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Velocity Filter Banks using 3-D FFT

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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 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, velocity filters are built using the spectral signature of each separate moving object. 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.

***Keywords*—**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 detection of multiple moving odjects. Additionally, velocity filtering have been used for detection of moving object 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 work [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 aplied 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 different velocities has been used. 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. 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. Experimentation with objects having various velocities, single or moving simultaneously with other objects has been carried out in order to test the capabilities of the constructed velocity filter bank.

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. In section 5 the conclusions are drawn.

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II. Data Base Description

Each 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 Fig. 1) is formed of 256^3 pixels. The number $256=2^8$ was selected to fit the FFT requirements for fast evaluation of the spectrum.

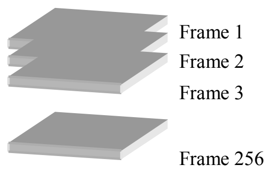
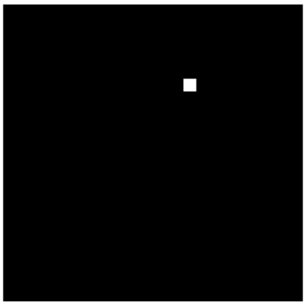


Fig. 1 256 Frames of 256x256 pixels each (Data cube)

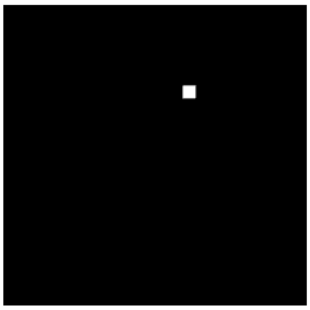
The time parameter is considered to be the distance from frame to frame. Based on this remark, the amplitude of the radial velocity of each object is reffered to as the number of pixels it comes across from one frame to the next. A simple example of one object of size 10x10 pixels that is moving with radial velocity of 1/3 pixels per frame is shown in Fig. 2. The object is moving in direction 240^o degrees with respect to horizontal left-to-right direction. Four different frames are given i.e. the 1st, 16th, 128th and 232th.

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 amplitudes of radial velocities 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^o as shown in Fig. 3. Accordingly, a total of 6x24=144 different data cubes (velocities) were implemented.

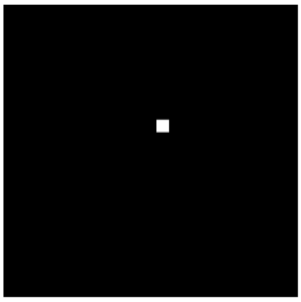
Before evaluating the spectrum of each data set, a preprocessing stage follows. In this stage averaging is performed only in the time domain i.e. the same pixel in all frames, so that random changes in the movement of the object are avoided and simulation of real objects is better achieved.



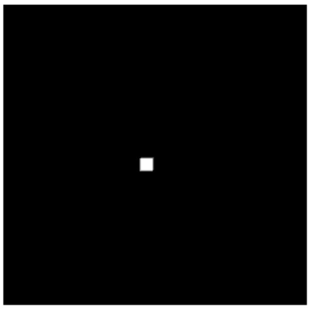
Frame 1



Frame 16



Frame 128



Frame 232

Fig. 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

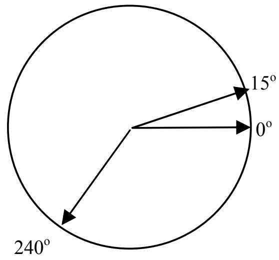


Fig. 3 24 different directions were chosen with the first one at 0 degrees (horizontal direction from left to right) and anti-clockwise every 15o

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 msecs. Since the spectrum is a complex quantity we evaluated its amplitude and phase separately. We have to mention here that parallel trajectories in the data cube which correspond to objects having the same velocity, possess the same spectral amplitude information 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 $256^3 \sim 2^{24} \sim$ 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). 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.

