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On a New Technique in Laser Spot Detection and Tracking using Optical Flow and Kalman Filtering

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Abstract. Laser spot emitted by laser pointers were widely used in numerous fields such as pointing during presentations, guiding robots in human machine interaction (HCI), and guiding munitions to targets in military, etc. Our interest is to develop an effective method for laser spot detection and tracking with exploiting fewer features. In this paper, we jointly combined pyramid Lucas–Kanade (PLK) optical flow for detection and extended Kalman filter for accurately tracking laser spot in low-resolution and varying background video frames. Using this new technique, we only need to deploy intensity of laser spot with displacement of laser spot and get a very good result. This technique could be embedded into multi-core processing devices with inexpensive cost for potential high benefits in the future.

Keywords: spot detection and tracking, PLK optical flow, extended Kalman filter.

1. Introduction

Laser comes from the initials of Light Amplification by Stimulated Emission of Radiation. It has many remarkable features such as monochromatic, highly concentrated, highly bright, etc. It is well known that the laser beam is produced in limited range frequency, which means the wavelength distribution is very narrow. In other words, laser could be easily avoided by polluting other colorful noise. The high centralization characteristic makes it emit narrow beam with low divergence over long distances. And high intensity means high energy density within the injection space. Due to these excellent features, laser could be practically exploited in different fields.

Today, there are many different varieties of laser products for industrial and commercial purpose. Thus, we can easily choose the right laser equipment for guidance in HCI. In [13], the authors used the librarian robots to identify the position of a target relying on the laser point. And for accurate tracking in launching munitions to targets, the system could seek and lock aim point without operator intervention by exploiting a beam of laser energy, as in [14]. Other applications are about surveillance, mapping, remote sensing, etc. So, there are many interesting studies focused on laser. Our interest is to develop an attainable algorithm to detect and track laser spot precisely.

It is a challenge to detect laser spot since it is very tiny in shape. And the spot would deform to ellipse, strip, or other irregular shapes in movement. So, it is hard to detect the whole spot in general conditions. Instead, we just detect the center of spot. The laser equipment could emit red, blue, green or other possible colored beam as well. Besides, the luminance of laser spot depends on the output power and background intensity. For safety, the output power of laser equipment is restricted in most jurisdictions. It cannot be very high to cause the moving laser spot changing in brightness and tending to be unstable in noisy environment. So, it is difficult to extract general features or segment from all possible laser spots under real environmental background. That means, it is very easy to miss detecting laser spots or false detecting noisy points. In the tracking parts, the moving speed and direction of laser spot are unknown. Obviously, the movement is nonlinear which makes tracking more difficult. The spots may drown in noisy obstructions in frames or even just move out of frames. It is a big challenge to track those missing spots correctly.

For now, there are already different methods proposed for object detection and tracking. These methods have deficiencies and their performance are limited. In [7], they reported success rate is low when using template matching technique, because their technique is not suitable for tiny object tracking. While in [6], color segmentation and brightness features were applied in color frames that increase the complexity of computation and could not work well when meeting similar color noises. In [10], the authors reported good result, but still used template matching.

Our algorithm mainly addresses the problem under some conditions of weakening the difficulties. Grayscale frames are processed to get rid of color limitation. At present, we only consider locate one spot each frame and leave multi-spots location in the future. We assume that the intensity of laser spot is brighter than the local background and there exists a displacement difference between the laser spot and background. The proposed method makes use of the relative ratio of intensity between the spot and local background. Besides, we take into account the movement trajectory of laser spot to detect small spot in low-resolution images in time. The detailed algorithm will be described in section II. The experiment demonstrates that this new method is fast attainable and very effective.

The rest of this paper is organized as follows. In section II, we present our algorithm framework in detail. In section III, the Pyramid Lucas- Kanade (PLK) optical flow technique is introduced. Next, in section IV, we describe the extended Kalman filter (EKF). And we present the experimental results in section V. In the last, section VI is the conclusion.

2. Algorithm Framework

In this section, we would like to introduce our method in detail. Before dealing with data, the color video frames are converted to grayscale images and to double precision [0, 1]. First, we make two adjacent images (fpre, fnex) subtraction to get the difference frame and set all negative pixels to zero. This adjacent frame subtraction processing is for removing noise and most of the background. Then, we apply the image gradient technique to detect the candidates of laser spot in the difference frame. The gradient, denoted by ∇f , is defined as the vector g_x in horizontal and gy in vertical direction in frame f ,

$$\nabla f \equiv grad(f) = \begin{bmatrix} g_x \\ g_y \end{bmatrix} = \begin{bmatrix} \dfrac{\partial f}{\partial x} \\ \dfrac{\partial f}{\partial y} \end{bmatrix} \tag{1}$$

where $\partial f / \partial x$ and $\partial f / \partial y$ are partial derivatives of frame f , correspondingly. They could be obtained by kinds of approximation operators in digital image processing, like Sobel operators, Prewitt operators, etc see [3]. Then, after we got the derivatives, the magnitude of vector ∇f , $M(x, y)$, is computed by

$$M(x, y) = mag(\nabla f) = \sqrt{g_x^2 + g_y^2} \tag{2}$$

It yields the gradient image.

Next, we can binary the gradient image by choosing suitable threshold and use dilation to get the backup areas. Because the gradient just stresses the variation of intensity, when the intensity of some areas changes from bright to dark, the gradient is still large. For removing some dark areas, we also binarize the frame f_{pre} by using the high intensity as threshold. Then we compare the areas extracted from the binary frame f_{pre} and the backup areas from the gradient image of difference frame. Then the spot candidates will be picked up if they belong to the two areas.

Assume the spot could not be too tiny or too large, we only pick k regions with middle size as laser spot candidates. For each region R_k, the shape is different, so only the region center is computed as

$$x_{kc} = \frac{1}{m} \sum_{j=1}^{m} x_{kj} \tag{3}$$

$$y_{kc} = \frac{1}{m} \sum_{j=1}^{m} y_{kj} \tag{4}$$

where m is the number of pixels in each region (generally 5< m < 150) and (x_{kj}, y_{kj}) represents the position of each pixel in region R_k. The (x_{kc}, y_{kc}) is a candidate location of the laser spot center.