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REAL-TIME IMAGE MOTION TRACKING USING EMDEDDED OPTICAL CORRELATOR TECHNOLOGY

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Summary

The paper presents an advanced approach for real-time image motion tracking, which serves as core technology for a large variety of embedded image processing products. The solution is based on 2D image correlation, which is independent of single image features, extremely robust against uncertainties and noise. Real-time realisation is provided with an advanced robust embedded Joint Transform Optical Correlator. System design aspects are discussed, performance results of optical correlator prototypes are presented. A promising application, smart opto-electronically stabilised pushbroom remote sensing camera, is shown.

1. Introduction

Image motion is considered as a time discrete motion of small image parts in a camera image plane – Figure 1. This is caused by a mutual motion of the camera and a scene in the camera field of view. The pattern of all motion tracks generally carries information about the motion of the camera with respect to the observed scene as well as information about the 3D structure of the scene. This is similar to the well known principle of stereo-vision, where the analysed scene is imaged by a set of fixed cameras from two or more view points.

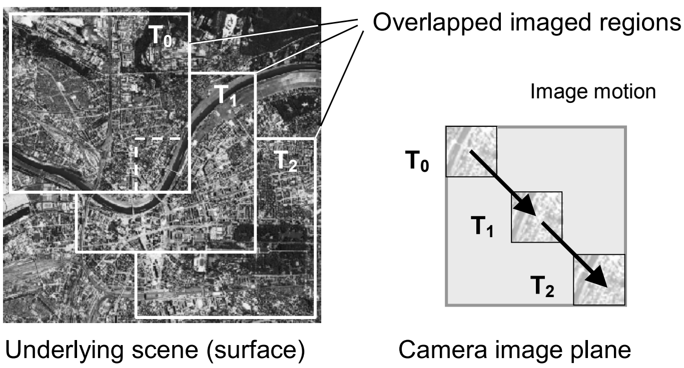


Fig. 1. Overlapped subsequent images – image motion

Special algorithms can extract the required information from these multiple images, which is necessary for solving diverse measurement problems in various application areas:

- smart imaging systems [1];
- industrial process monitoring;

- robot, machine vision;
- navigation [2];
- 3D modelling;
- automatic surveillance systems.

Real-time image motion tracking is characterised by large amount of processed image information, high required reliability and robustness to noise and distortions. The most powerful methods used today are 2D-correlation and Fourier analysis.

2. Image Motion Tracking Principle

The basic step for image motion tracking is a measurement of the shift between two overlapped images. Normally they are taken at two close time moments during camera motion with a single image sensor. The second image will be shifted with respect to the first by a shift vector. This vector is defined by the size and position of overlapped parts for both images. The overlapping can be effectively determined by two dimensional correlation of the images. The 2D correlation function represents the location of the part of the second image in the first image. This location is normally given by a distinctive peak in the correlation function. Detection of the correlation peak and measurement of its coordinate in the correlation plane allow to determine the shift between both images – Figure 2.

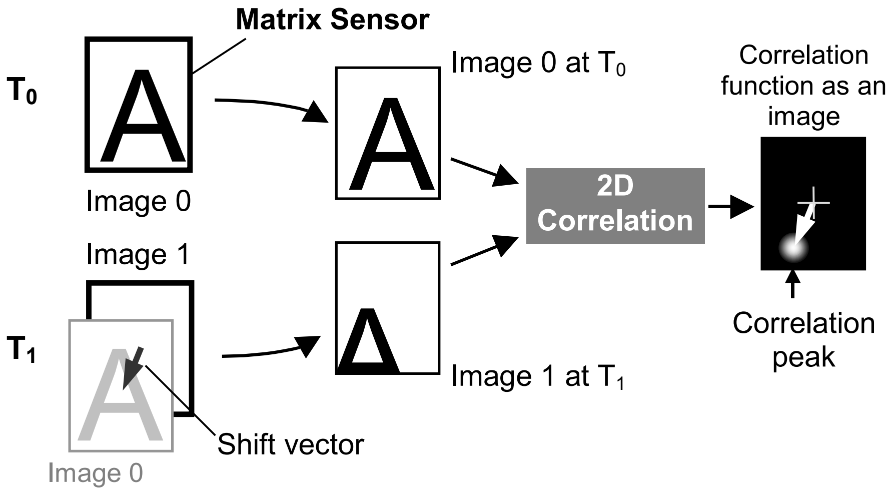


Fig. 2. Image shift vector measurement with the 2D correlation

For a large class of applications it is necessary to measure the motion of different parts of the camera image plane. In this case the size of the image sensor is much larger than the size of tracked image parts or blocks. This allows to measure the motion of the blocks on rather long distances and increases the information output of the image motion tracking system.

