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Demonstration of an Aspect of Data Acquisition in Mechatronics Education*

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A simple laboratory experiment is described, which allows the students to: (i) familiarize themselves with the basics of computer interfacing and data acquisition and (ii), examine the relationship between computer sampling rate, sensor resolution and extracting reliable information from the measured data. It is shown that often data are taken at a rate faster than the pulse train generated by the sensor. This means some adjacent data points can have the same value. Thus, the rate in which the data change, if determined based on these points, is zero even though it is actually not. Least-squares linear regression, using many points, is shown to potentially produce more meaningful information. The experiment has proven to be very effective in providing complementary practical understanding to senior mechanical engineering students enrolled in the 'Automatic Control' course. It will also be incorporated within a 'Mechatronics System Design' course, which is currently under development.

AUTHOR QUESTIONNAIRE

1. The paper describes a new laboratory experiment in teaching the basics of computer interfacing and an aspect of data acquisition to undergraduate Mechanical Engineering students. In particular, a problem associated with the derivation of velocity from position information using a quadrature interfacing board is explored.
2. The paper describes new equipment useful in undergraduate courses in 'Automatic Control' and 'Mechatronics System Design'.
3. Senior undergraduate engineering students are involved in the use of the equipment.
4. New aspects of this contribution are: (1) transformation of a pneumatic pick and place manipulator into an instructional test station, and (2) in-house development of necessary software tools, graphical presentation and experimental approach.
5. The material can be used (as described in the paper) in experiments to provide complementary practical understanding to engineering students.
6. The students are given a laboratory instruction for running the set-up. The lab manual also includes preliminary background related to computer interfacing, measurement and processing of data. Other documents, such as regression amongst data points, are also provided to students.
7. The development presented in this paper has been tested in classrooms. The set-up has proved to be very effective, in the sense that the students understood a problem associated with derivation of velocity from position information faster, since they can see what happens rather than having to imagine what should happen.
8. The benefit of this work for engineering education is that it provides a unique training tool to explore an aspect of mechatronics that deals with extracting accurate and reliable information from sensory data. Students can confirm their findings with the explanations provided in the course books (a 'do-and-see' approach).

INTRODUCTION

THE VELOCITIES required by controllers are usually obtained using the position readings from the encoder and the times at which those readings are obtained. A simple linear regression can be used to estimate the slope (derivative) of position history. However, this technique can be complicated by (1) the finite encoder resolution and (2) the sampling rates. At low velocities and/or high sampling rates, the joint movement between subsequent readings may be less than the encoder can measure, resulting in identical position measurements. In the limiting case of a 2-point regression, this phenomenon will result in the calculation of a false, zero velocity. When the encoder resolution is eventually surpassed, a spike in velocity will occur. At the other extreme, using many points in the regression will eliminate this impulse behavior, but can smooth the velocity profile excessively, obscuring details. Furthermore, because only the points on one side of the instant are used in real-time regression, a time lag is introduced. It is therefore

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necessary to understand the fundamental trade-off between the two extremes.

In this paper, we present a laboratory experiment developed at the University of Manitoba, which provides the senior undergraduate engineering students with practical experience on this issue. It is demonstrated that, when data are taken at a rate faster than the pulse train generated by the sensor, some adjacent data points hold the same value. Thus, velocity calculation using these points is zero, even though it actually is not. Least squares linear regression using more data points can be employed to rectify the problem. The number of data points used for the optimal regression, however, depends on the sampling rate, the operating range of velocities, sensor resolution as well as the requirements of the system to be controlled.

The development of this laboratory experiment is part of our continuous effort in offering cost-effective teaching tools in order to meet the requirement for future engineers. In particular, we are currently developing an introductory course on mechatronics. Mechatronics is concerned with designing systems possessing both a mechanical functionality and an integrated algorithmic control [1]. In view of advancements in microprocessor and sensor technology, engineering students are expected to learn about computer interfacing, real-time programming, collecting and processing sensory data [2]. One way to enhance learning is to expose students to direct experience.

The organization of this paper is as follows. First, the description of the laboratory set-up is given. A typical laboratory experiment performed by the students is outlined next. Results pertaining to this experiment are shown along with points to be made during each step.

