HARMONIC OSCILLATIONS MODELLING FOR THE PURPOSE OF CAMERA SYNCHRONIZATION

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Abstract: The goal of this paper to present a general method to synchronize cameras from the image modelled harmonic oscillations, which are in this work produced by a simple pendulum. The method essence is to recover from camera images a sine trajectory of a small ball, attached to 45cm string and suspended from a pivot so that it can swing freely. From this trajectory and given an equilibrium position of ball in space, for each camera a time is estimated needed to reach this equilibrium position from a neighboring frame during a ball swing. The difference in those times for two cameras yields a subframe time difference between cameras. The subframe time differences between cameras were computed using the proposed method and they were compared against the ground truth measurement values given by a camera manufacturer. Linear correlation coefficient is 0.996, while the mean absolute difference between two methods measurements is 3.5ms.

1 INTRODUCTION

Consumer cameras are offering, particularly nowadays, relatively good features (e.g. high frame rate and resolution, integrated storage media) at generally speaking affordable cost, which make them quite attractive to be used in various computer graphics and vision applications. However, one feature that consumer cameras do not typically support is hardware time synchronization. This presents a serious obstacle to use them for imaging and analysis of dynamic scenes such as 3D reconstruction of human movement. Therefore it has been an effort ever since to develop software methods for camera time synchronization. The crux of many methods is to record a common event on various cameras' images and use it as synchronization info. For such approaches firing a light from light emitting diode or other light sources is one usual alternative (Degueurce et al. 1996). Typically such methods synchronize cameras only up to a frame where time offset within a frame still remains unknown. Still, there are approaches which use stroboscopic lights and they are offering subframe accuracy as well (Bradley et al. 2009). Unfortunately, the use of stroboscopic lights not only additionally increases a system cost, but often it is not always easily applied, especially in outdoor conditions.

Another group of synchronization methods is based on the fact that unsynchronized cameras will have higher reconstruction error estimates (Yeadon and King 1999, Pourcelot 2000). Thus, those approaches search for a time offset between cameras which will minimize that error estimates. The phenomena of decreasing reconstruction error depends on a mutual spatial position between cameras and point(s) of reconstruction and perhaps even more importantly requires calibrated cameras, which in turn make the entire synchronization procedure dependent on the camera calibration (reconstruction) accuracy too.

Interestingly, a recording of sound was also used as a mean to synchronize cameras (Barros et al. 2006). Perhaps the biggest disadvantages of this approach are the requirements to accurately detect position of audio code in data stream, to use audio transmitter and above all an inherent restriction for cameras that record audio as well.

There are attempts which are based on the networked stations (Rai et al. 2003, U and Suter 2004). Each camera is attached to its own PC client and a server is responsible to dispatch a message for a simultaneous capture start. Besides a substantial

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increase in the system HW configuration, writing network scripts is not necessarily trivial since, for example, additional and non-deterministic operating system (network) latencies pose additional problems.

In this work we propose a method which models a harmonic movement produced by a common pendulum. The proposed method allows subframe synchronization, negligibly increase the cost, it is easily applicable both in outdoor and indoor conditions and it does not require a calibrated camera either.

2 METHODS

Our pendulum consists of a small ball, attached to a 45cm string and suspended from a pivot so that it can swing freely.

Step1 After displacing a ball sideways from its neutral (equilibrium) position, a ball swinging back and forth (i.e. ball oscillation about the equilibrium position) was recorded by pair of Point Grey (PGR) FireWire cameras DragonFly2 DR2-HICOL (PGR 2011).

Step2 For each camera and all captured frames, image coordinates of a ball center were detected with a subpixel accuracy.

Step3 On the detected image coordinates of ball throughout the frames, a principal component analysis (PCA) was applied on the image coordinates in order to align as much as possible the major axis of movements (3D displacements) with the image coordinates axis. We further consider only the horizontal image coordinate component (HIC) of a ball center throughout the time (i.e. frames).

Step4 In order to cancel out projective distortion, 2x2 homography **H** was applied on HIC values. **H** was computed based on three point pairs as follows (Hartley and Zisserman 2004). It was assumed that the most extreme detected image positions of a ball from its equilibrium position correspond to the actual end positions of a ball in 3D space. The third point pair originated from the fact that an equilibrium ball position can be easily detected on the image too.

