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Intensity-Difference Based 3D Video Stabilization for Planetary Robots

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Overview

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- Current approaches
- Our approach
- Algorithm
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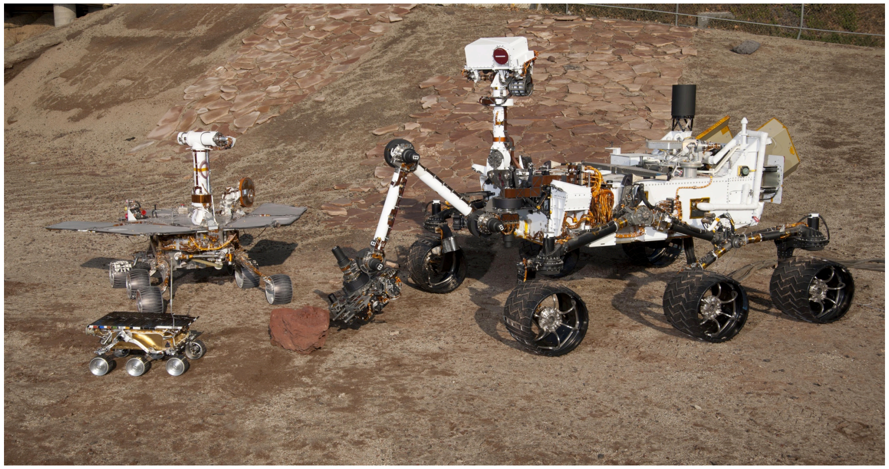
- Summary

Introduction

- In future missions, planetary robots, such as rovers, airplanes and entomopters, will use their cameras to capture not only still images but also image sequences of the terrain on which they are moving



Courtesy NASA/JPL-Caltech

Problem

- However, these videos often exhibit an annoying jitter due to the unwanted camera motion caused by the rough terrain, turbulence, etc.
- This jitter makes the observers feel tire and also greatly affects the performance of further applications

Courtesy Steve Curling (Blazar on SGL).

Current approaches

- In order to obtain smoother image sequences the camera jitter is removed by applying video stabilization algorithms
- Two categories:
  - two-dimensional (2D) video stabilization algorithms
  - three-dimensional (3D) video stabilization algorithms

2D video stabilization

- First, a 2D motion model, such as an affine or projective transformation, is estimated between consecutive frames
- Then, the estimated parameters are smoothed by low-pass filtering
- Finally, the stabilization is obtained by synthesizing a new video using the smoothed parameters
- Easy to implement and used in commercial cameras

2D video stabilization

- Weakness:
  - Limited because the true camera motion is in 3D not in 2D

3D video stabilization

- First, the 3D positions of a sparse set of scene feature points and the camera 3D motion are reconstructed using structure-from-motion (SFM) techniques
- Then, a new and smoother camera path is computed from the 3D reconstruction
- Finally, the stabilization is achieved by synthesizing a new video, rendering the scene as it would have been seen from the smoothed camera path

3D video stabilization

- Weaknesses:
  - SFM depends on precise tracking of feature points over the image sequence, which is a difficult task, where any tracking error could greatly affect 3D reconstruction
  - SFM is typically solved using bundle-adjustment, which requires random access to the entire video, making it impossible for real time applications

Approach

- 3D video stabilization algorithm able to operate in real time
  - We propose to estimate the surface 3D motion with respect to a fixed coordinate system and then to stabilize video using a smoothed version of the surface 3D translation only
  - For motion estimation neither feature point tracking nor bundle-adjustment are used. This enables the algorithm to operate in real time