DESCRIPTION OF THE EXPERIMENTAL SET-UP

This experiment uses the pneumatic pick and place manipulator shown in Fig. 1. The manipulator had its native mode controllers replaced some years ago, and is now controlled by a 66 MHz computer. Figure 2 shows the schematics of the entire system. An optical shaft encoder is mounted on the extend/retract axis of the manipulator. As this axis moves, the encoder rotates with it, generating a two-bit Grey code pulse train. With reference to Fig. 3, the optical encoder's disk is equally divided into transparent and opaque sectors. In two locations, light-emitter and light-detector sets are placed. These sets are labeled A and B in the figure. When a transparent sector is between the emitter and detector, the detector may be said to be in a high (logic 1) state. Likewise, when an opaque sector is between the emitter and detector, the detector may be said to be in a low (logic 0) state. The detectors are deliberately placed in such a way that, as the wheel turns, the output signals will be out of phase. As an example, when A and B are in the transparent portion of the wheel (as indicated by line C–C), they are both high. Clearly, as the wheel turns clockwise, detector B is blocked before detector A. Schematically, the effect of a clockwise rotation is the same as a transposition of line C–C to the right. Similarly, a counterclockwise rotation has the effect of moving line C–C to the left, where signal A goes low while signal B remains high. These transitions are used to increment an M5312 quadrature encoder input card, up or down. The card uses 24-bit counters that allow counts up to 16.7 million. The diameter of the rubber-tired wheel attached

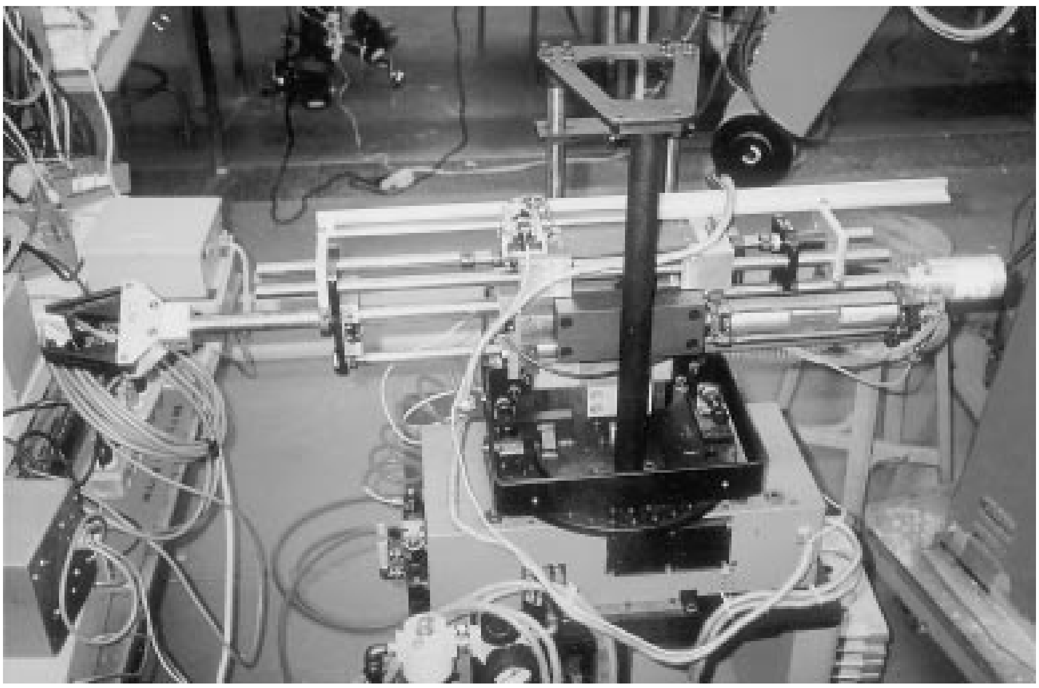

Fig. 1. General view of the experimental test station.

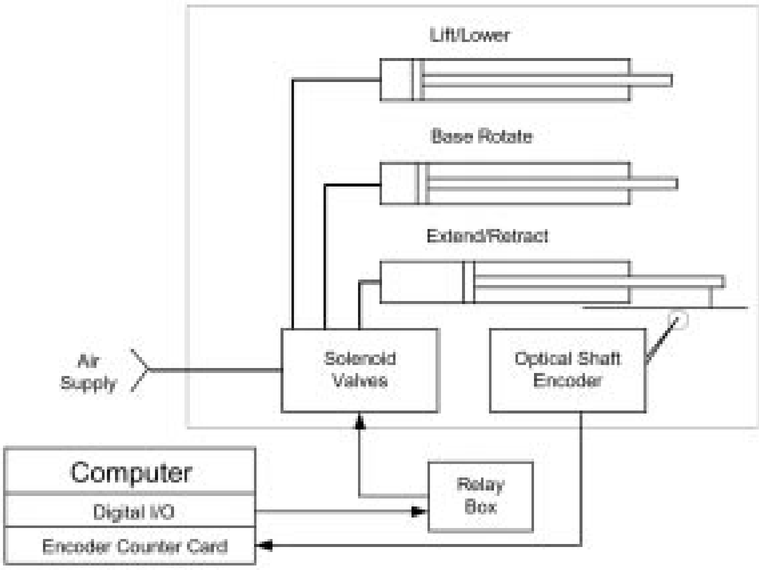

Fig. 2. Hardware configuration of sensory and control system.

