DETECTION AND TRACKING OF THREATS IN AERIAL INFRARED IMAGES BY A MINIMAL PATH APPROACH

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ABSTRACT
The goal of this paper is to develop an algorithm for extracting point features from sequences of aerial infrared images. We propose an efficient method for the detection of threats in a sequence of infrared images by looking for a trajectory which optimizes a regularized criterion. The regularity is introduced by a new concept of total curvature which eliminates too oscillating trajectories while allowing those with punctual changes of direction. In practice the research of an optimal trajectory is performed with an algorithm of dynamical programming type. Experimental results are also presented.

Index Terms— Point detection and tracking, infrared image sequence, total curvature minimization, minimal path, dynamic programming.

1. INTRODUCTION
The goal of this paper is to develop an algorithm for extracting point features in sequences of aerial infrared images. These point features represent threats for an airplane and should be robustly detected as rapidly as possible. This is not an easy image processing task as information in the background of infrared images is rich and makes the detection of point difficult. Indeed the specificities we have to handle are:

- The point features have a motion close to a piecewise rectilinear trajectory.
- Because of the limited resolution of the camera sensors, discretization effects are present in the image.
- Due to the optical system the threats are not always punctual and can have actually a support on several pixels in the image.
- The optical flow associated to the point feature is weak compared with the speed of the fly.
- Occlusion phenomena of the point feature are possible, because of, for example, the presence of clouds in the sequence.
- Of course the images are noisy.

Point feature detection in an image sequence relies on target detection and tracking which is a very active research area. Usual approaches consist in target detection and then tracking using a Kalman filter, an extended Kalman filter in the case of non-linear dynamical systems or Monte Carlo related methods as particle filter [1, 3, 4].

In this paper, we focus on point-like target detection and tracking, in a context of noisy infrared images with only one target to detect. Our approach is different form the ones mentioned above in the sense that we search for a point in a short sequence which has already been recorded. As it is impossible to detect the feature and discriminate it from other hot spots (noise or other elements of the scene) in only one image, a short sequence is recorded and the feature of interest is searched in the stack of images. It will be detected as it is a hot spot with a piece-wise rectilinear trajectory.

Our method consists in searching for the trajectories as optimal paths minimizing a cost function including a data term based on the observed image $I$ and a regularizing term. The data term forces the trajectories to be close to isolated luminous points. The regularization term avoids too oscillating trajectories. In practice our method for tracking minimal paths is inspired from dynamical programming tools.

The paper is organized as follows. In section 2 we present the specificities of the sequence of aerial infrared images. In section 3 we present our model for tracking point features and the dynamic programming algorithm we use. In section 4 we show some experimental results on sequences provided by SAGEM DS company for detecting threats.
2. SPECIFICITIES OF THE SEQUENCE OF AERIAL INFRARED IMAGES

2.1. Infrared imagery for threat detection

As it basically conveys a map of temperatures, thermal infrared imagery has been extensively used over past decades for the detection of threats. Infrared images make such threats - which include missiles for example - become detectable as hot spots even at long range, up to distances where they could not be suspected in the visible spectrum even though knowing of their existence and location. In the application under focus here, an infrared camera provides infrared sequences of the landscape seen from a low flying aircraft. In some of them provided as illustrative cases, a threat appears as a hot spot taking off from the ground and then flying over the landscape toward the aircraft. The images are of average quality, as we are interested in assessing the potential of our algorithms in conjunction with sensors in the low-to-medium bracket. Indeed, no matter how good the images are, the point of detection consists in being able to reliably single out a threat at a distance where its level compares with noise and clutter present in the sequence.

2.2. Motion compensation

As the aircraft flies over the ground, in turn, features of the landscape drift in the sequence taken from the aircraft. Background motion makes detection harder. Therefore, in order to overcome additional issues arising from background motion, we start by evaluating the motion of the landscape, in order to be able to compensate it - at short term - into a virtually stabilised sequence. In such a stabilised sequence, the threat normally represents the only outstanding motion. Algorithms used to perform motion analysis and compensation do not constitute the main focus of the article and therefore shall not be further detailed.

3. THE PROPOSED DETECTING METHOD

We denote $I^t(x, y)$, the infrared image at time $t$ after removing the background. We suppose that on a short time interval, the trajectory of the point feature is close to a straight line. We intend to do a local detection of the trajectory by searching for line segments approximating the trajectories. Taking into account the diffraction and integration on sensors, points appear as luminous patches in the sequence. So we enhance the resulting image by using a suitable filter $\chi$ which takes into account spread phenomena due to the imaging system. The construction of the filter $\chi$ is detailed in the next section.

