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Dynamic tracking with simultaneous edge enhancement

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ABSTRACT

Due to the isotropic edge enhancement, the vortex phase filters are of commonly used in spatial filtering. In general, these filters employ a spiral phase mask on the Fourier plane, the square modulo from this convolution is the edge enhanced image. Nonetheless, several digital filtering applications based on vortex phase filters leave aside the complex-valued information. This complex-valued field is obtained from the Laguerre-Gauss transform application over static or dynamic events, namely single images or frames in a video. We propose the usage of complex field to locate and track phase singularities in dynamic events. In this sense, not only each object edges in a given scene are enhanced, but also phase singularities related to each object. This imprints a characteristic marker given by the assignation of optical vortex to objects with unique core structure properties, allowing for tracking a particular object in dynamic events.

1. Introduction

In recent years' numerous contributions dedicated to image filtering techniques have aroused, the growing interest is supported by the novel emergent applications for smartphones, computer vision, machine learning, among others. There exists several and powerful image filtering techniques oriented to different purposes [1], and in this context the edge detection techniques have a proven relevance by making possible the identification and isolation from a particular object in a given scene. From optics field, the spiral phase filtering is a well-known technique, which allows for the enhancement of object edges in an image, this may be performed with orientation selectiveness and high noise tolerance [2–5].

The edge enhancement is a must-have operation between the image processing tools. This operation is useful in a wide range of applications from cosmological to microscopy imaging [6,7], because large amount of information can be learned from images, by the sharp edge identification from objects in a scene; the recovered data will depend on the processed information nature. The edge enhancement process can be accomplished by the usage of different filtering techniques.

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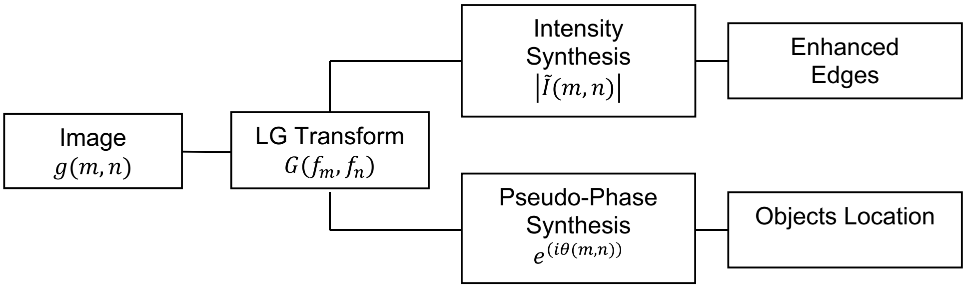

Fig. 1. Procedure scheme for both edge enhancement and object sub-pixel location.

By means of a converging lens it is possible to obtain the Fourier transform from information. Taking into advantage this fact, there exists an architecture formed by two converging lenses: one located a focal length apart from an image, the other two focal lengths apart from the latter; then in the plane located at the focal length of this last lens an image is formed, depending on the employed filtering mask on the first lens focal plane, the obtained image output will be modified (filtered). This architecture is commonly known as 4f architecture, and by selecting the adequate filter, the edges may be enhanced with directional selectiveness or in an isotropic manner [8]. An experimental implementation of the latter is presented in [9], where the authors employ a Laguerre-Gauss filter in the 4f architecture to enhance the object edges.

The digital implementation of this filtering technique for edge enhancement can be performed by using the Laguerre-Gauss transform. When using this transform it is possible to obtain a complex valued function from filtered images, even in low signal to noise ratio recordings [10]. With the complex information it is possible not only to find edges from a given object in a scene, but also to relate phase singularities to each object. A phase singularity will occur in those places where the real and imaginary parts are null. These singularities give each particular object a characteristic mark, which can be followed between different images or frames within a video or animation. The related phase singularities are used as image markers, giving the possibility to track several objects from different scenes or recordings, by matching the core structure properties from each of them [11].