Step5 We picked two consecutive camera frames where for first frame HIC amplitude value $\mathbf{A_1}$ is just below time axis and for the second frame HIC amplitude value $\mathbf{A_2}$ is just above time axis. Since two consecutive frames on time axis differ exactly by one camera frame rate period $\mathbf{T_C}$ and assuming the linear relationship between two HIC values, we compute the time offset **T** for which HIC reaches zero value zero on its path from the mentioned first to second frame.

$$T = \frac{|A_1|}{(|A_1| + |A_2|)} \cdot T_C \qquad (1)$$

This time offset **T** represents the moment when a ball swings through an equilibrium position.

Step6 After computing the time offset **T** for both cameras, a difference between those two time offsets yields us finally the subframe offset between cameras.

PGR cameras offer an accurate time stamping for each grabbed camera frame, allowing to compute camera subframe offset. We have used this info as a ground truth and compared our results against it. The camera frame rate was set to 15Hz and we have undertaken 30 different trials computing the camera subframe offset.

3 RESULTS

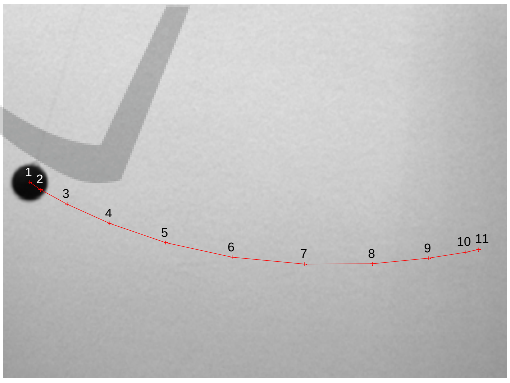

Figure 1: Camera image of a ball swing. Marked are positions of various ball positions and its trajectory for the first half of the harmonic period (Step1 and Step2).

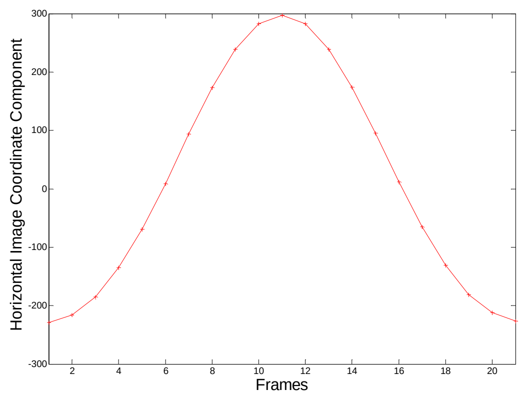

Figure 2: Original HIC of the ball position for a full harmonic period.

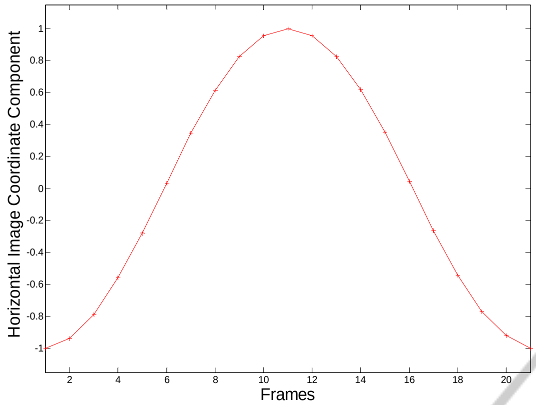

Figure 3: HIC of the ball position for a full harmonic period after PCA processing and projective rectification (Step3 and Step4).

Based on Figure 3, Step5 is carried out (Equation (1)), where in this particular example $\mathbf{A_1}$ and $\mathbf{A_2}$ would be HIC values at frames 5 and 6 respectively. Finally, computing similarly time offsets for other camera(s) and taking the difference between those times allow us to find subframe difference between cameras (Step6).

