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3-D FFT Moving Object Signatures for Velocity Filtering

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Abstract— **In this paper a bank of velocity filters is devised to be used for isolating a moving object with specific velocity (amplitude and direction) in a sequence of frames. The approach used is a 3-D FFT based experimental procedure without applying any theoretical concept from velocity filters. Accordingly, each velocity filter is built using the spectral signature of an object moving with specific velocity. Experimentation reveals the capabilities of the constructed filter bank to separate moving objects as far as the amplitude as well as the direction of the velocity are concerned. Accordingly, weak objects can be detected when moving with different velocity close to strong vehicles. Accelerating objects can be detected only on the part of their trajectory they have the specific velocity. Problems which arise due to the discontinuities at the edges of the frame sequences are discussed.**

Index Terms—**Velocity filters, filter banks, 3-D FFT.**

I. Introduction

Detection and tracking of moving objects (such as vehicles, people, planes, etc.) is one of the complex topics in the field of automotive applications, covered by many researchers all around the world. Several approaches have been made to detect multiple objects, their velocity or estimate the varying velocities of these objects using different kinds of sensors and procedures [1,2].

Velocity filters have been used so far for the detection of multiple moving odjects in image sequences [3] as well as in three-dimensional imagery [4-5]. Especially, the work in [3] extends the method of velocity filter banks by a heuristic search of possible target trajectories. In [4] a motion-based approach is presented to simplify the detection of moving objects, where the image sequence containing the moving object is interpreted as a three-dimensional signal. Also, in [5] an approach for detecting moving objects is presented, which is based on three-dimensional filters not only taking spatial but also temporal information into account. In [6] and [7] velocity filter banks were applied for moving object detection. Finally, in [8] a novel motion detection technique was proposed for multiple objects detection in image sequence. The algorithm is based on directional filtering in the spatio-temporal frequence domain using 3-D FFT.

In this paper, a bank of velocity filters is built for separating multiple objects with different velocities in a sequence of frames. In this procedure the 3-D FFT transformation of a large variety of different velocities has been used. The proposed approach is based on experimentation and avoids to employ theoretical concepts. Accordingly, an object moving each time with different velocity and various directions has been used in order to construct the filter bank. Multiple moving objects can be isolated from other objects with different velocities or from objects with the same amplitude of velocity but having different directions. Experimentation with objects having various velocities, accelaration or varying strenght in their illumination has been carried out in order to test the capabilities of the constructed velocity filter bank. Discontinuities of the signal are thoroughly discussed and ways to cope with signals that suddenly appear at the edges of the data cube are given.

The organization of the paper is as follows. In section 2 the data used are described while in section 3 the construction of the velocity filter bank is analytically explained. The experimentation regarding the performance of the filter bank on various data is carried out in section 4. Finally, the conclusions are drawn.

II. Data Base Description

Each simulated data set that was used in order to create the spectral signatures of different moving objects consists of 256 frames, of 256x256 pixels each. Accordingly, a data cube (shown in Figure 1) is formed of 256^3 pixels. The number $256=2^8$ was selected to fit the FFT requirements for fast evaluation of the 3D spectrum.

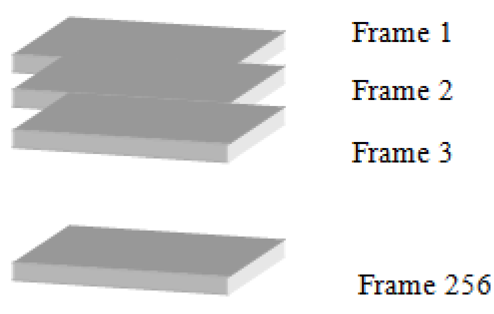

Figure 1. 256 frames of 256x256 pixels each (Data cube)

The time parameter is considered to be the distance from frame to frame. Based on this remark, the amplitude of the radial velocity of each object is reffered to as the number of pixels it comes across from one frame to the next. A simple example of one object of size 10x10 pixels that is moving with radial velocity of 1/3 pixels per frame is shown in Figure 2.

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The object is moving in direction 240° degrees with respect to horizontal left-to-right direction. Four different frames are given i.e. the 1st, 64th, 128th and 256th.