This long range tracking procedure is implemented by a prediction of motion for each tracked block and a subsequent correction of the predicted shift with the correlation data. The correlation is performed for the image from the initial position (reference image) and the image from the predicted position (current image). The prediction can use some external information about camera motion or previous results of image motion measurements.

The images are normally represented by matrices. Therefore, the correlation function is also computed as a matrix. The following approaches are known for realisation of this operation:

- direct numerical computation;

- Fast Fourier Transformation (FFT);
- Optical Fourier Transformation (OFT).

The direct correlation is computationally very extensive and its realisation is feasible only for rather small images or for a limited range of the image shift and requires very good predictable image motion. Using small images as well as performing sparse computation of the correlation function decrease the system robustness to image noise and distortions.

The speed of existing digital FFT processors is not sufficient for certain real-time applications where reliable and robust image tracking must be achieved together with compactness and low electrical power of the hardware.

Optical Fourier processors are based on parallel, light-speed processing and can provide extraordinary processing power. The latest achievements in the development and manufacturing of opto-electronic components allow to build a compact embedded image correlator, which is much faster than available FFT processors.

3. Real Time Optical Correlator

Optical correlation is based on two general approaches: Van-der-Lugt Correlator and Joint Transform Correlator [3]. The first approach requires one additional Fourier transformation and is therefore not optimal for fast image tracking. In the joint transformation procedure both images are processed concurrently. The Joint Transform Optical Correlator (JTC) [4] includes two identical optoelectronic modules – Optical Fourier Processors (OFP), as sketched in Figure 3.

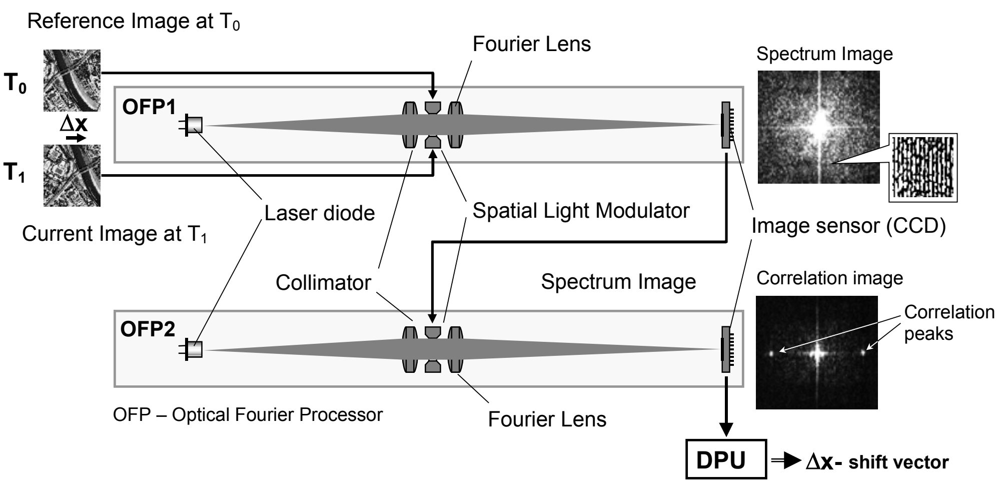
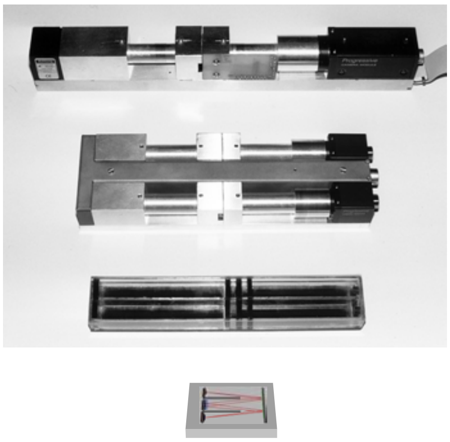


Fig. 3. General structure of the Joint Transform Optical Correlator

Two digital images (current and reference images) are entered side by side into the optical system of the first OFP by a transparent spatial light modulator (SLM). After optical Fourier transformation, the joint power spectrum (JPS) is read by the image sensor and loaded to the SLM of the second OFP. A second optical Fourier transformation forms the correlation image, which is detected by the second image sensor. If both input images are of the same region, the joint power spectrum will be modulated by spatial frequencies, which cause the correlation image to have two symmetric correlation peaks. The shift of these correlation peaks relative to optical axis (at the central bright pattern) corresponds to the shift between the current and reference images. The position of peaks on the correlation image can be measured with sub-pixel accuracy using standard and simple algorithms for centre of mass calculation. A standard digital signal processor can be used for this task.