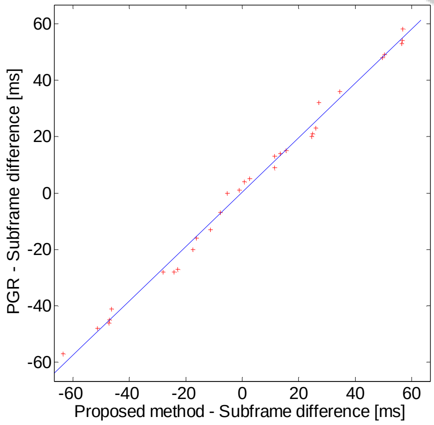

Figure 4: Comparison of results between PGR method (ground truth) and the proposed method. Linear correlation coefficient is 0.996, while the mean absolute difference between two methods measurements is 3.5ms.

4 DISCUSSION AND CONCLUSIONS

Mathematical pendulum is a substantial idealization of dimensionless point with mass *m*, attached to a string (of negligible mass) and which can be swung around its central equilibrium position. Ideally, 3D ball movement is a planar movement where an elongation of point can be described along one coordinate axis. Furthermore, it can be shown that an elongation of point swinging on its string can be described according to sine law. Essentially, a proposed method aims to model and recover this sine like movement in one spatial dimension.

In practice camera(s) can be put in absolutely arbitrary 3D position with respect to a pendulum. Even if a plane of ball 3D movement is parallel with a camera sensor it is very likely that camera is rotated around its optical axis such that image coordinate axis are not aligned with the spatial coordinate axis of 2D coordinate system within a ball oscillates. Therefore, the goal of PCA on the raw detected ball center image coordinates (Step1 and Step2; Figure 1, Figure 2) is to try indentifying the major direction of ball position change within an image coordinate system. Re-computing ball center image coordinates according to PCA direction axes is a first step in aligning, as much as possible, the image coordinates with the major spatial axes of movements.

Second issue to consider is to model an effect of a perspective distortion. Fortunately, the task is somewhat simplified since we are primarily interested with the change of spatial movement (elongation) in one dimension only. It is well known from a projective geometry that to compute transformation **H** which relates one 1D projective space to another 1D projective space we need at least three correspondent point pairs. Extreme positions of a ball in space where it is the furthest from its equilibrium position can be expressed in canonical projective coordinates as $[-1\ 0]^T$ and $[1\ 0]^T$. Their correspondents on the image can be approximated as the most extreme positions on the image within a particular frame. Similarly an equilibrium position can be described as $[0\ 0]^T$ where its image correspondent represent simply position on the image of a ball standing still. Consequently, when we apply PCA transformation and homography **H** on the original image coordinate values (Figure 2), we restore sine shape describing our ball oscillation (Figure 3).

It is assumed that crossing point on time axis (signal on (Figure 3)) is the common point in time and space that both cameras can refer to for synchronization (We recall that this point actually represents an equilibrium ball position). In principle we could pick another point for synchronization (e.g. maximum/minimum of sine). However, this particular choice, along with the reasonable assumption that sine in this area is linear, enabled a straightforward calculation of a subframe difference (Step6) using Equation (1).

Shown results on Figure 4 reveals that the proposed method yields basically the same data about cameras time offsets as manufacturer does. Compared to other methods, a proposed one is easily applicable in outdoor and indoor conditions. Pendulum itself is a cheap device that basically anyone can make and use. It has such physical structure that a large number of cameras can simultaneously image and model a ball movement. In turn, compared to many other methods, a proposed one is easily applicable in outdoor and indoor conditions. In fact, it allows cameras to be perhaps conveniently arranged first for synchronization and then calibrated, since it does not require camera parameters for synchronization at all. In addition, a proposed method SW implementation is extremely simple, compared to some solutions which use network as a tool, require PC server etc. Our method comes down to tracking a ball on the images for a couple dozen of frames (i.e. minimum a period of ball swing) only.

The sine shape that our method recovers (Figure 3), potentially offers other means of processing while trying to detect cameras subframe offsets. For example, we plane to explore if interpolating a sinusoid (from the directly detected ball positions), and thereby finding a sinusoid corresponding phase offset, would eventually give better results. Also, a proposed modeling of harmonic oscillations is rather generic where it is not necessary to use a pendulum only. Therefore, other devices such as weight on a spring or music metronome could be worth to explore as well.

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