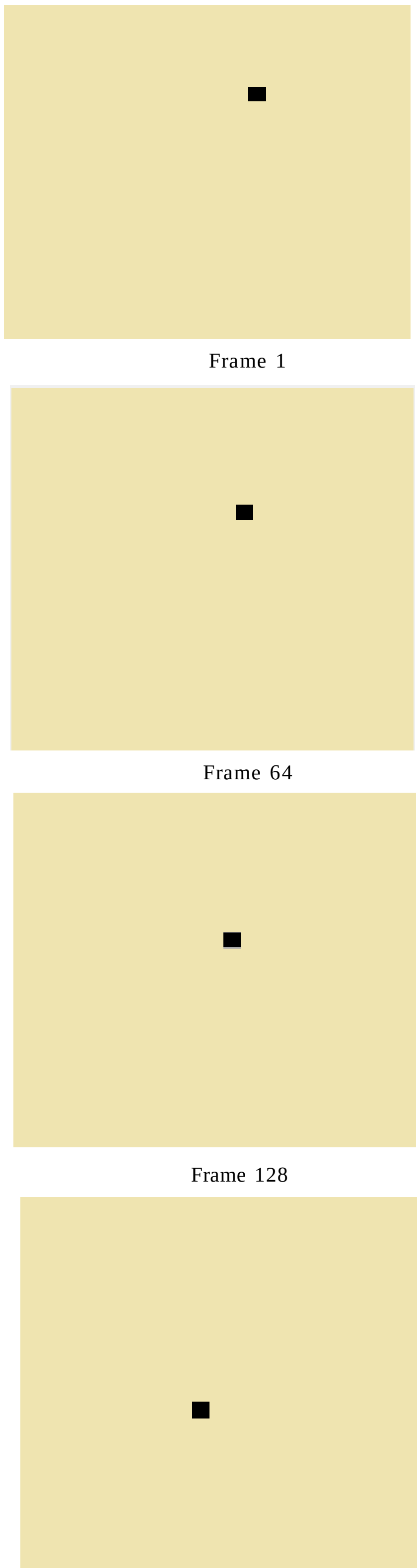

Figure 2. An object of size 10x10 pixels that is moving with radial velocity of 1/3 pixels per frame. The object is moving in direction 240o degrees with respect to horizontal left-to-right direction

In the frame sequence shown in Figure 2, the object appears suddenly in frame 1 at the position shown and ends at frame 256 in a different position. This will create spectral leakage artifacts in the 3D spectrum evaluation. A simple technique is described in the next paragraph to overcome this problem.

The data sets used for experimentation cover a wide range of velocities as far as the amplitude and the direction is concerned. Specifically, six different radial velocities (amplitudes) were selected i.e. 1/2 (fast), 1/3, 1/4, 1/8, 1/16 and 1/32 (slow) pixels per frame. For all these velocities 24 different directions were chosen with the first one at 0 degrees (horizontal direction from left to right) and anti-clockwise every 15°, as shown in Figure 3. Accordingly, a total of 6x24=144 different data cubes (velocities) were implemented. The directions of 240° shown in this figure is the one on which is moving the object shown is Figure 2.

Before evaluating the spectrum of each data set, a preprocessing stage follows. In this stage averaging is performed only in the time domain i.e. the same pixel in all frames, so that random changes in the movement of the object are avoided and simulation of real objects is better achieved. The averaging process employes a three point averager. Thus, smoothing spreads in the time domain the energy of each pixel only in the two neighboring pixels. Furthermore, abrupt changes between the first and last frame are suppressed so that spectral leakage is avoided. Moreover, spectral leakage is suppressed by employing objects moving away from the edges of the data cube. This way spectral leakage related to signal discontinuity at its edges is very small.

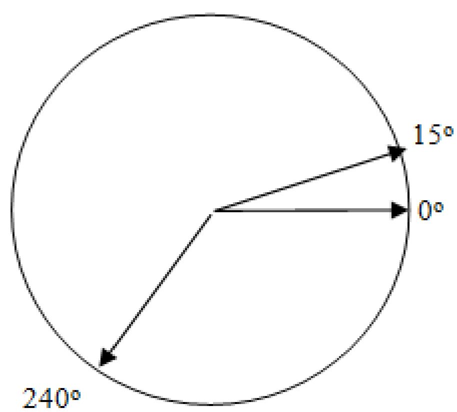

Figure 3. 24 different directions were chosen in the experimental procedure, with the first one at 0 degrees (horizontal direction from left to right) and anti-clockwise every 15°

III. 3D FFT FILTER BANK

The spectrum of each data set (frame cube of 256^3) was evaluated using the MATLAB routine fftn. The execution time is on average 0.25 secs (in a PC having an Intel(R) Core(TM) i7-2600 CPU @ 3.40 GHz processor). Since the spectrum is a complex quantity we evaluated its amplitude and phase separately. We have to mention that parallel trajectories in the data cube which correspond to objects having the same velocity, possess the same spectral amplitude informa

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tion and differ in the phase information. Accordingly, irrelevantly of the initial position of an object, its velocity corresponds to specific amplitude of the spectral content. Thus, only the amplitude information is of interest and was recorded.