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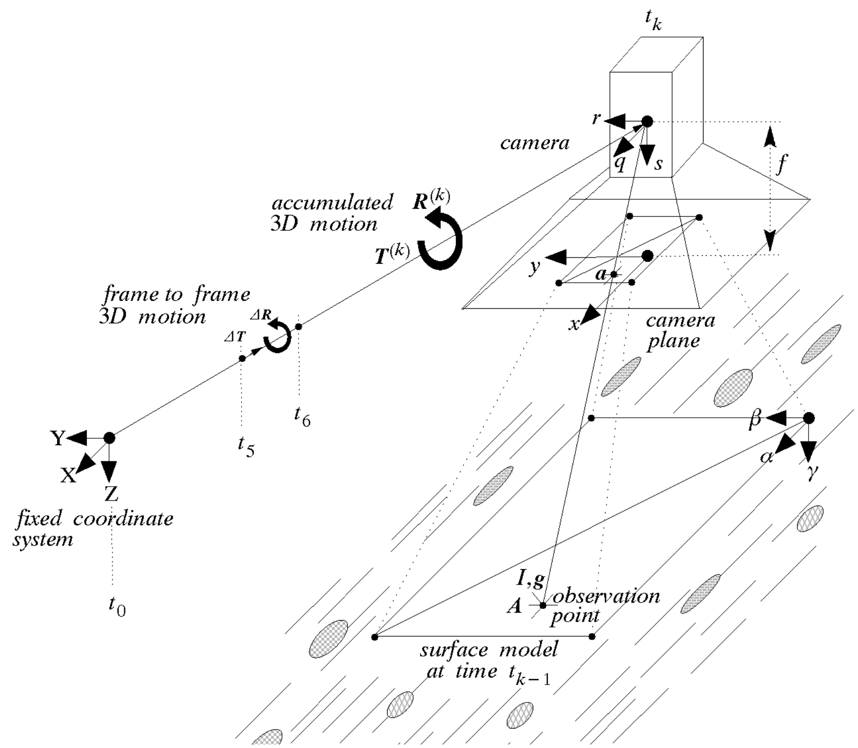
Algorithm

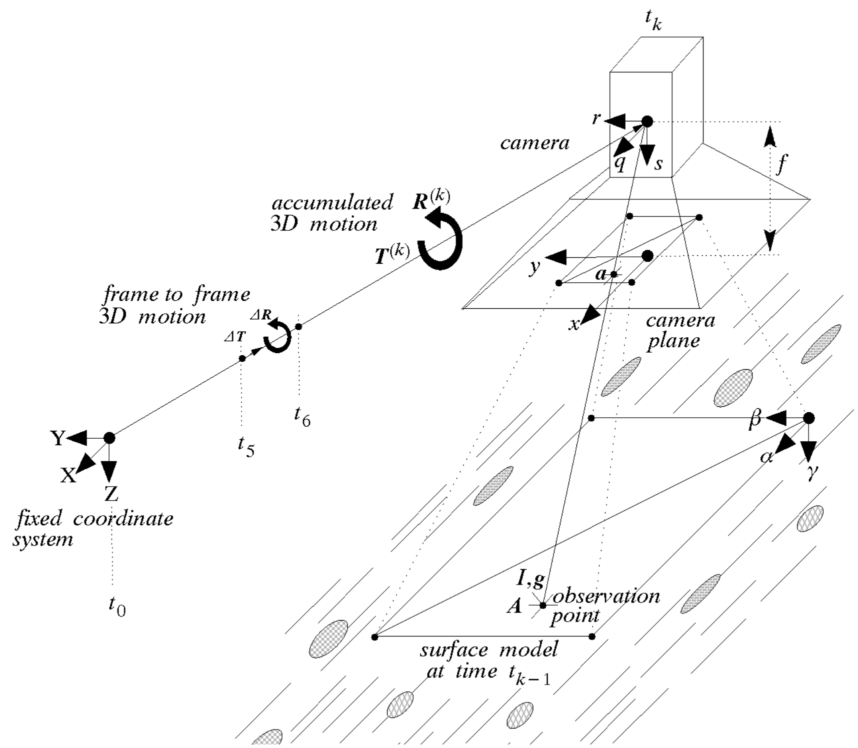
1. Estimate the frame to frame surface 3D motion with respect to the camera coordinate system by maximizing the conditional probability of the intensity differences at key observation points between consecutive images, where the key observation points are image points with high linear intensity gradients

