Machine Vision for Dynamic Loads

Alexandar Djordjevich, Robin T. Bradbeer and Paul S. Y. Wu

City Polytechnic of Hong Kong
Tat Chee Avenue, Kowloon, Hong Kong

Abstract

Control of structures under dynamic loading requires arrays of measurements of deflections or strains within solid members. A network of novel fibre optic sensors for carrying on such measurements is embedded in a beam element which exemplifies an arm of a robot. The leads of the optic fibres form a bundle which is scanned using a ccd array. The deflection measurements are based on the light loss of optical fibres, sensitised to make this loss dependent on curvature. Suitable treatment enables the sensitivity to relate selectively to curvature about a preferential axis.

1 Introduction

It is possible to measure impressively small material strain with fibre optic sensors using interference principles. The design of these sensors includes a resonant cavity, typically between a full silvered and a half-silvered mirror. Peaks and nodes in the light signal indicate changes in the path length in the resonant cavity as the fibre stretches along with the surrounding structure.

However, this technology has not moved out of the laboratory. The primary reason is the cost of the detection equipment which must maintain tolerances of the order of ¼ wavelength of light. Other limitations may include the effects of temperature on the readings, the necessity to make partially silvered joints of the fibres, the difficulty of differentiating phase increases from phase decreases for rapidly moving peaks in the presence of noise [2], and the difficulty of establishing an absolute reference point.

The true/apparent strain ambiguity during measurements is also a frequently reported problem with all direct sensors of strain - which is discussed in Section 2.1 of this paper.

A different type of fibre optic sensors for measurement of mechanical loads is a well known "microbend" sensor. It is an intensity modulated sensor. Fibre microbending is used to achieve the modulation. To produce a microbend strain sensor, an optical fibre is placed between two corrugated end plates (pressure platens); Figure 1.

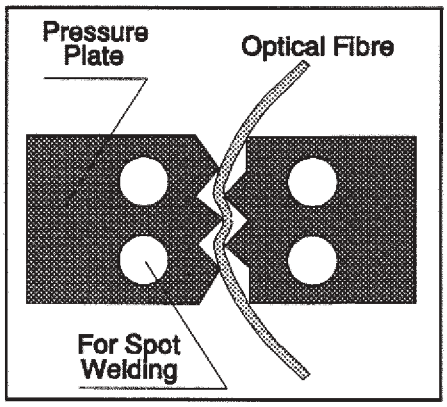

Figure 1: Microbend Sensor

The light losses between the core and the cladding change as the radius of curvature of the fibre is changed. These resulting changes in the light intensity can then be detected with simple and inexpensive optoelectronic components. The fibre is pre-loaded (bias compression) by the pressure platens to provide tensile and compressive measurement capability. Load transverse to the fibre can be sensed. The need for corrugated plates is a disadvantage. An improved "curvisensor" is proposed in this paper.

2 Curvisensor

A new fibre optic "curvisensor" is proposed with the fibre transmissivity sensitive to deflection. The physical principles of the "microbend" concept (Figure 1) are employed using a general strategy of making the optical fibre itself sensitive to deflection by applying a suitable treatment. Thus, the need for pressure platens has been abandoned. There are no mechanical components attached to the curvisensor, making it suitable for structural embedment, Figure 2.

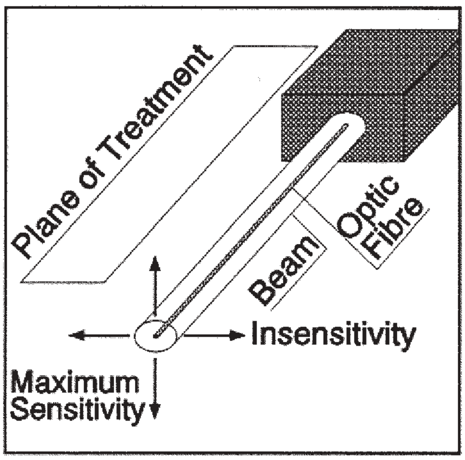

Figure 2: Polarity of Measurements

Curvisensor measures structural curvature during deflection. Directionality and polarity of measurements are achieved.

2.1 Advantages in Measuring Curvature (Rather Than Strain)

It is an imperative for strain measurements based on interference principles that sensors be unobtrusive. Despite the small diameter of optical fibres (of the order of 125-500 microns), their diameters are large in comparison with those of typical structural reinforcing fibres (diameter of graphite fibres is approximately 5-10 microns and a single layer of advanced composite material is about 120-140 microns thick). Although fibre optic sensors may be embedded relatively easily in laminated materials, these inclusions have been shown by many authors [3,4] to cause local stress/strain concentrations. For example, an optical fibre included in a fibre/resin composite (Figure 3) causes formation of the resin rich areas (representing local discontinuities in material properties).