Studying the amplitude of the spectral content of a data cube, one can easily observe that from the total of $256^3 \sim 2^{24}$ ~ 16 million harmonics, only a very small percentage has significant value. Thus, for each direction of the moving object with a specific velocity, we have created a file which contains the positions of the most important harmonics (about 4000). As important harmonics are considered those spectral component which are larger than the 12% (pixel value 30 with max 255) of the biggest spectral component. Accordingly we need ~ 4000 memory positions for storing information about a specific velocity and consequently 4000x144x4 ~ 2Mbytes of RAM for storing all information needed for 144 different velocities.

However, when later on, processing of complicated signals is necessary, the 20 largest harmonics among the 4000 will be recalled and their use in the final filter will be examined again. This is needed when, in the signal to be processed the vehicle to be recorded is not among the strongest objects. Accordingly, the larger harmonics belong to objects other than the one we are interested in. Thus, these harmonics are, once more, stored separately. The RAM needed for these harmonics is much smaller than the one previously evaluated since 20 values are stored for each velocity and orientation.

If we need to isolate an object moving with a specific velocity (velocity filtering) among other objects in a data cube, we have to perform the following steps:

1. Find the spectral content of the specific cube.
2. Eliminate from the spectral amplitude all harmonics except those corresponding to the specific velocity. For this purpose employ the 4000 positions recorded for the specific velocity and eliminate the harmonics to all rest positions of the spectrum.
3. Also, if the signal is complicated and we consider that the largest harmonics belong to strong vehicles and not to the object to be recovered, then the 20 largest harmonics of the spectrum must be removed. These harmonics are removed even if at their position a strong harmonic of the object we are interested in, exists. Thus, in case that the object to be detected and monitored is moving among strong objects in the previous step 2, the 20 largest harmonics from the corresponding 4000 are not used. This action is suggested since in this case harmonics due to other objects have contaminated the harmonics of the object under detection. Accordingly, not using these strongest harmonics we reject the strong objects and we reveal the vehicle we are interested in, by using the rest of the 4000 harmonics.
4. Evaluate the inverse 3D FFT to recover the data cube containing only the object with the specific velocity.

The number of 20 harmonics referred previously was determined experimentally using moving objects with various intensities to be detected among strong ones.

In Figure 4 are depicted the frames 1, 15, 251 and 256 from the amplitude spectral cube corresponding to the data cube, part of which is shown in Figure 2. In this figure all the harmonics in the specific frames are shown in a logarithmic scale so that even weak parts of the spectrum are visible.

IV. Testing The 3D FFT Velocity Filter Bank

The previously outlined filtering procedure was carried out in eight different cases.

In the first and second case, only one object is moving with velocity equal to 1/3 pixel/frame in direction 240° and with intensity 255 and 25 in each data cube respectively. Filtering with the filter which corresponds to this exact velocity, objects in both data cubes are totally recovered. Specifically, the 3D-FFT is carried out on both data cubes and after that only the harmonics the location of which has been preserved by the corresponding filter are kept (filtering) on the spectrum amplitude. The inverse 3D-FFT is applied using the modified spectrum amplitude and the original phase. It was not necessary before filtering to remove the largest harmonics of the spectrum amplitude, since no other strong signals are contained in the original image cubes. Furthermore, not additional normalization or other kind of processing is necessary to recover the moving objects.

In the third case, only one accelerating object in direction 240° and with intensity 255 is employed. It is better while processing the spectrum amplitude of the data cube with the filter (240, 1/3) to remove additionally the 20 largest harmonics. These harmonics are mostly affected by the other velocities of the accelerating object. The object is totally recovered only in this small part of its trajectory in which its velocity is 1/3 pixels/frame. No other kind of processing is necessary to recover the part of the accelerating object with trajectory direction 240°.

In the fourth case, an object with velocity equal to 1/3 pixel/frame, direction 240° and intensity 255 is moving together with an object accelerating in direction 240° and intensity 255. In order to isolate the object with the constant velocity 1/3 pixel/frame we performed directly 3-D inverse FFT without removing the largest harmonics due to other signals or performing any kind of normalization. The results are very good since the accelerating object disappears except the frame in which its velocity is around 1/3 pixel/frame.