In this paper, we propose the usage of complex fields obtained when filtering, allowing for synthesizing both the location and edges from objects in a given scene. In Section 2 we describe the process to synthesize the complex-valued information obtained by performing a Laguerre-Gauss transform from frames in a dynamic event. In Section 3 we present the results by using the procedure described in Section 2. First we present the processing of MRI images by using Laguerre-Gauss transform as stated in literature [2–5], second we present the complex field synthesis for video frames in a real video of an expanded polystyrene ball in a vibrating surface and in a simulated orbital movement of four particles. In the expanded polystyrene ball case, we tracked the phase singularities from pseudo-phase maps by matching its core structure properties. In the last example, we identify each object in a given scene by using simultaneously the intensity and pseudo-phase map information. Finally, each object trajectory can be determined.

2. Edge enhancement and tracking procedure description

The filtering and tracking process is accomplished by transforming the image of discrete spatial coordinate's m and n with Laguerre-Gauss transform, the output of this operation is a complex field related to the real-valued function from the image. Those complex fields can be interpreted as intensity and pseudo-phase maps, the field intensity will determine the objects edges within a scene, and pseudo-phase map synthesis in the context of phase singularities will determine the object location. This process is schematized in Fig. 1, and is conducted for each frame into dynamic events allowing for identify and track the motion of a given object in a scene.

To achieve this, for a given real valued function $g(m,n)$ its Fourier Transform $G(f_m,f_n)$ is obtained. It is possible to relate an analytic complex signal $\tilde{I}(x,y)$ by using a linear integral transform, where a Laguerre-Gauss filter $LG(f_m,f_n)$ is employed, the transform and the filter are described by [12]:

$$\tilde{I}(x,y)=\iint_{-\infty}^{\infty} LG(f_m,f_n)\,G(f_m,f_n)\,e^{2\pi(f_m x,f_n y)}df_m,df_n \tag{1}$$

$$LG(f_m,f_n)=(f_m+if_n)\,e^{-(f_m^2+f_n^2)/\omega}=\rho e^{-(\rho^2/\omega^2)}e^{i\beta} \tag{2}$$

where $\rho=\sqrt{f_m^2+f_n^2}$ and $\beta\equiv arctan\left(f_n/f_m\right)$ are the polar coordinates in the frequency domain and ω allows for controlling the bandwidth of the Laguerre-Gauss function. This transform can be applied over images and video frames as well, by defining the transform as the convolution from image with the inverse Fourier transform from filter. This provides a powerful tool to analyze and synthesize the information by relating a particular complex signal to each record, and in this manner obtain the intensity and pseudo-phase map in each case.

Among each of these complex-valued functions it is possible to locate and characterize phase singularities. The phase singularities are located where the imaginary and real parts from complex signals are null, in these points the phase has a helical behavior. Wang et al. described the core structure of each singularity in [12] by using the eccentricity e, the zero-crossing angle θ_{RI}; the topological charge q, and the vorticity defined as $\Omega \equiv \nabla \left\{ \Re \left\{ \tilde{I}(x,y) \right\} \times \nabla \left\{ \Im \left\{ \tilde{I}(x,y) \right\} \right\} \right\}$. The real and imaginary parts from complex field in the vicinities of a phase singularity are described as:

$$\Re \left\{ \tilde{I}(x,y) \right\} = a_r x + b_r y + c_r \tag{3}$$

$$\Im \left\{ \tilde{I}(x,y) \right\} = a_i x + b_i y + c_i \tag{4}$$

where the coefficients $a_k, b_k, c_k\,(k = r, i)$ are obtained by the least square method from the complex values near each phase singularities; the geometrical parameters for the core structure properties can be expressed in terms of these fitting coefficients as:

$$e = \sqrt{1 - \frac{\left(a_r^2 + b_r^2 + a_i^2 + b_i^2\right) - \sqrt{\left(a_r^2 + a_i^2 - b_r^2 - b_i^2\right)^2 + 4\left(a_r b_r + a_i b_i\right)^2}}{\left(a_r^2 + b_r^2 + a_i^2 + b_i^2\right) + \sqrt{\left(a_r^2 + a_i^2 - b_r^2 - b_i^2\right)^2 + 4\left(a_r b_r + a_i b_i\right)^2}}} \tag{5}$$