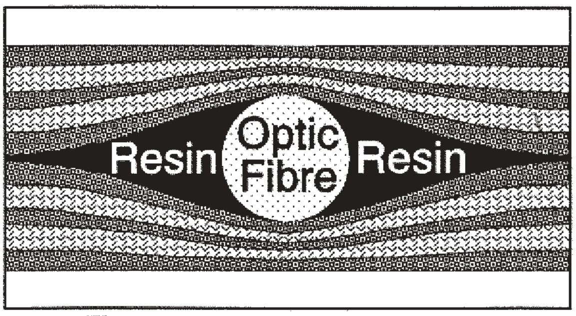

Figure 3 : Material Discontinuity

These local strain perturbation effects have received considerable attention in the literature as the accuracy of strain measurement is adversely affected by strain perturbations introduced by the inclusion of the optical fibre. Furthermore, selection of the optical fibre coating also plays an important role as it cushions strain transmission onto the fibre itself. Hence, optical fibres must be regarded as multi-phase entities [4] and this further complicates interpretation of the signals obtained. This is particularly noticeable if optical fibres are glued to a metal surface or embedded into concrete where it is desirable to retain the fibre's protective coating.

Measurements with the curvisensor, on the other hand, are NOT based on strain measurements and for that reason are insensitive to local strain perturbations. It is the structure's change in curvature with bending which is the measured quantity; this is a variable NOT local to the sensitised zone of the fibre. The optical fibre by itself renders little resistance to bending, and the cushioning effects of the resin-rich area or fibre coating do not affect the fibre curvature in bending since they are constant in the adjacent local sections.

In other words, even if the shape of the structure's section changes during loading (i.e. because of its multi-phase content), this change is equivalent for adjacent sections (unless the bending moment changes between these sections which is not a micro-scale variation). The curvature of the structure upon loading is defined by the change in angular position of adjacent sections, and is uniquely correlated to the curvature of the fibre (as adjacent local sections deform equally). Hence, although the fibre's presence perturbs the local strain field, its curvature is the structure's curvature. Degradation of the structural properties due to the inclusion of the optical fibres can be accounted for by providing adequate reinforcements (which is a macro-scale aspect of the problem) - while the measurements with the deflection sensor are unaffected by micro-structural effects caused by its embedment.

A further advantage in measuring curvature rather than strain is that curvature measurements can be made anywhere in the cross section, including along the neutral axis where there is no strain in bending.

The depth at which a curvisensor is embedded in a structure's cross section is of no relevance since curvatures change negligibly within the section. This is in sharp contrast to the strain values which vary within the section from their maximum negative to their maximum positive value. Hence, curvisensors' structural embedment and interpretation of the signals obtained are simplified.

2.2 Calibration of Curvisensors

Measurements were made on a structure schematically represented on Figure 2. The cantilever beam, a half inch (1.3 mm) steel rod 1037mm long, had a curvisensor glued to its surface. The beam was held in a chuck of a lathe and its free end was deflected horizontally by moving the tool-post of the lathe in 2.5mm increments. Sensor readings were recorded (Figure 4) for the amount of such deflection in the plane close to the curvisensor's plane of maximum sensitivity.

The graph of Figure 4 demonstrates that the curvisensor differentiates between deflections in the two opposite directions in a given plane (directionality : positive/negative side).

Resolutions better than 0.5mm tip movement were achieved over short time intervals (beam length over 1m). Data acquisition for graph of Figure 4 lasted approximately an hour. Over this time period, resolution was better than 2.5mm. It should be emphasised that no reference signals were used and the graph of Figure 4 included effects of disturbances. By providing reference signal paths, compensation for temperature effects and source fluctuations can be introduced in order to further improve the long-term resolution.

