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TRACKING VERTEBRAE IN CINEMATIC FLUOROSCOPIC X-RAYS

A thesis presented in fulfilment of the requirements
for the degree of Master of Technology
at Massey University

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October 1992

Abstract

This thesis concerns the evaluation of an image subtraction statistic that is used by a prototype of a chiropractic image processing package to track spinal movement. The image subtraction statistic is calculated by summing the absolute differences in pixel intensity of two images. Also included in the thesis is a brief discussion of different methods of tracking and a literature search of alternative statistics that may be appropriate for the image type (low contrast and noisy).

In summary the experimental work concluded that inter frame rotation does not have a significant effect on the performance of the image subtraction statistic when tracking inter-frame but when tracking from a particular frame to one which is significantly later in the sequence rotation must be included in the algorithm. It was also found that discretisation of the image had a detrimental effect on performance. This can be compensated for by adding a sub-pixel location calculation into the algorithm. In the original prototype a median filter (rank 5) was used to smooth the noise in the image to be searched. This was found to have marginal affect on the performance of the statistic.

Many of the algorithms presently defined in the literature were found to be unsuitable for this application as they tracked clearly defined lines or searched for a two-dimensional shape that matched a predefined three-dimensional model.

An algorithm that may prove to be a suitable alternative compared the rate of change in intensity across a window so is based on locating a change of intensity pattern rather than a pixel to pixel comparison.

There are some features that could be included in the tracking procedure to make the algorithm more efficient (the two-dimensional logarithmic search) and provide checks

to safeguard against points incrementally deviating from the correct location as tracking progresses (referencing a moused frame, using the vertebra rigid body property). The benefit of incorporating the safeguard features would have to be weighed against the cost of extra computational time.

In conclusion, the image subtraction technique can be improved from, in some cases, total tracking loss to accuracy within two pixels of the correct location. This is achieved by tracking inter frame, that is from one frame to the next in the video sequence, and including a sub-pixel location calculation.

Acknowledgements

I would like to take the opportunity to thank the following people for their assistance with my research:

- Professor William Monteith for his supervision and motivation.

- Wyatt Page for his patience and comradeship in deciphering and reorganising early programming code.

- Dr Roger Browne, Wyatt Page, and Elliott Blennerhasset for the foundations they laid with their original ideas and work.

- Dr Les Whitehead of "Whitehead Chiropractic" for making available the patient data from his cine X-ray equipment.

- DSIR for their funding and support meetings.

- My husband, Philip, for his patience, understanding, support and encouragement.

- Our Creator who makes all things possible.

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Chapter 1
Introduction

In pursuit of progress chiropractors are turning to scientific diagnostic aids. One such innovative chiropractic package was designed and a prototype produced by a team of Palmerston North technologists in association with a local chiropractic clinic.

The package allowed an X-ray video of spinal movement to be captured to computer hard disk, points of interest to be marked on an initial frame using a mouse and these points to be automatically located on each subsequent frame of the video. From here analysis software allowed calculation of vertebra rotation, planar displacement and axial displacement and their rates of change. Graphs of this data allow the chiropractor to monitor how vertebrae interact - a new dimension in diagnosis after years of only static x-ray film and measurements.

1.1 Dynamic versus static measurements of the spine

The use of static X-ray images as a diagnostic tool for medical practitioners means that dynamic features of the human body movement are not shown. For instance, a static X-ray image of the spine shows the position of the vertebrae at the instant of exposure, but the relative positions of the vertebrae through the full range of motions of the body are not available. Characteristic data of static measurements include the relative angular position, feature separation, planar translation and structure definition. Cinematic X-ray motion sequences of the human spine were first produced by Reynolds [Reynolds, 1938] in 1921 but accumulated X-ray exposure for even a short sequence was large and consequently this method was not widely used because of the danger to patient and operator health. The use of modern highly sensitive image intensifiers has dramatically reduced the X-ray dose. This coupled with a highly sensitive video camera, enabling the display of motion X-ray video images on a conventional VDU, makes dynamic measurements of spine movement possible. Some characteristics of the dynamic data are feature angular velocity, feature angular acceleration, feature separation velocity, feature separation acceleration, feature translation velocity, feature translation acceleration and rate of change of acceleration (jerk). The equations used to calculate these dynamic measurements are derived in chapter 3. These dynamic characteristics may prove useful in the diagnosis of spinal disorders.