$$\theta_{RI} = \left\{ \begin{array}{c} |\tan^{-1}\left[\dfrac{a_r b_i - a_i b_r}{a_r a_i - b_r b_i}\right] ||\theta_{RI}| < \dfrac{\pi}{2} \\ \pi - |\tan^{-1}\left[\dfrac{a_r b_i - a_i b_r}{a_r a_i - b_r b_i}\right] ||\theta_{RI}| > \dfrac{\pi}{2} \end{array} \right\} \tag{6}$$

$$\Omega = |a_r b_r - a_i b_r| \tag{7}$$

$$q = sgn\left(a_r b_i - a_i b_r\right) \tag{8}$$

Note that core structure properties are determined by the image values in the vicinity of a singularity and the filter definition, thus act as image markers which allow tracking them between scenes. The process is conducted by matching the core structure properties from the singularities related with a given object with those singularities found in a new scene. The phase singularities have in theory arbitrary location but due the experimental conditions its localization has some resolution and noise constrains, these restrictions where studied and presented in our previous work [13].

3. Experimental results

Albeit of being already implemented on 4f architectures, this filtering technique is useful on a further range of applications. This means, that the information not always may be processed on laboratory, nonetheless by using a linear integral transform with a Laguerre-Gauss filter, we obtained a powerful tool for the synthesis and analysis of images, not only enhancing the edges but also providing a versatile tool for tracking dynamic events. This becomes handy when expanding the usage of the available equip on a laboratory, as in the case of an optical microscope; or in the case of dealing with images of any kind recorded by any means, such is the case of smartphone camera images or video frames.

As it is well known, it would not be possible to retrieve information from medical images without the help of image processing techniques. By using this algorithm, it is possible to process and synthesize different images obtained by a given technique. We used two brain MRI Image from MRI Multiple Sclerosis Database (MRI MSDB) [15–17]. In Fig. 2a) the original images are depicted, in b) the filtered image intensities when using the Laguerre-Gauss Transform, these images contain the information related with original image edges; in c) the superposition from the obtained edges and the original images. It should be noted that the boundaries related structures in the image are well defined, no preprocessing stage was conducted. In the original image noise is present given the registration method. In summary, the procedure allows identifying edges that help improving the quality of the MRI images and in judging their significance.

Besides the edge enhancement capabilities, the digital filter also allows for track objects in dynamic events. As it is well known, ordinary real-valued images do not have phase singularities. However, as it was described in Section 2, this is achieved by using the complex information assigned when the linear integral Laguerre-Gauss transform is employed as detailed in Section 2. Then, the procedure converts a real-data image into an analytical field that permits the finding of the singularities, which uniquely determine the image under investigation. The phase singularities contained in the pseudo-phase information generated from images is determined. The tracking process is conducted by matching the core structure properties from the singularities related with a given object with those singularities found in a new scene. As mentioned above, the core structure properties are determined by the image values in the vicinity of a singularity and the filter definition, thus act as markers which allow tracking them between scenes. In Fig. 3 we record a video from an expanded polystyrene ball in a vibrating surface, obtaining random trajectories, which were followed and depicted by using the proposed filter. The experiment of object tracking making use of the information about the location and the core structure of the pseudo-phase singularities, and demonstrate the performance for non-uniform displacement measurement. Then, we verify that the singularity core structure can serve as a marker that uniquely characterizes an individual pseudo-phase singularity, and can be used for the purpose of tracking the complicate movement of the expanded polystyrene ball (see video in Fig. 3).