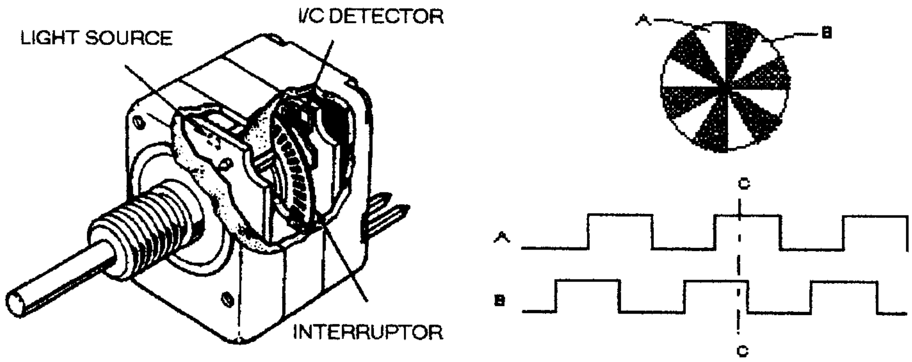

Fig. 3. Optical shaft encoder used in the experiment.

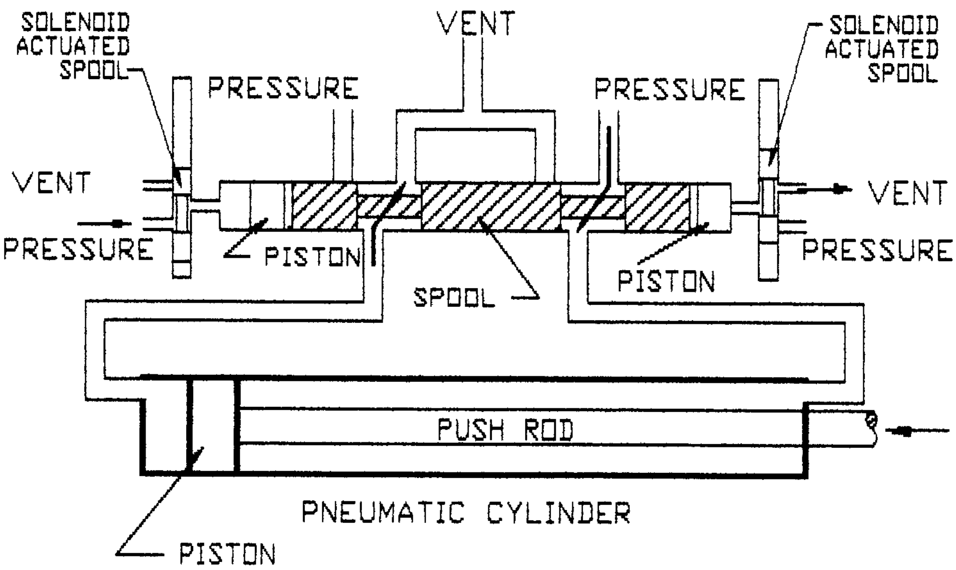

Fig. 4. Valve arrangement in the extend/retract pneumatic cylinder.

to the encoder is 31.75 mm; its circumference is 99.75 mm. With quadrature decoding, the 256 physical pulse cycles per revolution are expanded to 1024 pulses. The resolution of the measurement system is, therefore, 99.75/1024 or approximately 0.1 mm/pulse.

With reference to Fig. 2, the computer has a digital I/O card (PIO-12) which signals the relays in the original relay box. The relays, in turn, drive the on-board solenoid valves. Figure 4 shows the function of these valves. The solenoid-actuated spool on the left is in a position which pressurizes the left end of the main control spool, thereby driving it to the right. This orientation of the main spool causes the pneumatic cylinder to be pressurized on the right, causing the push rod to move to the left. The opposite orientations of the solenoid-actuated spools cause the push rod to move to the right.

An interactive 'C' program has been written which toggles the extend/retract axis and collects the data. As data are collected, the computer program directs the data to a buffer in RAM. DOS/BIOS monitors the size of the buffer and, when it is large enough, the CPU is interrupted and the buffer is purged by writing to a virtual disk drive resident in random access memory (RAMDISK) [3].