   – No tracking of feature points required
   – No bundle-adjustment required



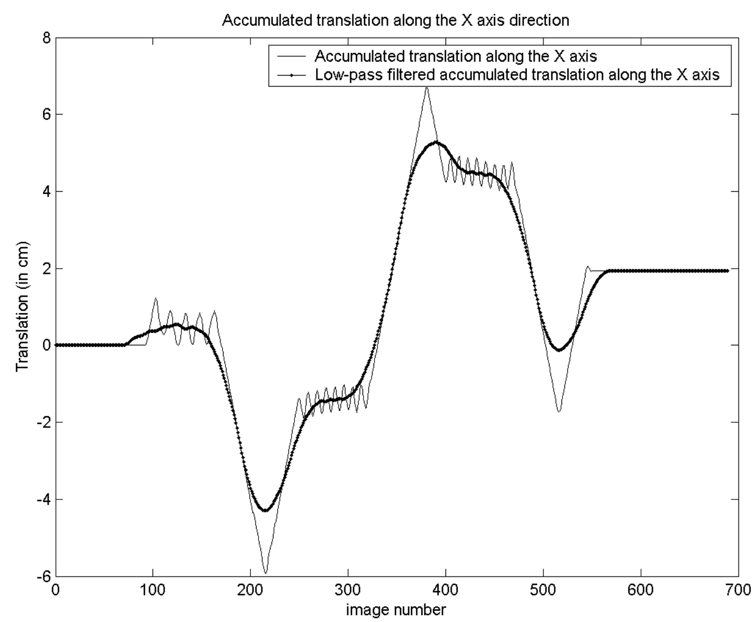
Algorithm

2. Compute the surface 3D motion with respect a fixed coordinate system by accumulating the frame to frame motion estimates



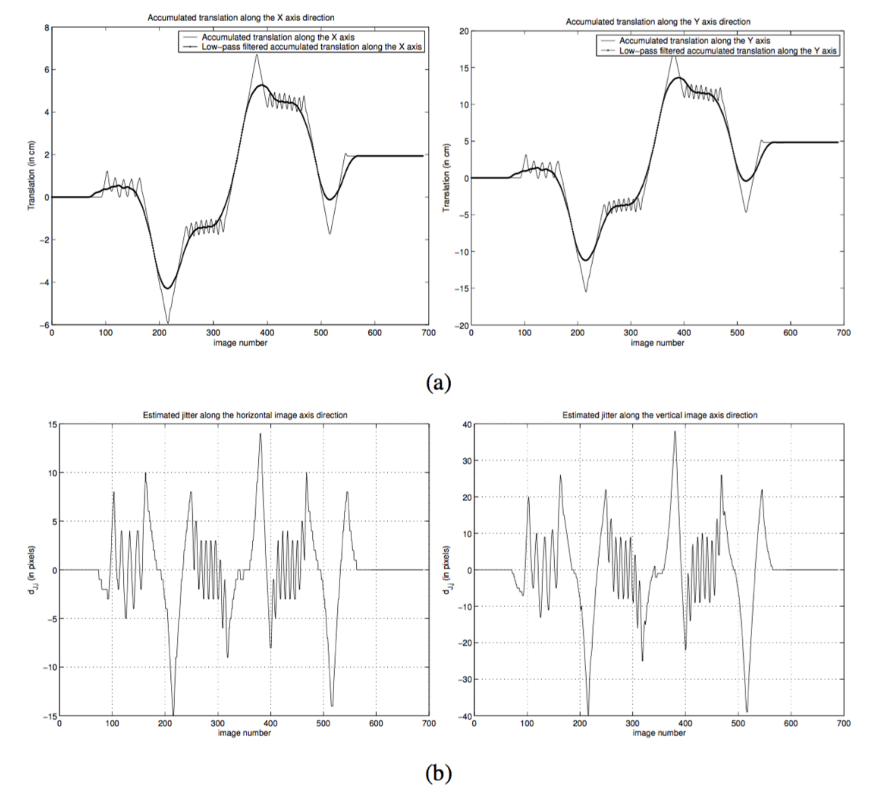
Algorithm

3. Smooth the accumulated translation by applying a time domain M point moving average low-pass filter



Algorithm

4. Estimate the jitter for each frame as the perspective projection onto the image plane of the difference between the accumulated translation minus the smoothed version of it



Algorithm

5. Synthesize the stabilized video by moving the entire content of each image with a vector having the same magnitude but opposite direction to the estimated jitter for that image

Experimental Results

- The proposed 3D Video Stabilization Algorithm has been implemented in the programing language C and tested in a Clearpath Robotics Husky A200 rover platform to assess its accuracy, limitations and advantages
- In total 54 experiments were carried out in indoor and in outdoor sunlit conditions