In order for the dynamic characteristics to be calculated static measurements have to be made for each frame. The process used to define the points of interest and then locate them in each frame is called 'tracking'.

1.2 The Tracking Procedure

The procedure used by the prototype to track spinal movement is for the clinician to display an initial frame on a computer screen and to define the set of points of interest (usually corners of vertebrae or the edge of the skull) using a mouse. The purpose of the tracking software is to map these points through a sequence of frames. When tracking is complete the sequence can be reviewed with the tracked points in place. The sequence of tracked points may also be used to calculate quantitative features of the movement of the spine which may be viewed in tabular or graphical form to aid diagnosis of the spinal condition. The tracking software compares the window surrounding the known point with windows of the same size within a precalculated area of probable point location in the next frame. An algorithm is used to measure the similarity of the windows. In the prototype of the tracking package the algorithm is based on the sum of absolute intensity differences [Schalkoff, 1989]. The absolute difference in intensity between each corresponding pixel within the window is calculated and summed. This algorithm is explored more fully in chapter 4.

1.3 The prototype algorithm

The prototype of the spinal tracking package initially gave a very variable performance. Because of the limited knowledge of the algorithm behaviour for the particular images being used it was unclear what was causing the variations in performance. This report concerns the exploration of the affects of some of the more obvious possible factors. There were some surprising and exciting finds.

The first factor, the quality of the original point selected, was improved by user training and implementing a test on a selected point for tracking quality. The user was requested to select points on definite features in higher contrast areas. The moused point was compared to those in the surrounding area as a point that is not unique from the neighbouring points has questionable tracking ability. For example, a point selected along an edge of a feature will not be clearly distinguishable from other point along the same edge. When a point was deemed as an unsatisfactory choice the user was given the option of selecting an alternative point to track.

The effects of rotation and discretisation were explored. Neither were taken into account in the original algorithm. The main reason for this was that for unknown benefit there would be severe increases in calculational overhead.

From a series of tests it was found that rotation could be disregarded if tracking was strictly interframe. Interframe tracking, or tracking from one frame to the immediate next in the sequence, has itself a cost as points that deviate from their correct position will not recover.

Discretisation was found to cause incorrect locations to be selected. There are two straight forward ways around this problem. The first is to always track from the reference moused frame. This will mean that discretisation will not cause most sensibly selected points to deviate more than a pixel and the tracking error over a sequence will not be cumulative. The cost of always using the reference frame is that rotation and intensity scaling has to be included in the calculations. The second method of overcoming the effects of discretisation is to calculate sub-pixel location. This means that although the location of a point is written to the screen as an integer pixel position when the point is tracked to the next frame the previous location may be a fraction of the way across the pixel.

1.4 Algorithms available from literature

A number of the algorithms documented in literature can not be used directly on the vertebra tracking application but the ideas can be modified to improve the performance of the simple sum of the difference window statistic. For example it is not possible to have a predefined three-dimensional model of the vertebra being tracked but because the z rotation is kept to a minimum a two-dimensional outline of the vertebra can be used to aid tracking if the majority of the points remain accurate.

Other algorithms track lines or curves - edge detection may give enough outline of the vertebra to enable tracking of that line. The success of this method would be very dependant on the stability and clarity of the vertebra outline.

Many algorithms that predict the location of missing points depend on the smoothness of motion criteria in order to interpolate the movement of the point over the image series. Patients spinal movement is often jolty in the problematic cases that would be videoed for analysis.

Two alternative statistics that could give good results for this application are the moment of inertia statistic and the rate of intensity change statistic. The benefit of calculating the moment of inertia of pixels within a set radius of the specified point is that the result is independent of rotation. The rate of change of intensity across a window is also promising as it is looking for change of intensity patterns and is independent of shifts in intensity from frame to frame.