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DEVELOPMENT OF A SUNSPOT TRACKING SYSTEM

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1. Introduction

Large solar flares produce a significant amount of energetic particles which pose a hazard for human activity in space (Moore et. al. 1990). In the hope of understanding flare mechanisms and thus better predicting solar flares, NASA's Marshall Space Flight Center (MSFC) developed an experimental vector magnetograph (EXVM) polarimeter to measure the Sun's magnetic field (West and Smith 1994). The EXVM will be used to perform ground-based solar observations and will provide a proof of concept for the design of a similar instrument for the Japanese Solar-B space mission.

The EXVM typically operates for a period of several minutes. During this time there is image motion due to atmospheric fluctuation and telescope wind loading. To optimize the EXVM performance an image motion compensation device (sunspot tracker) is needed. The sunspot tracker consists of two parts, an image motion determination system and an image deflection system. For image motion determination a CCD or CID camera is used to digitize an image, than an algorithm is applied to determine the motion. This motion or error signal is sent to the image deflection system which moves the image back to its original location. Both of these systems are underdevelopment.

2. Tracking Algorithms

Two algorithms will be tested for use with the sunspot tracking system. The centroid algorithm works by calculating the centroid of each successive image then determining the shift in the centroid from one image to the next (Mansfield 1996). A modification of the centroid algorithm is presented here where the motion in each direction is calculated using only one row and one column respectively,

$$X_{cen} = \frac{\sum_{i=1}^{N} x \cdot f(i, M_x)}{\sum_{i=1}^{N} f(i, M_x)}, \qquad Y_{cen} = \frac{\sum_{j=1}^{N} y \cdot f(M_y, j)}{\sum_{j=1}^{N} f(M_y, j)}, \tag{1}$$

where $f(i,M_x)$ and $f(M_y,j)$ are the image intensity for a pixel in a particular row and column respectively, and M_x and M_y are the row and column number. The row and column are chosen to overlap the true centroid of the sunspot of interest.

A simplified correlation algorithm (SCA) has been developed specifically for sunspot tracking. The SCA works by first determining error parameters from the initial image. This is done using,

$$E_r = \sum_{i=1}^{N} sign(x_{ref} - i)[f_{ref}(i) - f(i)], \tag{2}$$

where $f_{ref}(i)$ and $f(i)$ are the image pixel intensity for a given row or column of the reference image and the currently acquired image respectively, and i is a pixel index. The variable x_{ref} is an arbitrary reference point such as the centroid of the reference image and has units of pixel width (e.g., if the reference point is in the center of the fifth pixel, x_{ref} would be equal to 5.5). The function sign($x_{ref}-i$) is +1 if $x_{ref}-i > 0$ or -1 if $x_{ref}-i < 0$. The error scaling parameter α is determined by shifting the reference image one pixel and then applying Equation 2 with the shifted image used as $f(i)$. x_o, the image motion, is defined as

$$x_o = \alpha E_{r1} + x_{ref}, \tag{3}$$

where E_{r1} is the value obtained from Equation 2 with $f(i)$ being the reference image shifted by one pixel. The reference image being shifted by one pixel yields α is equal to $1/E_{r1}$. As the reference image is not symmetric, the error scaling parameter α is calculated separately for movements in the positive and the negative direction (α_+ and α_-) for both the X and the Y axes. An appropriate α is selected based on the direction of sunspot movement which is determined from the sign of E_r (Chmielowski and Taylor 1997, and Chmielowski and Klien 1993).

There are obviously advantages and disadvantages to each algorithm. The centroid algorithm is easy to understand and to implement once the image has been preprocessed. The difficulty is with preprocessing the image. In order for the centroid algorithm to work any linear trends in the data must be removed (i.e. the linear trend in intensity near the limb of the sun), and any extraneous features, like a portion of a second sunspot, must be masked out. The disadvantage of the SCA algorithm is that it requires the initial calculation of error parameters, and a scheme might be necessary for updating the error parameters if the intensity of the image changes over time. The advantage of the SCA algorithm is that it will track on whatever is in the field of view, provided there is a sufficiently large object, a sunspot, somewhere in the image. The linear trend of the image near the limb of the sun is not an issue, nor are extraneous features.

3. Sunspot Tracking System

Testing of the preceding sunspot tracking algorithms on simulated sunspots suggested that only one row and one column of pixels were necessary for tracking, providing a factor of N savings in calculation time and image acquisition time over algorithms requiring an entire image. Furthermore determination of movement in each direction is independent implying two identical independent systems for tracking can be developed. Figure 1 shows a diagram of the sunspot tracking system for one axis.

I. Image Motion Determination System.

To acquire the image a CID camera was chosen. The CID camera has the capability of reading out selected rows or a selected row of pixel information at higher rates than the entire image, 700Hz for one row. Two CID cameras will be used, one rotated 90° with respect to the other with a beam splitter used to send the image to each camera. The system will start by reading the entire image and locating a sunspot. Once a sunspot is located a row from each CID camera will be chosen, for one camera this will correspond to a column of data. The row and column will be chosen to include either the centroid of the sunspot or the minimum value of the sunspot, note these are not necessarily the same location.