Experimental Results

- The used camera has an image resolution of 640x480 pixel^2 and a horizontal field of view of 43 degrees. It is located at 77 cm above the ground looking to the right side of the rover tilted parallel to the surface
- The images are acquired in real time and processed by a laptop onboard the rover with an Intel Core i5-3340M CPU @ 2.7 GHz and 8.0 GB RAM

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Experimental Results

- During each experiment, the rover is commanded to drive on a predefined path, moving forward and backward, changing the speed and acceleration rapidly, while the camera captures images at 15 fps. There are also some small rocks along the path on which the rover moves

Experimental Results

- Jitter reduction in a factor of 20 !
- Real time operation possible: 0.06 sec/image !

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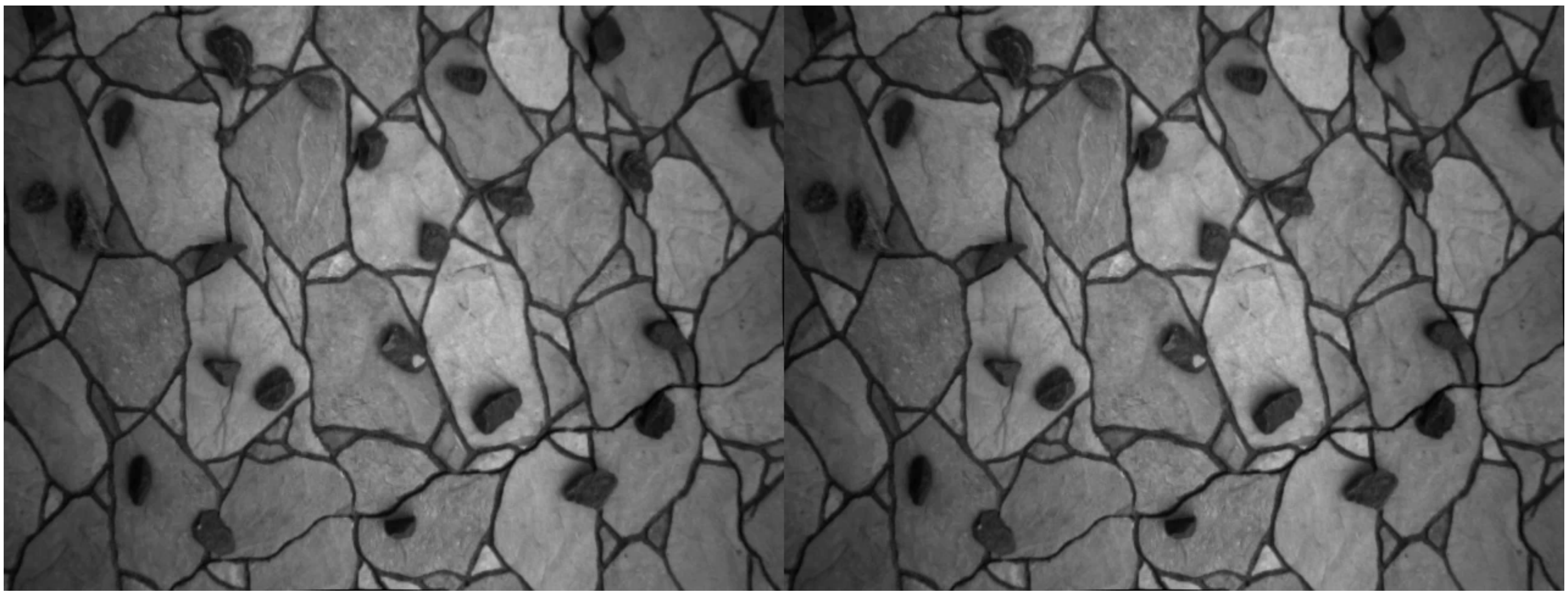
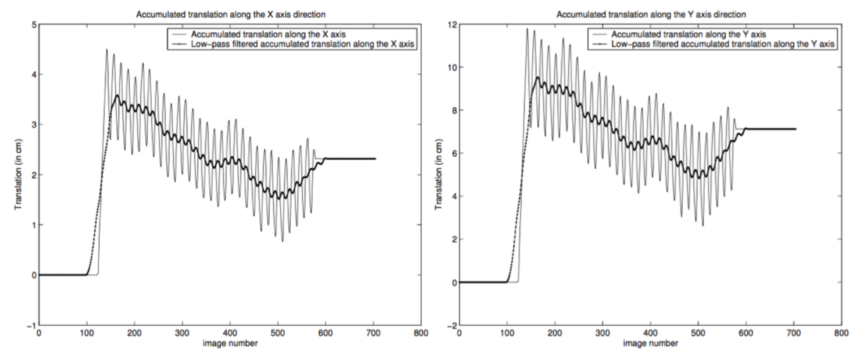
Experimental Results