This technology and its applications are studied during last years at the Institute of Automation of the Technische Universität Dresden. Figure 4 shows the state-of-the-art as well as planned future goals in the development of embedded optical processors.



Laboratory model 2000
standard industrial components
15 corr./sec, size 290x42x30 mm

Laboratory model 2001
compact industrial components
60 corr./sec, size 230x30x62 mm

Design goal – Compact System
customised CMOS image sensor,
integrated electronics
200 corr./sec, size 180x20x32 mm

Design goal – Hi-End System
customised components
1000 corr./sec, size 65x20x30 mm

Fig. 4. Evolution of the optical correlators (TU-Dresden)

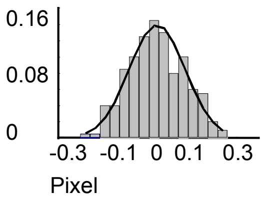
The first laboratory models were built using standard elements: industrial CCD cameras and liquid crystal microdisplays. It was shown, that a compact design with good real-time performances can be realised on the basis of customisation of the existing optoelectronic components.

Due to special design the devices are very robust to mechanical loads and do not require precise assembling and adjustment [5].

4. Performances of Image Motion Tracking with the Optical Correlator

The typical performances of the optical correlator were estimated also using the developed hardware prototypes – Figure 5.

Accuracy	0.1-0.15 pixel (sigma)
Speed	up to 1000 corr./sec
Shift range	± 80 pixel (H and V)
Noise robustness	up to 0 dB
Scale distortion	up to 3 %
Block size	128x256 pixel



Experimental and estimated image shift error distribution

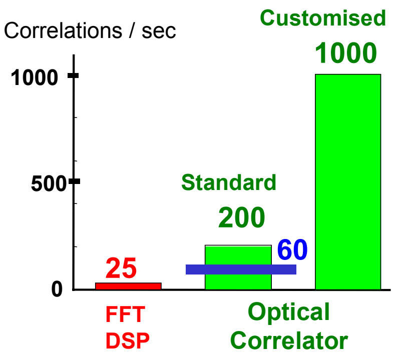


Fig. 5. Typical performances of the optical correlator (experimental results)

The measurement error is mainly an error of determination of the correlation peaks position. The error is shown to be normally distributed and generally texture dependent (see the histogram in Figure 5). Robust accurate measurements can be provided under various measurement conditions: image noise and geometrical distortions. The shift range characterises the correction ability of the predictive image tracker. The maximum measured image motion is primarily defined by the dimensions of the image sensor.

The bar diagram in Figure 5 shows a performance comparison of the developed and future optical correlators with existing FFT digital signal processors.

5. Smart Imaging System Using Image Motion Tracking

This linear scanning (pushbroom) system can provide good quality images from unstabilised satellite and aeroplane based image acquisition platforms. The general scheme of image acquisition is shown in Figure 6. The linear sensor scans the image of the desired region. At the same time, the image motion in the focal plane is recorded by real time processing of the auxiliary sensors images with an Optical Joint Transform Correlator onboard the satellite. The recorded image motion is transmitted to the ground station together with raw image data, which are distorted due to attitude instabilities. The image motion record is used by a ground computer for correction of the raw image data.