The CID camera operates at a significantly lower rate than CCD linear arrays. CCD linear arrays are available that operate near 10kHz as opposed to operating at 700Hz. The primary advantage of using the CID cameras is that a row of pixels exist at the location of the sunspot and must simply be chosen. If two linear CCD arrays were used they would have to be mechanically moved to the location of the sunspot. The scientific camera would have to be used to locate the sunspot to give a location for the CCDs to be moved to.

The locating algorithm will be implemented in the controller digital signal processing (DSP) board, Figure 1. Once the image motion is determined a control algorithm will determine a signal to send from the DSP through an amplifier to the image deflection system.

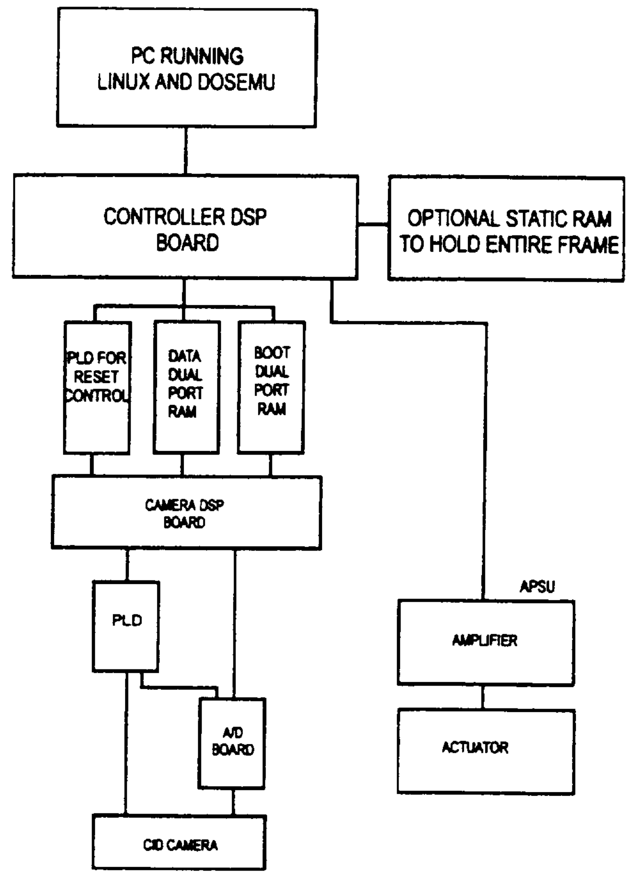

Figure 1.

II. Image Deflection System.

A one mirror image deflection system will be used for each independent tracking system. A magnetostrictive actuator has been chosen to move each mirror about the given axis. A magnetostrictive actuator was chosen over piezoelectrics due to their larger range of motion and larger driving force. The design issues to consider are how to mount the actuator, how to mount the mirror, and what to use to allow the mirror to rotate about one axis only.

The EXVM has already been built and a limited amount of space is available for the entire tracking system. In order to conserve space an attempt was made to mount the actuator vertically. In this configuration the actuator produced significant transverse vibrations in the optical table it was mounted on. Note that the optical table is similar in size and design to the bottom of the EXVM where delicate instrumentation will be mounted. Mounted vertically the actuator "beats" the optical table like a drum. It was determined the actuator must be mounted horizontal to the table surface. In this configuration it "stretches" the table top, like stretching the head of a drum. In order for the image deflection system with the horizontal mounted magnetostrictive actuators to be used with the EXVM, the EXVM "box" with have to be redesigned.

It is desired that the horizontal actuator mount have resonant frequencies above the operating frequencies of the system. This is a desire for optimal performance, but is not a requirement; the control algorithm could compensate by reducing the gain at the resonant frequency. A combination of structural modeling using MatLab and experiment are being used to design the actuator mount. Testing the first design showed a resonant frequency at 160Hz. MatLab modeling showed that the resonant frequency was at 130Hz. The usefulness of modeling in this case is not its ability to predict; its usefulness is in its ability to give insight into what is causing the resonance. From the understanding gained from MatLab modeling, the actuator mount has been redesigned and should have a resonant frequency over 800Hz.

The remaining design issues are with mounting the mirror and designing something that allows the mirror to rotate about one axis with a high angular resolution. These issues are being addressed through a combination of testing and modeling.

4. Summary

Two algorithms are available for sunspot tracking which require the use of only one row and one column of image data. To implement these algorithms two identical independent systems are being developed, one system for each axis of motion. Two CID cameras have been purchased; the data from each camera will be used to determine image motion for each direction. The error signal generated by the tracking algorithm will be sent to an image deflection system consisting of an actuator and a mirror constrained to move about one axis. Magnetostrictive actuators were chosen to move the mirror over piezoelectrics due to their larger driving force and larger range of motion. The actuator and mirror mounts are currently under development.

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