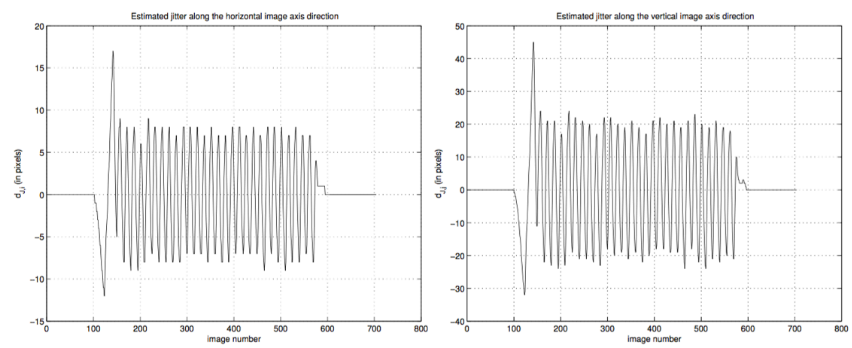
Original video No. 51 Stabilized video

Experimental Results

Results obtained with real image sequence 51. (a) depict the accumulated surface 3D translation along the X axis (left) and the Y axis (right) and the low pass filtered versions of it. (b) depict the corresponding estimated jitter along the horizontal image axis (left) and the vertical image axis (right), respectively.



(a)



(b)