In the fifth case, a similar with the previous situation occurs where the object with the constant velocity is of intensity 25. This object is isolated from the accelerating one by simply performing the 3-D inverse FFT without removing the largest harmonics due to other signals or performing any kind of normalization.

In the sixth case, three different objects are present in the scene, two of them with the same velocity equal to 1/3 pixel/ frame in direction 240° but with different intensities one with 255 and the other with 25 and the third accelerating in direction 240° and with intensity 255. We employ only the inverse 3-D FFT after filtering. It is not necessary before filtering to removed the largest harmonics due to other signals or after filtering to normalize the whole signal or perform any kind of

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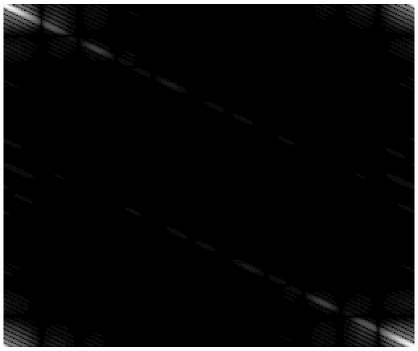
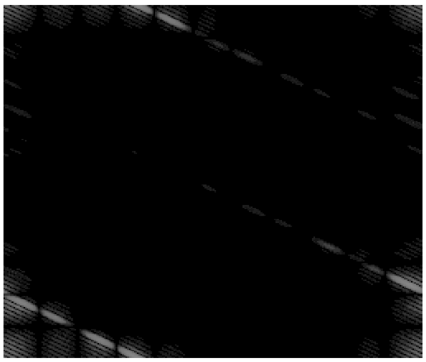
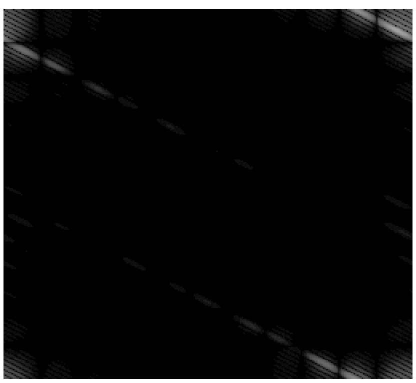
normalization. In fact, in this case we observed that if we



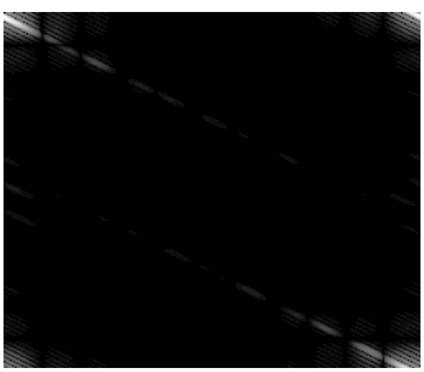
Frame 1



Frame 15



Frame 251



Frame 256

Figure 4. Frames 1, 15, 251 and 256 from the amplitude spectral cube corresponding to the data cube, part of which is shown in Figure 2

remove before filtering the largest harmonics due to others signals, we do not recover any of the two objects.

In the seventh case, the above three objects together with other objects with different velocities moving in different directions and one moving on a circle with intensity 255, are used. The data cube containing these objects is shown in Figure 5. Two different processing approaches were found to reveal the objects with the specific velocity and suppress all the others. In the first approach the largest harmonics are firstly removed and then after inverse filtering, normalization is performed to the whole data cube. In the second approach the same steps are followed while a thresholding step is added in order to remove small noisy artifacts at the background of the recovered data cube. Both cases give excellent results with the second to be slightly better. It is not necessary before filtering to removed the largest harmonics due to other signals.

