After these beam splitters, the available energy exceeds the damage threshold of the focal plane array of the camera. So it is necessary to reduce the beam power to limit the effects to dazzling. Three devices are used: i) an attenuator using the Nd:YAG laser polarization to attenuate its power; ii) an uncoated glass plate reflecting only the Fresnel loss of a few
percents towards the camera; iii) a set of neutral density filters that can be used to adjust the power of the incident beam on the camera.

The laser beam is finally directed towards the camera which observes a scene. A hole pierced in a screen representing an artificial scene makes it possible to overlap the dazzling laser beam with the artificial scene that is observed by the camera. The experimental results presented below were obtained for the case that the dazzling laser beam was very close to the normal incidence of the CCD camera’s focal plane array.

2.2 Laser beam quality

The beam quality was measured through a z-scan of the laser beam diameter at 1/e².

The Nd:YAG laser delivers a quasi TEM₀₀ beam with a circular beam profile (Fig. 2). Its divergence is 2 mrad, and the beam M² is less than 1.1. The beam can be focused into a circular spot in the doubling KTP crystal, using the telescope to adjust the beam waist in the crystal.

For the 532-nm beam, the divergence is 2.7 mrad. The green beam has not a perfect TEM₀₀ mode, but is yet circular and homogeneous. The beam quality factor M² is close to 1.5, and the beam quality is therefore considered high enough for the dazzling experiments (Fig. 2).

![Fig. 2. Laser beam profiles: 1.064µm (left) and 532 nm (right).](image)

2.3 The TV-camera

The TV-camera used in these experiments is a low cost Sanyo VCB 3440-P camera. It is classically used for video-monitoring. It is an interlaced-frames CCD camera, with an 8-bit resolution, and a 1/3 inch CCD image device containing 542 x 584 pixels.

This very standard camera has an interesting feature: all its automated electronic tools can be switched off and set manually. These include an Automatic Gain Control (AGC) tool, a backlight compensation tool and an electronic iris. There is also a tool to synchronize the camera’s clock with the power line alternate current. The exposure time can be chosen between 1/50 s and 1/10000 s.

The camera was equipped with a NLENS3314MI varifocal lens from National Electronics. The focus and aperture were set manually. The focal length varies from 3.3 mm to 14 mm, and the f-number from F1.4 to F∞.
3. DAZZLING EXPERIMENTS

3.1 Physical phenomena taking part in the dazzling effects

The observation of the physical phenomena that gradually impair the image from the CCD-camera is done by comparing successive images obtained for increasing values of the laser pulse energy and increasing PRF.

Three classes of phenomena were distinguished: first, saturation appears as the increasing laser energy incoming on the camera spreads over the pixels, creating a saturated spot in the image; second, some electronic effects during charge transfer appear, directly related to the ratio between the PRF of the laser and the read out frequency of the camera; third, optical effects created in the optics (lens and aperture) of the camera modify considerably the saturated spot on the camera.

At a low pulse energies received by the camera, the first observable effect is the saturation of the pixels located at the point of incidence of the laser beam. At very low energy levels, only a few pixels are saturated (typically 4 pixels, corresponding to a diameter of around 20 µm for the laser beam on the focal plane array), and the laser dazzling is barely visible in the image.

As the energy per pulse increases, the over-exposed area spreads over a larger number of pixels, creating a white bright spot in the image.

The next step is when "instrumental effects" show up. These are optical effects in the lens and through the aperture of the camera. The "lens flare" effect is one of them, but more generally, a complex lighting structure appears revealing a mix of multiple reflections, diffraction and scattering effects in the lens of the camera. More bright spots appear around the over-exposed area (Fig. 3) and the surface of the image that is impaired gets wider when the energy per pulse increases.

![Fig. 3. Dazzling effects at low level of energy per pulse](image)

When pulse energy is further increased, these effects keep on raising tremendously. Multiple concentric rings centered on the laser spot can be observed. These rings are the results of multiple reflections and diffraction of light in the lens of the camera.
When the energy per pulse is high enough, the pixels located in the same column as the laser spot begin to saturate too (Fig. 4). As these pixels are not directly exposed to the laser beam, this saturation is related to electronic effects occurring during the charge transfer process of the CCD camera. During the charge transfer process, charges should be drained to the ground. But such high energy levels create so many charges simultaneously, that this flux of charges overflows and manages to reach the read-out circuit of the CCD camera. But as these charges are not synchronized with the charge transfer process, some of them are created after the beginning of this process. Consequently, they are interpreted by the camera as coming from pixels located on the same column as the dazzled pixels but at a distance depending on the delay between the beginning of the charge transfer process and the creation of these overflowing charges. So, the number of saturated spots in the column depends on the ratio of the laser PRF and the camera read-out frequency, or more precisely depends on the number of laser pulses reaching the camera during the total read-out time.

For low PRF, only a few saturated spots can be observed on the column of the dazzled pixels. But at high PRF, the entire column can be saturated, as so many saturated spots are created that they overlap and fill the entire column.

Finally, at very high pulse energies, the pixels located at the center of the saturated spot tend to become gray, which indicates that they do not remain at their maximum level.

### 3.2 The pattern recognition algorithms

To study the dazzling effects a pattern recognition algorithm was developed. The patterns used in these first experiments were letters, as they are very commonly used to assess visual acuity in ophthalmology. We are also efficiently trained to recognize these patterns, and the experimental results obtained with letters could easily be interpreted visually.