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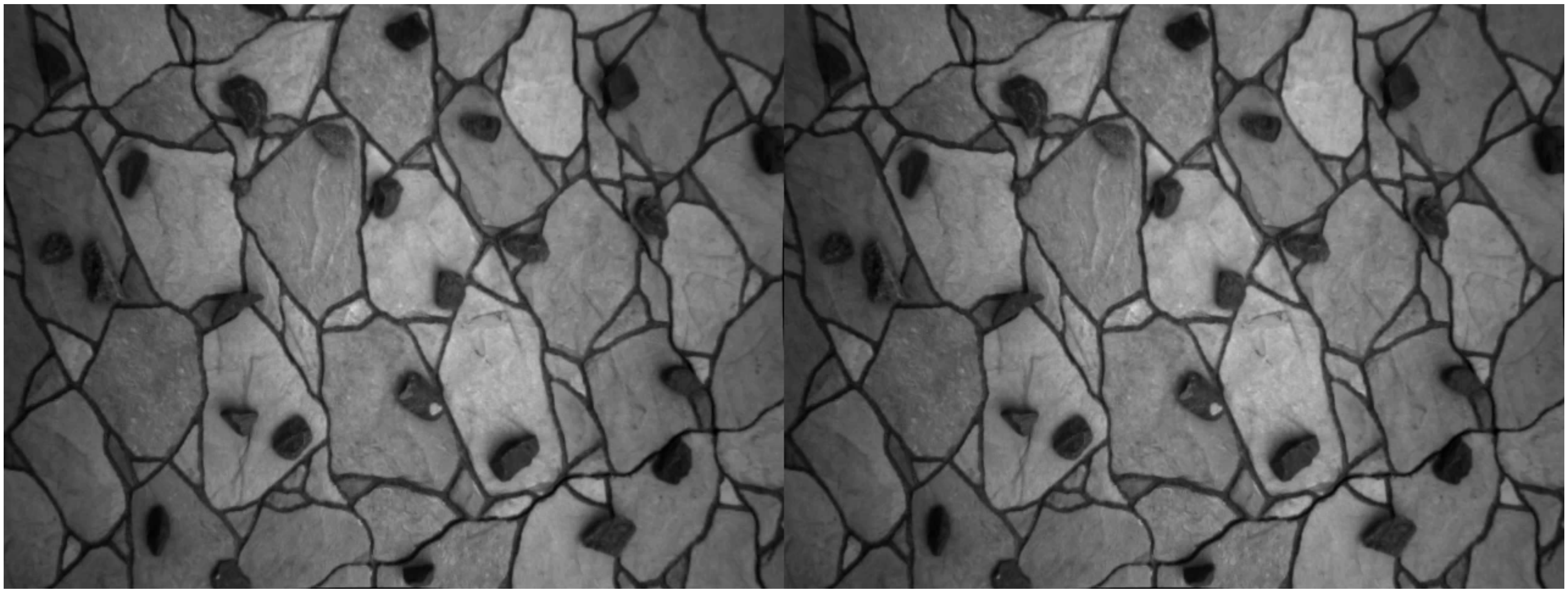
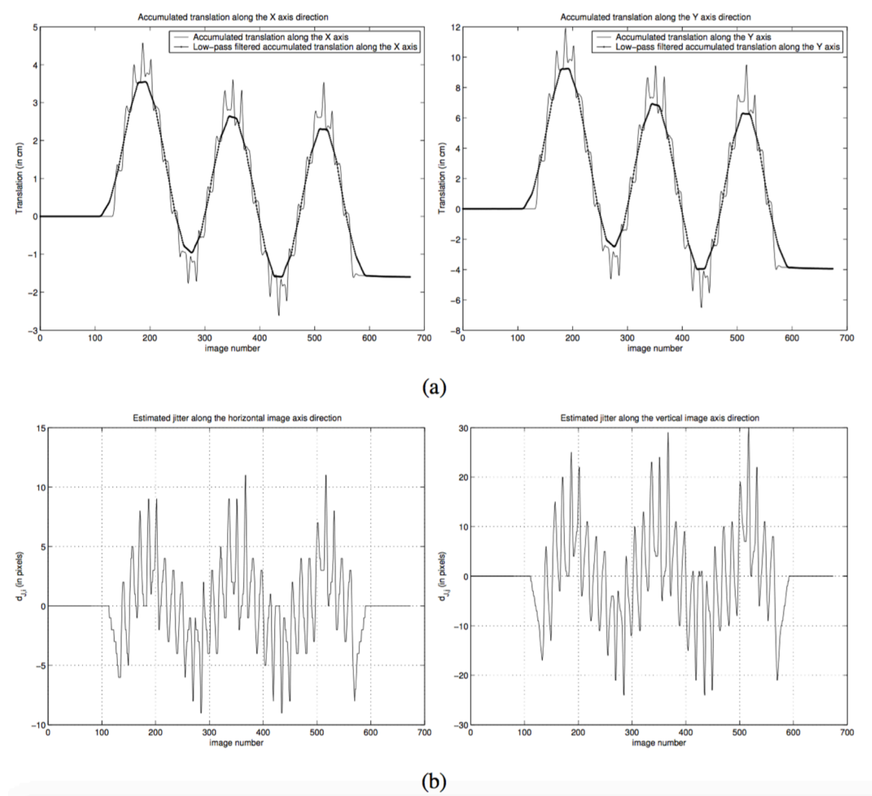
Experimental Results



Original video No. 53 Stabilized video

Experimental Results

Results obtained with real image sequence 53. (a) depict the accumulated surface 3D translation along the X axis (left) and the Y axis (right) and the low pass filtered versions of it. (b) depict the corresponding estimated jitter along the horizontal image axis (left) and the vertical image axis (right), respectively.