3.1. Enhancement filtering

We consider two disks $S_1$ and $S_2$ of radius $r_1$ and $r_2$ with $r_1 < r_2$ (see Fig. 1). As we suppose that paths are locally close to straight line in the space $2D + t$, we suppose that luminous patches in the image $I^t$ are included in the disk $S_1$ whose center belongs to the trajectory. We define the function $\chi$:

$$\chi(x, y) = \begin{cases} 
\frac{1}{r_1^2} & \text{if } \|(x, y)\| < r_1 \\
-\frac{1}{r_2^2 - r_1^2} & \text{if } r_1 \leq \|(x, y)\| < r_2 \\
0 & \text{otherwise}
\end{cases} \quad (1)$$

For all $t$, we define $J^t = I^t * \chi$. This convolution means that we calculate the mean on the disk $S_1$ minus the mean on the ring $S_2 \setminus S_1$. $r_1$ is chosen according to the range of the spread due to the PSF of the imaging system. The luminous points in $J^t$ correspond to luminous patches in $I^t$. The image $J^t$ is similar to the Laplacian of $I^t$.

3.2. The detecting model

In this part we present our model for the detection of threats in a sequence of infrared images by seeking a trajectory which minimizes a regularized likelihood criterion. We search for the trajectories passing through the luminous points of $J^t$ as seen before. These trajectories must be close to piecewise rectilinear movements. Let be $A$ and $B$ two points of the image sequence $J^t$, we denote the curve $C_{AB} = (x(t), y(t), t)$ linking $A$ and $B$. We introduce the following cost function for the trajectories:

$$\text{Cost}(C_{AB}) = \sum_{t=t_1}^{t_2} -J^t(x(t), y(t), t) + \alpha C_T(C_{AB}) \quad (2)$$

We look for the trajectory which minimizes the cost (2). The first term corresponds to a data term favouring the trajectories which are close to luminous points and the second one...
is a regularizing term. The regularity is introduced by a new concept of total curvature introduced by A. Baudour in [5] and denoted by $C_T$. This notion eliminates too oscillating trajectories and allows those which present punctual changes of direction. The total curvature of the curve is designed to estimate the oscillating amount of $C_{AB}$ and forces piecewise affine trajectories. In the case where the curve $C$ is $C^2$ and if its curvature at $s$ is denoted by $k(s)$ (supposed to be positive), then:

$$C_T = \int_0^L k(s) ds.$$  

(3)

The total curvature extends this notion to more irregular curves. For more details, we refer to Appendix A.

**Remark 3.1** We can show [5] that the total curvature is additive with respect to the sum of curves and this property implies the additivity of the cost function (see Fig.2 and Appendix A) and this additivity property is essential for the implementation of a fast method of dynamical programming type.

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**Fig. 2.** Illustration of the graph algorithm and cost decomposition property. $Cost(C_{AB}) = \min(Cost(C_{AC}) + Cost(C_{CB}), Cost(C_{AD}) + Cost(C_{DB}), Cost(C_{AE}) + Cost(C_{EB}))$

Now we define

$$dist(A, B) = \min_{C_{AB}} Cost(C_{AB})$$

(4)

where the minimum is calculated over the set of curves $C_{AB}$ which link the points $A$ and $B$. Let $A$ be a predetected point of the trajectory at the time $t_0$, the aim is to find for a given time $t > t_0$ the point $B$ on the image $J^t$ which minimizes the distance $dist(A, B)$ to obtain a minimal curve $C_{AB}$. The optimal trajectories are calculated by searching for minimal points thanks to a dynamical programming algorithm which gives a fast method. For that we use a method based on the Dijkstra’s algorithm which is devoted to the single-source shortest path problem for a graph (see [6]). Taking into account the causal nature of the trajectories in this application, the graph is oriented and in this case the algorithm could be described as follows:

**Minimal paths in $2D + t$**

The method consists in calculating the distance from $A$ at time $t_0$ to the other points of the slide at time $t > t_0$. The initial point $A$ is detected as a luminous point in the sequence $J^t$, in other words, it is a point where its intensity is higher than an absolute threshold (the sequence $J^t$ is normalized for every observation) and we take the first image (time $t_0$) of the sequence $J^t$ where such a point is detected. Then we use this information to calculate the distance from $A$ to the points of the slide at time $t + 1$. The following algorithm provides a fast method to minimize the criterion (2).