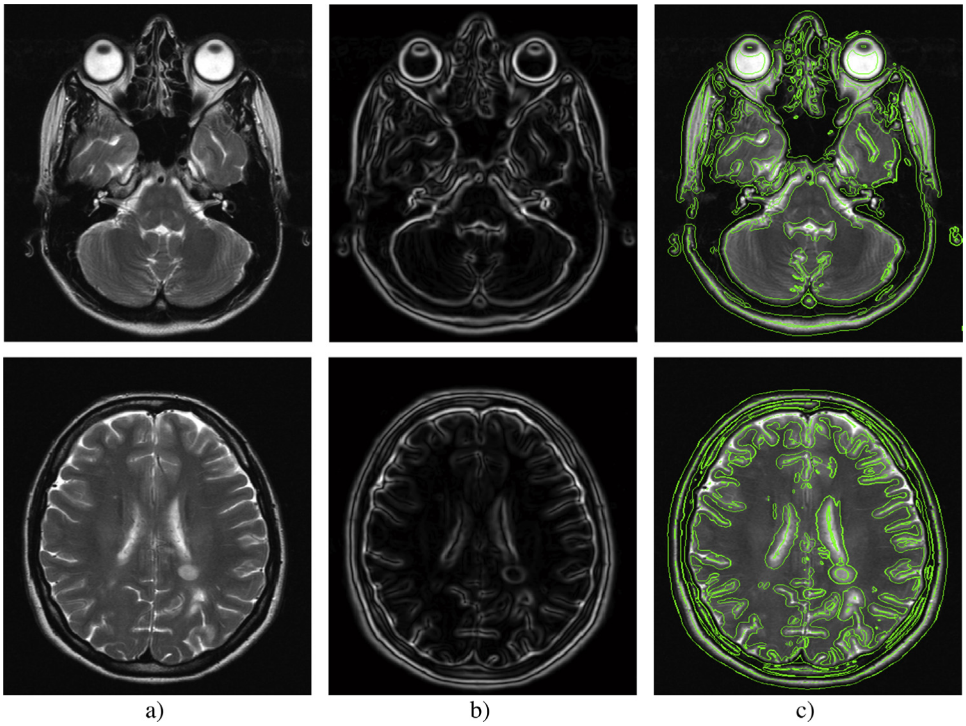

Fig. 2. MRI image. In a) the head upper-view MRI is depicted, while in b) the outcome of the edge enhancement digital filter applied, in c) the superposition from the obtained edges and the original images.

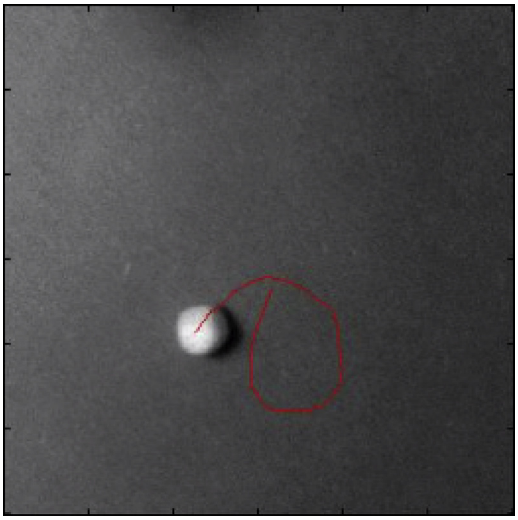

Fig. 3. Video frames tracking from an expanded polystyrene ball moving a vibrating surface.

Note that the parameters characterizing the pseudo-phase singularities remain without significant changes permitting the adequate tracking of the expanded polystyrene ball.

They key idea of the newly proposal is that, in addition to the information about the core structures of the phase singularities, we simultaneously determine the object size and shape. Simulations have been conducted to demonstrate the validity of the idea. In Fig. 4 two frames from a synthetic video with three different shapes are depicted, in a) and b) the recorded frame with enhanced edges; in c) and d) the information related with the Laguerre-Gauss intensity synthesis; and in e) and f) the pseudo-phase map generated from filtering, the phase singularities related with each shape are tracked and preserve the core structure properties in the different frames. If the objects slightly change their shapes, the phase-singularities may be also slightly decorrelated, and then to track the phase singularities, a tolerance value range must be previously selected. Note that these properties are given by the image function and the Laguerre-Gauss filter properties.