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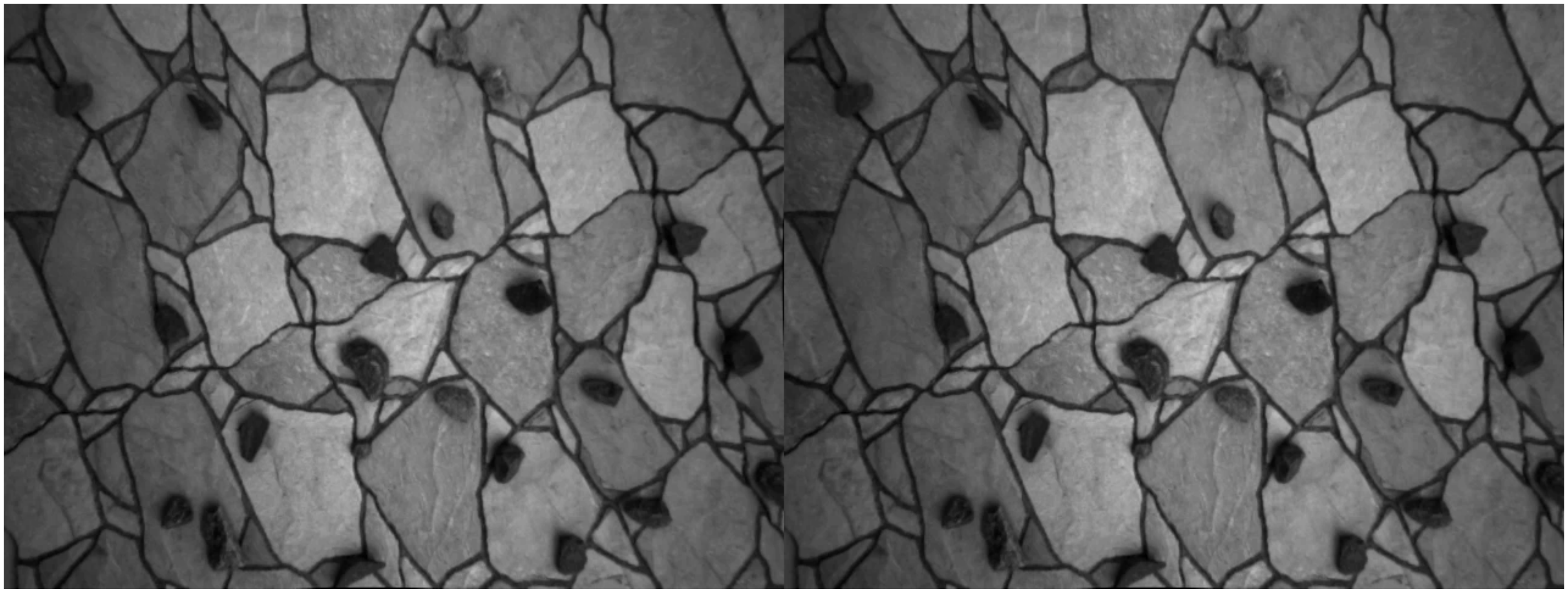
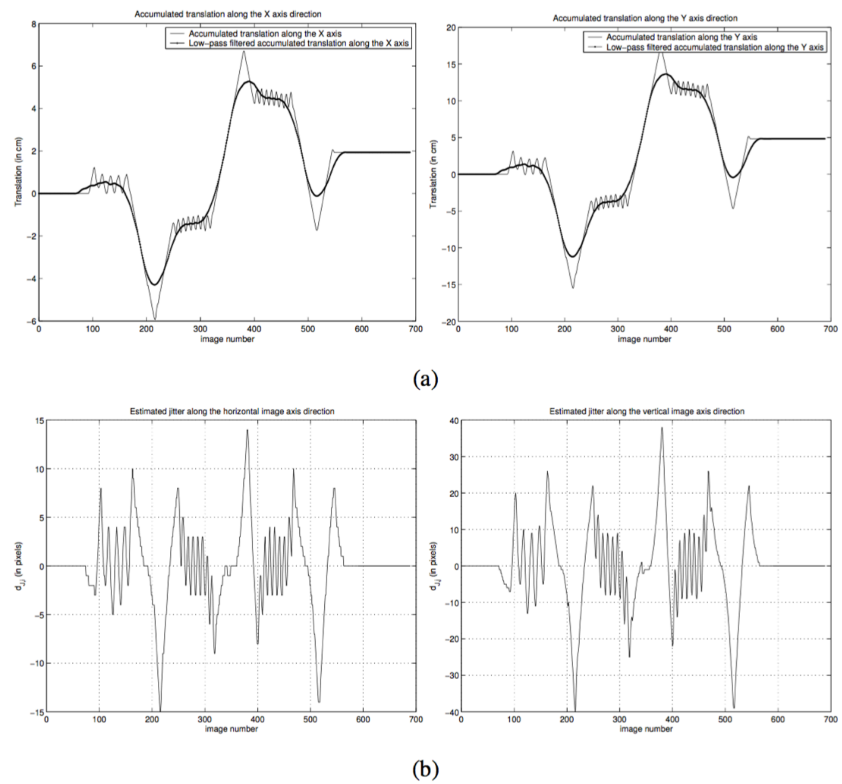
Experimental Results