1. At step $t$ we know the distance $dist(A, P_t)$ for each point $P_t \in J^t$.
2. For all point $P_t \in J^t$ with $dist(A, P_t) < S$ where $S$ is a threshold, for all point $P_{t+1} \in J^{t+1}$ in the neighbourhood of $P_t$, we calculate the cost of $dist(A, P_t)^t + Cost(P_tP_{t+1})$.
3. For all point $P_{t+1} \in J^{t+1}$, we determine $dist(A, P_{t+1})$ (see Fig. 2) and we update the distance from the point $A$ to the point $P_{t+1}$.
4. We start again at point 1.

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4. RESULTS

We have obtained detection results with this method on sequences of aerial infrared images supplied by the SAGEM DS Company. Several signal on noise ratio have been tested. In fact we do vary in our experiments, the distance of the target from the camera on the plane. The more the target is far, the more the signal to noise ratio is small due to less signal intensity and resolution. The method shows good results up to a noise which corresponds to a PSNR (standard ratio) of 10.7 dB for the sequence $I_j$. Sequences will be shown at the conference. We present here one image from the sequence (Fig.3 the original image and Fig.4 the detection).

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5. CONCLUSION

We have presented a method devoted to the detection of point features in sequences of aerial infrared images. The research of an optimal trajectory is phrased in terms of a regularized-criterion and the regularizer is based on the new concept of
total curvature. This notion eliminates too oscillating trajectories and allows those with punctual changes of direction which can correspond on change of acceleration of the target. The model is complemented by its implementation using an algorithm of dynamical programming type which is known to be fast. The experimentations show that the proposed approach performs well, the optimal trajectory is determined and the threat is detected in the tests on the infrared images supplied by the SAGEM DS Company.

6. APPENDIX A: TOTAL CURVATURE

In order to detect filaments in images, A. Baudour has introduced in [5] the notion of total curvature to take into account the oscillations of the filaments and piecewise regular curves.

Let be $C(s)$ a simple curve (i.e. which does not intersect itself) of $\mathbb{R}^2$, continuous, piecewise $C^1$ and parameterized by its arclength parameter, with $t \in [0, L]$, $L$ being the length of the curve $C$. We denote $T(t) = (T_x(t), T_y(t))$ the unit tangent vector to $C(t)$, and let be $A$ and $B$ the points $C(0)$ and $C(L)$. We define the set of regular test functions $\phi : \mathbb{R}^2 \to \mathbb{R}^2$ with compact support:

$$E = \{ \bar{\phi} = (\phi_1, \phi_2), \bar{\phi}(C(0)) = \bar{\phi}(C(L)) = 0, \phi_1^2 + \phi_2^2 \leq 1 \}$$

The total curvature $C_T$ of the curve $C$ is defined as:

$$\sup_{\bar{\phi} \in E} \int_0^L T_x(s) \frac{\partial \phi_1(C(s))}{\partial s} + T_y(s) \frac{\partial \phi_2(C(s))}{\partial s} \, ds$$

Actually total curvature is defined as the total variation of the unit tangent vector to the filament. The notion of the total variation (TV) has been widely used for image regularization see [7,8]. A theorem called “collage theorem” is also established in [5]. This property is essential for using dynamical programming method. This theorem implies the additivity of the cost function.

**Theorem 6.1 (Collage theorem)** Let be two bounded total curvature curves $C_1$ and $C_2$, of length $L_1$ and $L_2$, such as $C_1(L_1) = C_2(0)$. Let be $D$ the continuous and piecewise $C^1$ curves of length $L_1 + L_2$ defined by:

$$D(s) = \begin{cases} C_1(s) & \text{if } 0 \leq s \leq L_1 \\ C_2(s - L_1) & \text{if } L_1 \leq s \leq L_1 + L_2 \end{cases}$$

Then $D$ is a bounded total curvature curve and

$$C_T(D) = C_T(C_1) + C_T(C_2) + \| \vec{T}_1(L_1) - \vec{T}_2(0) \|.$$ 

Numerically the total curvature of a piecewise affine curve in the sequence $J$ is then calculated with the “collage theorem”:

$$C_T = \sum_i \| \vec{v}_{i+1} - \vec{v}_i \|$$

where $\vec{v}_i$ are the unitary direction of the curve and the sum is evaluated on the set of segments which constitutes the curve.

7. REFERENCES