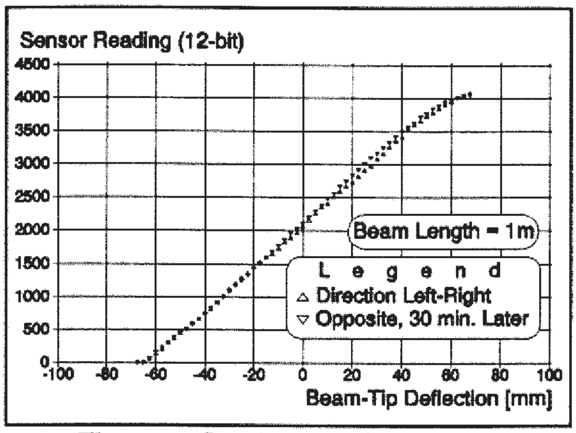

Figure 4: Curvisensor Calibration

2.3 Polarity of Curvisensors

The following graph (Figure 5) illustrates the change in sensitivity of the curvisensor with the plane of bending (polarity). The graph was established by manually turning the spindle of the lathe (with the beam in the chuck), and with the beam tip deflected a constant amount in the horizontal plane. This is equivalent to deflecting the stationary beam in different planes.

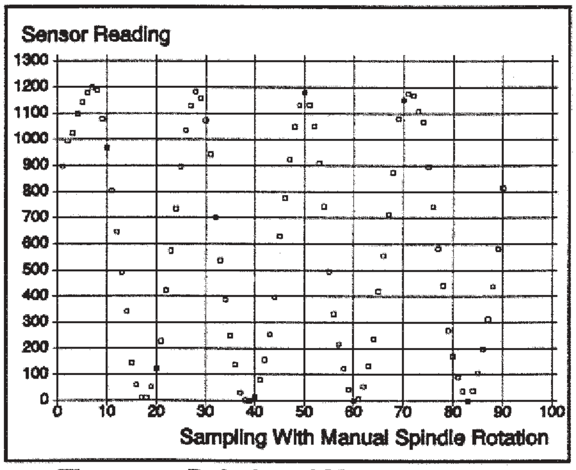

Figure 5 : Polarity of Measurements. Consecutive Readings While Rotating the Deflected Beam About Its Main Axis

The obtained graph approaches the cosine curve. The difference is due to the inconsistent relationship between the sensor sampling time and the speed of the spindle rotation - which was manual and without synchronization. It was verified that in the plane orthogonal to the curvisensor's plane of maximum sensitivity, there is virtual insensitivity.

3 Applications

3.1 Vibration Monitoring

When long robot arms are considered, or when improvements to their poor payload-to-weight ratio are sought, vibrations become a problem which reduce the overall accuracy of robots. Compensatory control may then have to be introduced for such arms of increased structural flexibility.

An example of structural vibration feedback obtained using a curvisensor is shown on Figure 6. It pertains to the previously described half inch (13mm) steel rod, 1037mm long.

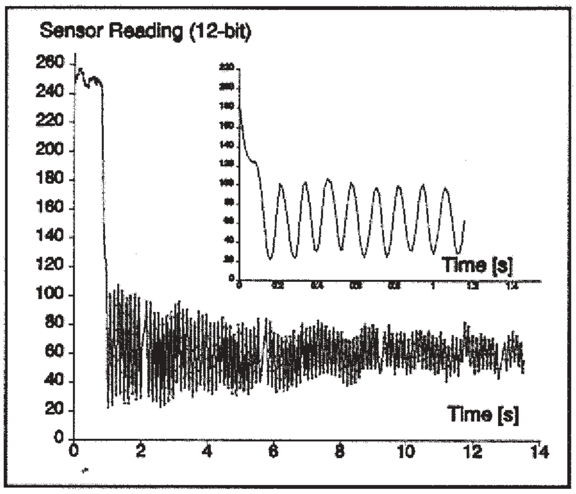

Figure 6 : An Example of a Structural Vibration Signal With a Cantilevered 13mm Steel Rod 1m Long

3.2 Torsional and Axial Loads

Curvisensor may also be used as an axial force and torque sensor, Figure 7. The change in curvature during either of these loadings is functionally related to an equivalent structural bending which produces equivalent sensor readings. In the case of axial sensors, active zones must be in curved segments of the fibres as the straight segments remain straight - while changing the slope only. Decomposition of these simultaneously acting loads (together with bending loads) into elementary load components is then possible with an array of curvisensors.