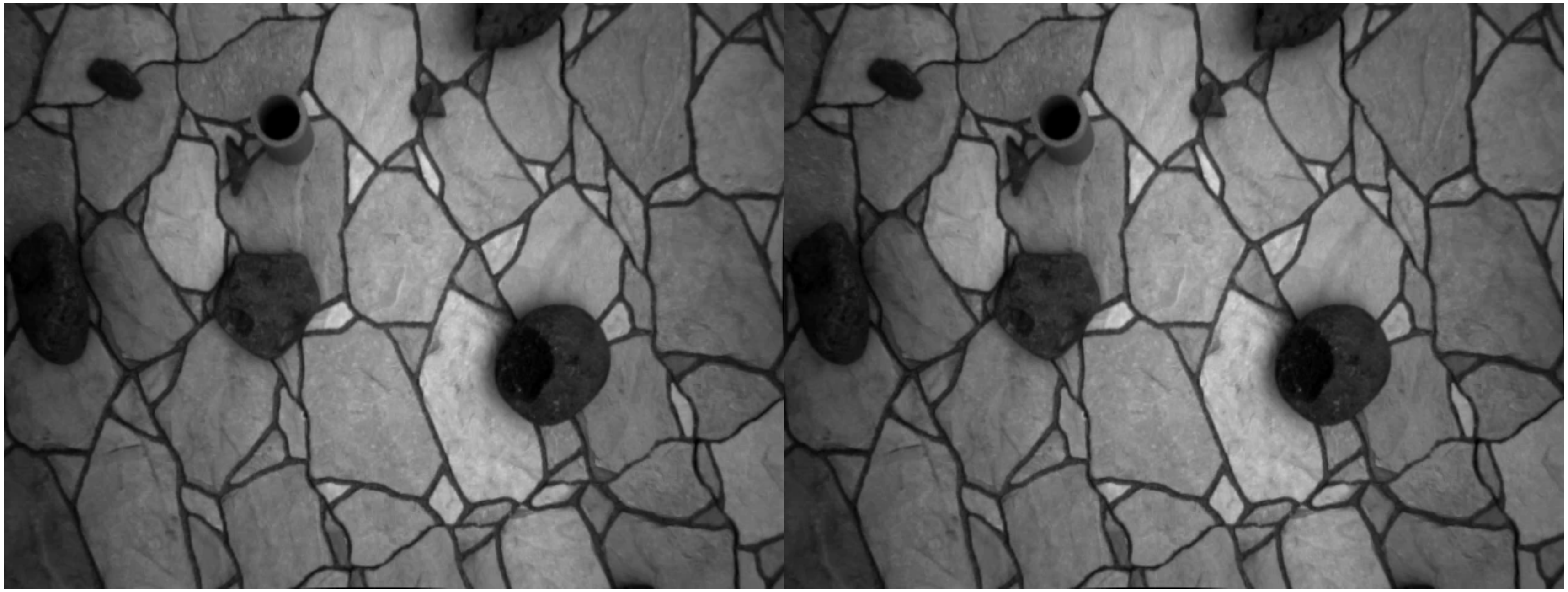
Original video No. 54 Stabilized video

Experimental Results

Results obtained with real image sequence 54. (a) depict the accumulated surface 3D translation along the X axis (left) and the Y axis (right) and the low pass filtered versions of it. (b) depict the corresponding estimated jitter along the horizontal image axis (left) and the vertical image axis (right), respectively.



Experimental Results



Original video No. 47

Stabilized video

The wobble due to the parallax effect is still disturbing and needs to be addressed in future work.

Summary

– 3D video stabilization algorithm proposed

– Real time operation (0.06 sec/image)

– Jitter reduction in a factor of 20

– 3D motion directly estimated from intensity differences, neither feature point tracking nor bundle-adjustment required

– The wobble due to the parallax effect needs to be addressed in future work

Thanks!
Questions?

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IPCV-LAB's rovers