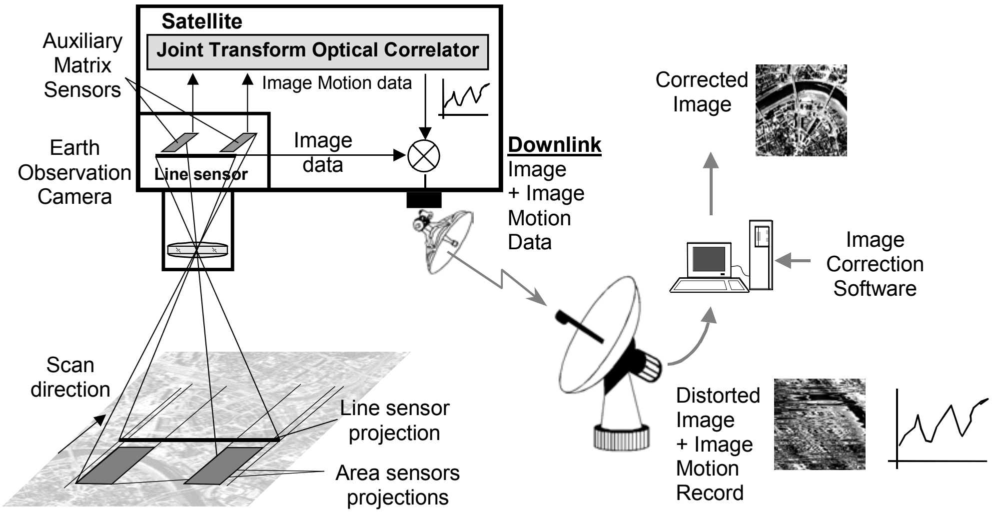


Fig. 6. General scheme of the image acquisition and correction

A hardware prototype of the system has been built under ESA (European Space Agency) contract. It consists of a pushbroom camera breadboard and embedded real-time optical processing unit with standard camera interfaces – Figure 7.

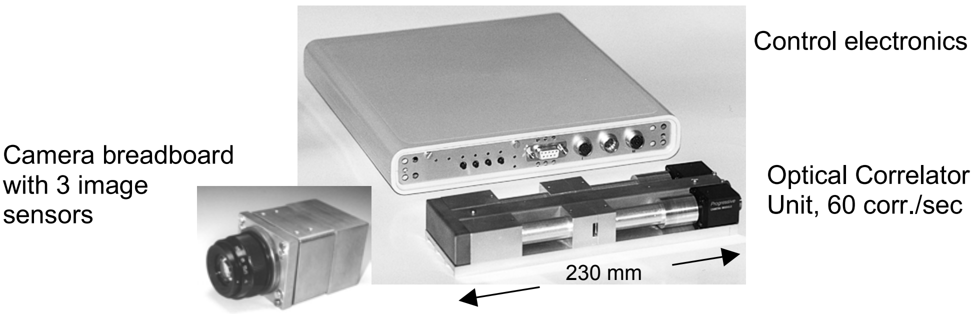
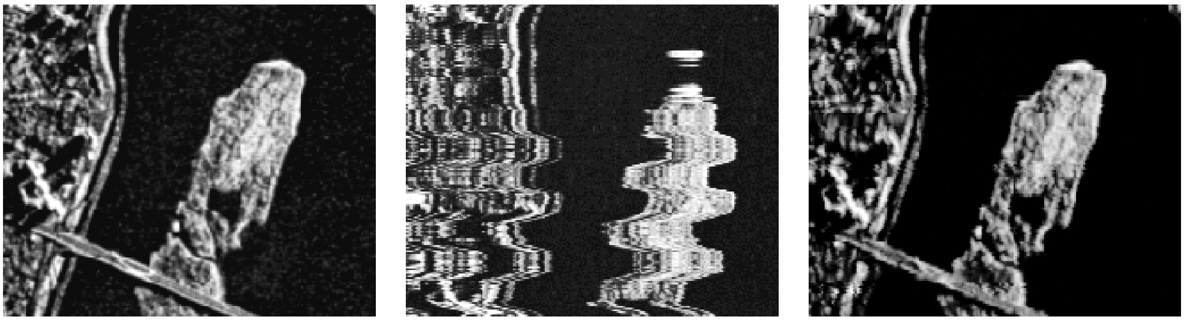


Fig. 7. Laboratory models of the pushbroom camera and the optical correlator

This prototype has been successfully tested on a satellite motion simulator with real images. It was shown, that the system can provide good image correction quality - Figure 8.



real image distorted image corrected image

Fig. 8. Test results of image correction

The geometrical distortions can be effectively reduced to the level of 0.3 pixel (sigma) for the high frequency distortions and 2 pixel for the long term smooth distortions.

6. Conclusion

The particular advantage of spectral image information processing is known to be independent of single image features, but relying only on the overall image texture. Thus correlation methods are rather accurate, extremely robust against uncertainties and noise and they are most appropriate if complex image textures are available. It has, however, one significant drawback - a huge amount of calculations, required to perform the 2D correlation digitally. To overcome this limitation, fast optical image processing techniques are applied. Since the calculations here are performed by light propagation, the optical correlator is able to provide an outstanding real time image processing capability at very small size, power consumption and high degree of robustness to mechanical loads. These competitive features as well as standard data interfaces open a wide spectrum of applications, which could not be covered by pure digital processing technology.

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