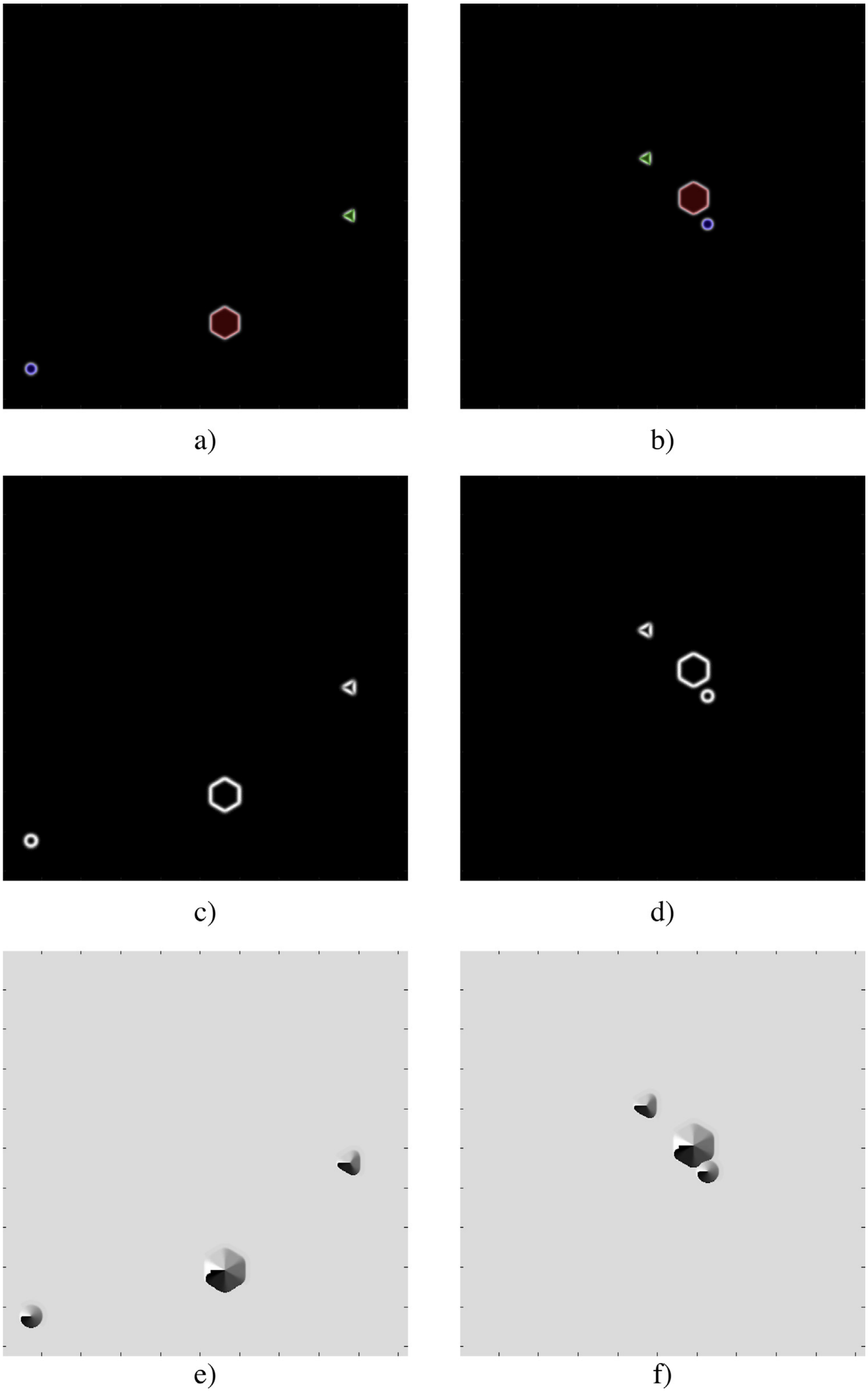

Fig. 4. Frames from synthetic video with three different shapes are depicted, in a) and b) recorded frames with enhanced edges; in c) and d) information related with the Laguerre-Gauss intensity; and in e) and f) the pseudo-phase map generated from filtering.