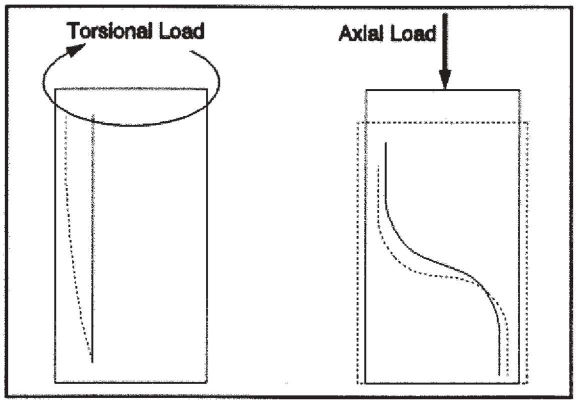

Figure 7 : Application of Curvisensors for Axial and Torsional Loads

3.3 Distributed Tactility

Robotic structures coated in flexible substrate such as a sheet of foam 1-2 mm thick will deflect integrated optical fibres upon pressure, Figure 8. By analogy to the human arm/body that is touch sensitive throughout, a term "distributed tactility" is used to indicate larger coverage. Distributed tactility would be a supplement to existing ("concentrated") tactile sensors often located at the robot's end-effector. The distributed tactility concept would provide information on the location of the loading point on the structure.

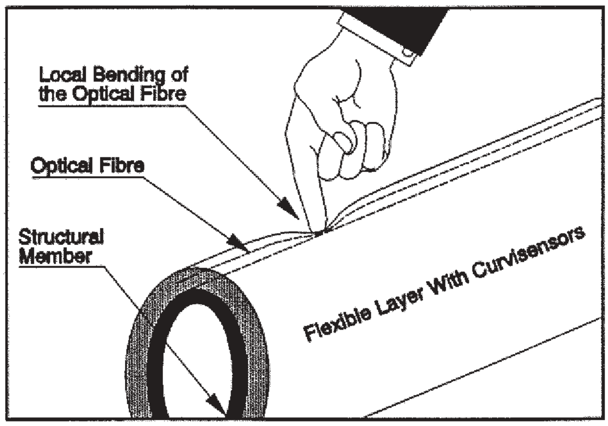

Figure 8 : The Concept of Distributed Tactility

3.4 Curvisensors in Moulded and Extruded Plastic Products

Application of curvisensors is initially expected in robotics, aerospace and building & construction industries and prosthetics. Being inexpensive, the technology is anticipated to gain wide acceptance in the commercial products industry. The toy and plastics industry would benefit from it particularly well.

As already mentioned, the operation of the curvisensor proposed herein is based on the curvature (rather than strain) measurements. Hence, curvisensors may be fully coated for thermal resistance to the short-term high temperature exposure which accompanies manufacturing of plastic products.

4 Detecting the complex image

Once the sensors have detected anything, the problem then becomes analysing what could be a potentially complex amount of data. For a few sensor fibres, simple phototransistors would suffice. The changes in light level could then be simply detected as analogue voltages. As the number of fibre sensors increases, the power, size and number of inputs to any control system becomes unmanageable.

Current work suggests that the use of ccd arrays may help solve these problems. A low cost "intelligent" ccd array, or camera, has been designed which is based around the TC211 ccd array. This has 165 lines of 192 pixels. The output from the array is sent directly to an ADC, and then to a dual port RAM. A 8031 micro-processor controls the whole process. Once in RAM, it is possible to process information page by page. The scanning is under software control, as is the definition of the picture. This 'intelligent' camera has been developed for machine vision use, but will also be used in processing the information from an array of fibres.

Initially, a simple linear ccd array of 256 pixels is being used. Simple bonding of the fibre end to the array means that each fibre interfaces with 40 pixels, the diameter of the fibre being 0.5 mm and each pixel being a 12.7 μm wide square, thus allowing six fibres to be used. The output from the array is read, via a six bit ADC, into RAM ready for processing.

Using well established techniques, the changes to each pixel set can be detected by subtracting information from successive frames.

Thinner fibres of 0.25 mm diameter will be used in the near future. The 256 array will be followed by a 2048 array, initially allowing 50 fibres, then 100, to be interfaced.