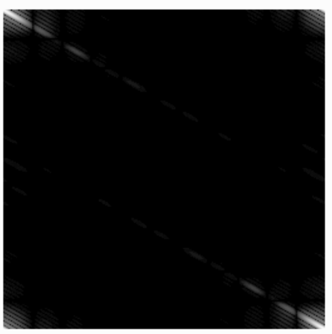
If we need to isolate an object moving with a specific velocity among other objects in a data cube, we have to perform the following steps:

1. Find the spectral content of the specific cube.
2. Eliminate from the spectral amplitude all harmonics except those corresponding to the specific velocity.
3. Evaluate the inverse 3D FFT to recover the data cube containing only the object with the specific velocity.

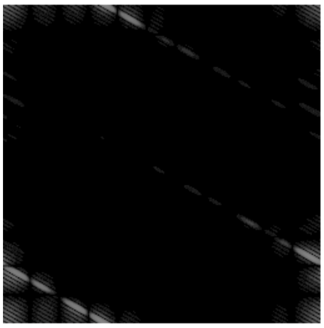
In Fig. 4 are depicted the frames 1, 15, 251 and 256 from the amplitude spectral cube corresponding to the data cube, part of which is shown in Fig. 2. In this figure all the harmonics in the specific frames are shown in a logarithmic scale so that even weak parts of the spectrum are visible.

IV. 3D FFT Bank Velocity Filter Bank

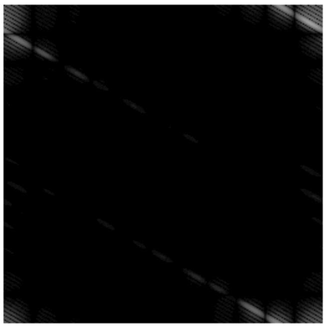
The constructed velocity filter bank was tested using a data cube containing various moving objects. Especially, it was tested against the following cases:



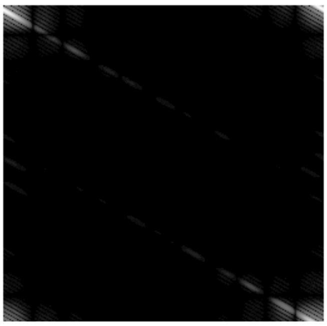
Frame 1



Frame 15



Frame 251



Frame 256

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

a. Two of the objects are moving in parallel with the same velocity (that we are interested in) one of which is very weak.

b. One of the objects is accelerating from standstill.

c. One of the objects is moving on a circle.

The data cube containing these objects is shown in Fig. 5.

Performing the three step filtering procedure, described in the previous section, on the data cube given in Fig. 5 we had the following experimental results regarding the filtering capabilities of our velocity filter bank.

a. Two objects moving with trajectories that form angle of at least 15^o can be easily resolved. The one (in our case) with direction 240^o is isolated on the background of the data cube. Smaller difference in the angle of the directions was not tested.

b. If two objects, the one strong and the other weak, are moving with direction 240^o, both are resolved and isolated on the background of the data cube.

c. An accelerating object appears only when its velocity coincides with 1/3 pixels/frames which is the one corresponding to the selected filter.

d. Objects, even with the same trajectory direction but differing 1/32 pixels/frame in their velocity amplitude, are also resolved.

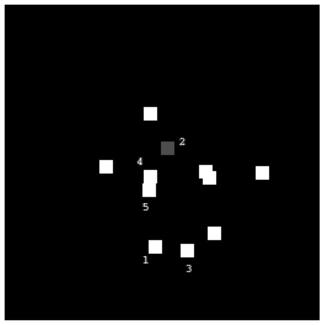


Fig. 5 Test data cube. Objects 1 and 2 have parallel trajectories (240o) and the same velocity amplitude (1/3). Object 3 has velocity 255o, 1/4. Object 4 is accelerating with direction 240o. Object 5 is moving on a circle

V. Conclusion

An experimental approach for building a velocity filter bank was presented. No theoretical background related to the design of 3D filters was employed. The spectral signature of specific objects moving towards various directions was used for building the 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. Currently, the velocity filter bank is expanded to cover wider range of velocities regarding both the direction and the amplitude of the velocity.

Acknowledgment

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