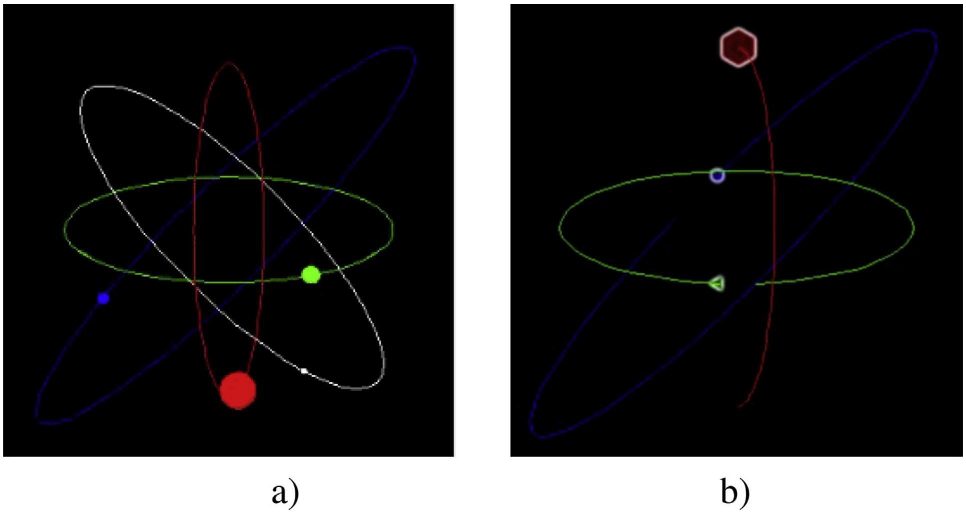

Fig. 5. a) Particles with different size and velocity movement tracking, b) particles with different shape and velocity movement tracking.

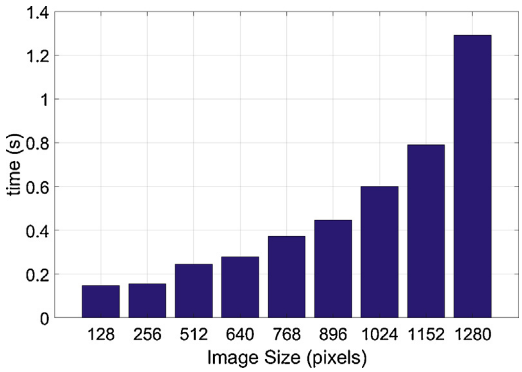

Fig. 6. Computational times for the tracking of 4 particles orbital motion simulation when increasing the search space.

We present dynamic events synthesis, in both simulated and real videos recordings. First we simulate the orbital motion of 4 particles. In Fig. 5a) each particle has different size and velocity, and then we find and depict the motion trajectories, by isolating each of them and matching the core structure properties from the phase singularities available in each frame. A second simulation (Fig. 5b) was performed with different shapes, depicting both the trajectories and edges in each frame. The videos are linked with the frames presented in Fig. 5a) and b) respectively.

When using the Laguerre-Gauss transform to synthesize the different frames from a dynamic event the scenes are globally evaluated, for this reason it is no necessary to have a-priori information about object position. The phase-singularities associated to the objects are tracked and matched frame to frame. In order to evaluate the computational times required to process each frame we track the objects in the 4 particle orbital motion simulation, we used squared frames ranging from 128×128 to 1280×1280 pixels while the number of objects and their sizes remain constant, increasing the search space of the objects on each frame. The computing time results when using a computer with an Intel(R) Core(TM) i7-3770 CPU at 3.40 GHz processor and 10.0 Gb RAM are depicted in Fig. 6. It should be noted that frame size is the main contributing factor in the computing time as the objects recognition and tracking is performed globally.

In summary, the method allows tracking different particles in each frame of a dynamic video by using the complex field from the image, obtained from the Laguerre-Gauss transform. As mentioned above, the intensity map will determine each particle edges within a scene (object shape and size) and pseudo-phase map synthesis will determine each particle location. Both tools represent an alternative to distinguish different particles (size, shape and core structure properties) and determine its trajectory. Note that the singularities are located in each frame with sub-pixel resolution as stated by Wang et al. [12], allowing for accurately tracking the location from given object with same precision.

4. Conclusions

We propose the synthesis from a digital spiral phase filter complex-valued function to track objects in dynamic events with sub-pixel resolution. We showed that this filter is suitable to the digital edge enhancement from images, as well as a tracking alternative by means of the analysis from the complex fields obtained by its usage. The latter, gives the possibility to recognize and locate multiple objects in scenes; by following the phase singularities present in pseudo-phase maps assigned to each particular image. We foresee the diverse range of applications for this digital filter, based on the presented capabilities for accurately resolve low quality images.

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