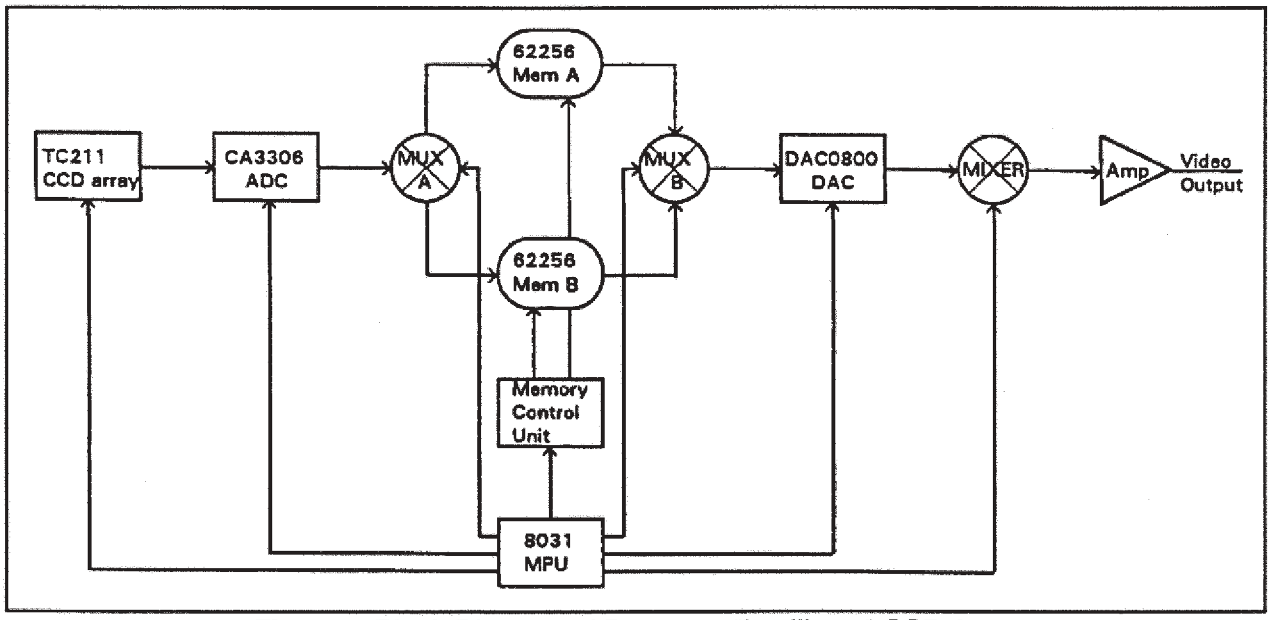

Figure 9: Block Diagram of Prototype "Intelligent" CCD Array

The objective is to eventually use a 325 by 485 array. This would allow around 400 fibres to be interfaced. Investigations are in progress with the low cost ccd array sensor described above to determine whether it could be controlled by a DSP. If current work in this area is successful then processing such a complex array of information should be simplified.

The present work assumes that the fibres are bonded directly to the ccd array. This means that a large number of pixels are used for each fibre as there is no optical focusing. It is possible in principle to terminate all fibres in a convex lens and so achieve some focusing. This would clearly increase the number of fibres that each array could interface. However, the increase in cost and complexity may not be worthwhile, as ccd arrays are inexpensive.

5 Conclusion

A new fibre optic "curvisensor" is proposed with the fibre transmissivity sensitive to curvature of structures under dynamic loading such as robotic arms. Advantages in measuring structural curvature - rather than strain (which is usual) - are presented. In contrast to direct sensors of strain where reliable structural strain transmission onto the sensor must be assured, curvisensors are unaffected by mechanical properties of intermediate objects such as the cushioning effect of the fibre protective coating, adhesives, resin, etc.

Curvisensor gives preferential sensitivity about a chosen axis, so that vector measurements can be made with an array of such sensors. Axial and torsional loads can also be measured.

With the presented "distributed tactility" concept based on curvisensors, the entire surface of structures (robotic arms) can be made touch sensitive. The loading point or distribution of loads on the structure can then be determined.

Fibre transmissivity in measuring curvature can be read using ccd optical arrays. This gives ease of interfacing to a computer and analysing complex data ; the total system is inexpensive.

6 References

[1] B. Grossman, T. Alavie, F. Ham, J. Franke and M. Thursby: "Fibre-optic Sensor and Smart Structures Research at Florida Institute of Technology", SPIE Vol.1170 Fibre Optic Smart Structures and Skins II.

[2] R.M. Measures : "Fibre Optics Smart Structures Program at UTIAS", SPIE Vol. 1170 Fibre Optic Smart Structures and Skins II (1989).

[3] J.S. Sirkis and A. Dasgupta : "What do Embedded Optical Fibers Really Measure?", Proc., 1st European Conf.on Smart Structures and Materials, Glasgow '92

[4] J.S. Sirkis and A. Dasgupta : "Optimal Coatings for Intelligent Structure Fibre Optical Sensors", SPIE Vol. 1370 Fibre Optic Smart Structures and Skins III (1990).