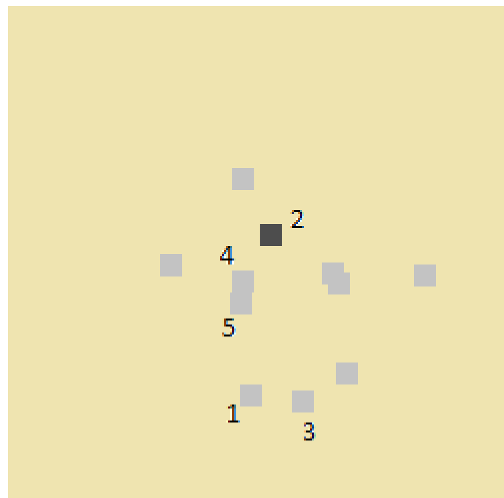


Figure 5. Test data cube. Objects 1 and 2 have parallel trajectories (240°) and the same velocity amplitude (1/3). Object 3 has velocity 255°, 1/4. Object 4 is accelerating with direction 240°. Object 5 is moving on a circle

Finally, in the eighth case we examine what happens when a small object is moving at the side of a large one. Two different examples were run. In the first example shown in Figure 6, the large object is strong while the small one is weak. Both objects are moving with the same velocity (direction 240° and amplitude 1/3). Both objects are completely recovered when the specific data cube is filtered with the corresponding filter. No interference or masking of the small object is observed. It is not necessary before filtering to removed the largest harmonics due to other signals. In the second example the small object is strong and the large weak, as shown in Figure 7. Both are moving towards the same direction of 240° with different amplitude velocities. The small object has amplitude velocity 1/3 (fast) while the large 1/32 (slow). Using the corresponding filter to isolate the velocity of the small object it is found that this is achieved without any additional processing of the spectral harmonics. The large object is almost eliminated.

Discontinuities in the data cube could create artifacts and give misleading harmonics that are not really present in the 3D signal. Such cases could occur even in a very simple signal when

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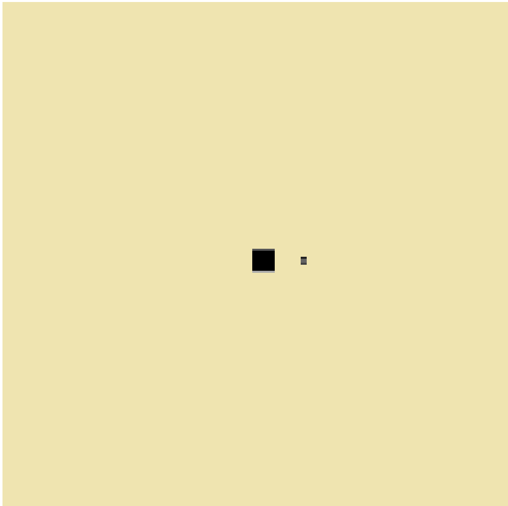

Figure 6. The large object is strong while the small one is weak. Both objects are moving with the same velocity (direction 240^o and amplitude 1/3)

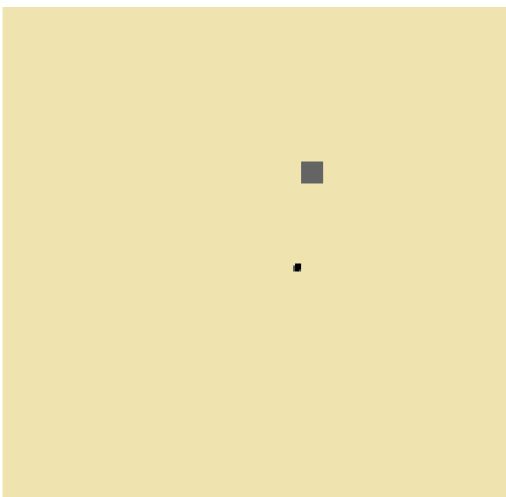

Figure 7. The small object is strong and the large weak. Both are moving towards the same direction of 240^o with different amplitude velocities. The small object has amplitude velocity 1/3 (fast) while the large 1/32 (slow)

a. A moving object appears suddenly in the sequence of frames with strong signature.

b. The moving objects appear and disappear from the data cube in different positions.

c. Strong moving background is present.

In these cases windowing can be applied to assure continuity among repetition of the frame cubes. Furthermore, a specific averaging procedure was applied to smooth frame-to-frame discontinuities.

Conclusions

An experimental approach for building a velocity filter bank was presented. Velocity filters are built using the 3D FFT spectrum of objects moving with specific velocities. No 3D filter theory is needed to build the velocity filters. The filter bank covers a significant range of velocities (amplitude and direction). The filters are designed so that objects with a specific velocity are isolated even if they are dim or close to another object with velocity vector quite close. In the experimental procedure various cases of velocities and moving objects were examined. It is evident that the filtering procedure to be followed depends on the number of objects present, the energy of the moving object to be recovered with respect to the rest objects as well as on the noise background. Discontinuities of the signal are thoroughly discussed and ways to cope with signals that suddenly appear at the edges of the data cube are given.

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