Target recognition very often uses edge-detection based image processing techniques. For this reason, the algorithm is also based on such a technique, and the first step of calculation is to locate and draw all the edges existing in the camera’s frame. The algorithm operates on real frames acquired with the CCD camera. These frames are acquired in raw format so that no compressing algorithm mixes with the process.

The edge-detection is performed using a Canny algorithm: An edge in an image may point in a variety of directions, so the Canny algorithm uses 4 masks to detect horizontal, vertical and diagonal edges. The results of convolving the original image with each of these masks are stored. For each pixel, the largest result at that pixel is then marked, as well as the direction of mask which produced that edge. From the original image, this step of algorithm creates a map of intensity gradients and direction of the intensity gradient at each point in the image. With these estimates of the image gradients, a search is then carried out to determine whether the gradient magnitude as estimated from the image gradient operators assumes a local maximum in the gradient direction. From this stage referred to as non-maximum suppression, a set of edge points will be obtained, which can be referred to as "thin edges".

The higher intensity gradients are more likely to be edges. There is not an exact value at which a given intensity gradient switches from not being an edge into being an edge. Therefore Canny uses thresholding with hysteresis. Thresholding
with hysteresis requires two thresholds: high and low. Making the assumption that important edges should be in continuous lines through the image allows to follow a faint section of a given line, but avoids identifying a few noisy pixels that do not constitute a line. Therefore, the first applied threshold is the high threshold. This marks out the edges that can be fairly sure as genuine. Starting from these, using the directional information derived earlier, edges can be traced through the image. While tracing a line, the lower threshold is applied, allowing to trace faint sections of lines as long as a starting point is found.

Once this process is complete, the result is a binary image where each pixel is marked as either an edge pixel or a non-edge pixel. Fig. 5 gives examples of resulting images for the H letter.

Fig. 5: Examples of binary images given by the Canny edge-detection algorithm

In an undazzled image, the user selects the pattern to be recognized by a simple mouse click-and-span move. The Canny algorithm computes the edges of the basic pattern. Then, the Canny algorithm is applied to a real dazzled image and the edges are computed again.

During its last step, the algorithm scans the dazzled image with the sampled pattern edges picture, and assesses the degree of correlation between the pattern edges picture and the different areas of the dazzled image. Therefore, the algorithm is only successful to recognize an identical pattern with same size and same orientation.

A forthcoming improvement to the algorithm is the ability to recognize patterns with same shape but different size and/or orientation.

Fig. 6: Results of pattern recognition analysis displayed by the algorithm

Fig. 7: Histogram of the results of pattern recognition analysis displayed by the algorithm
The algorithm finishes by displaying the points in the image where the highest values of correlation were obtained (Fig. 6), as well as an histogram indicating the number of points with the highest degrees of correlation detected in the dazzled image (Fig. 7).

3.3 Experimental assessment of the dazzling effects on pattern recognition algorithms

When dazzling occurs, some parameters of the image considerably impair the chances to be able to recognize any pattern in it: these parameters are mainly the size and contrast of the pattern to be recognized, and the distance between the pattern and the laser spot (correlated with the pattern size).

Therefore, the scene presented in front of the camera during these dazzling experiments contained multiple clones of the reference pattern, each of them located at a different position from the laser spot. Experiments with variable size and contrast of patterns were also performed.

For a given laser PRF, when the energy per pulse is increased, the dazzled area spreads widely and masks many of the letters to be recognized. Of course, the algorithm is very sensitive to this spreading of the dazzled area and could not recognize the patterns located in the brightest part of the image (Fig. 8).

But the algorithm is able to locate patterns if they are in the less bright part of the dazzled area as can be seen in Fig. 9.
The experiments were performed for different values of the laser parameters (PRF and energy per pulse) and of the image parameters. The results are promising to achieve quantified assessment of the dazzling effects efficiency on an edge-detection based pattern recognition algorithm.

The experiments also revealed an interesting effect of laser dazzling: the complex structure created by the laser dazzling in the image contains numerous edges that the Canny algorithm will detect (Fig. 10).

![Fig. 10: Edge detection by the Canny algorithm in the case of a dazzled image](image)

These numerous edges generate false alarms and points out where the degree of correlation of the reference pattern can be high enough to be interpreted by the algorithm as a positive recognition.

These results indicate clearly the sensitivity of automated imaging systems to laser dazzling. They give preliminary hints for the design of an efficient way to protect automated imaging systems against dazzling, as the number of false alarms generated by the edge detection process should be reduced by the use of appropriate post-processing and filtering algorithms.

4. CONCLUSION

An experimental dazzling set-up using a pulsed frequency doubled Nd:YAG laser with tunable PRF was developed. The first dazzling experiments were conducted on a black and white low cost CCD camera, with manually controlled electronic features. The first results evidenced the physical phenomena involved in the dazzling effects.

An image processing algorithm for pattern recognition was developed. This algorithm is based on an edge detection Canny algorithm, and computes the degree of correlation between a reference pattern and different locations in an image. Experiments were performed to assess the effects of dazzling on the performances of such algorithms. These experiments demonstrated the sensitivity of automated imaging systems to laser dazzling.

These experimental results give preliminary hints towards improved algorithms with fewer false alarms generated by the edge detection process. Such hardened algorithms should be used in automated imaging system to decrease their susceptibility to dazzling.

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REFERENCES