Upon completion of the actual experiment, the program calculates velocities. The velocities are created based on the least squares linear regression on the data using any selected number of adjacent

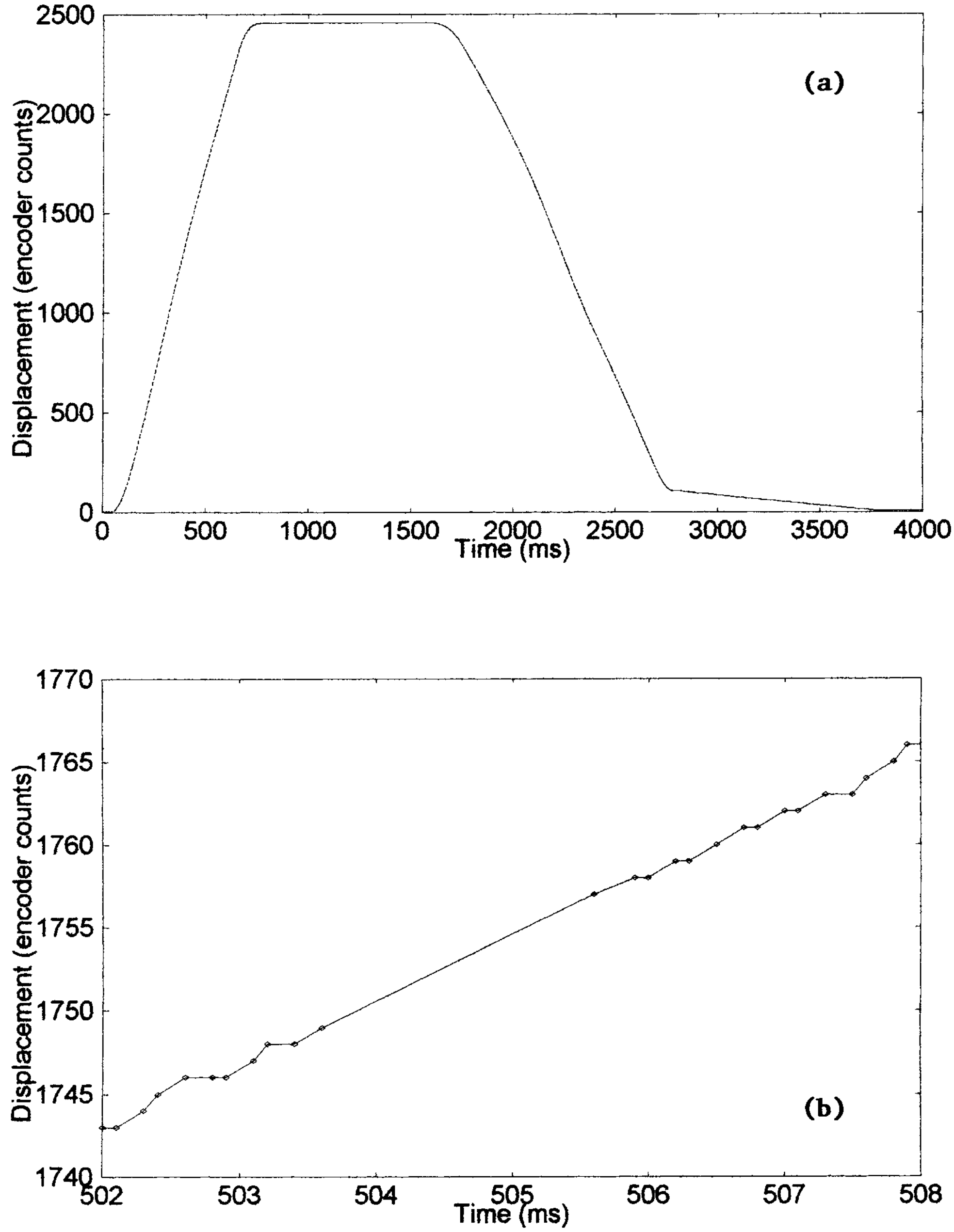

Fig. 5. (a) Typical displacement profile. (b) Close-up of the displacement.

data points. The 2-point regression calculates slopes according to the following relationship:

$$v_i = \frac{(x_i - x_{i-1})}{(t_i - t_{i-1})} \quad (1)$$

The n-point regression take the set of last n measurements of time and displacements $(t_i, x_i; i = 1, 2, \ldots, n)$, and fits a least-squares line through the points. The slope of the line is then taken as current velocity. The general expression is [4]:

$$v_i = \frac{n \sum_{k=i-n+1}^{i} x_k t_k - \sum_{k=i-n+1}^{n} x_k \sum_{k=i-n+1}^{n} t_k}{n \sum_{k=i-n+1}^{i} x_k^2 - \left(\sum_{k=i-n+1}^{i} x_k \right)^2} \quad (2)$$

RESULTS

In this section, the laboratory experiment to be performed by the students is presented. Students first study the software program and explore how the interfacing between the computer, the encoder and the solenoids are established through the software and hardware connections. Then, they execute a program that takes the data from the encoder, while the pneumatic axis extends then retracts for about 4 seconds. A large data file, in the order of 500 Kbytes, is created on the virtual disk drive. A typical plot of the displacement is shown in Fig. 5a. Figure 5b shows a scaled-up portion of the data taken between 502 to 508 milliseconds. By examining the plots, several

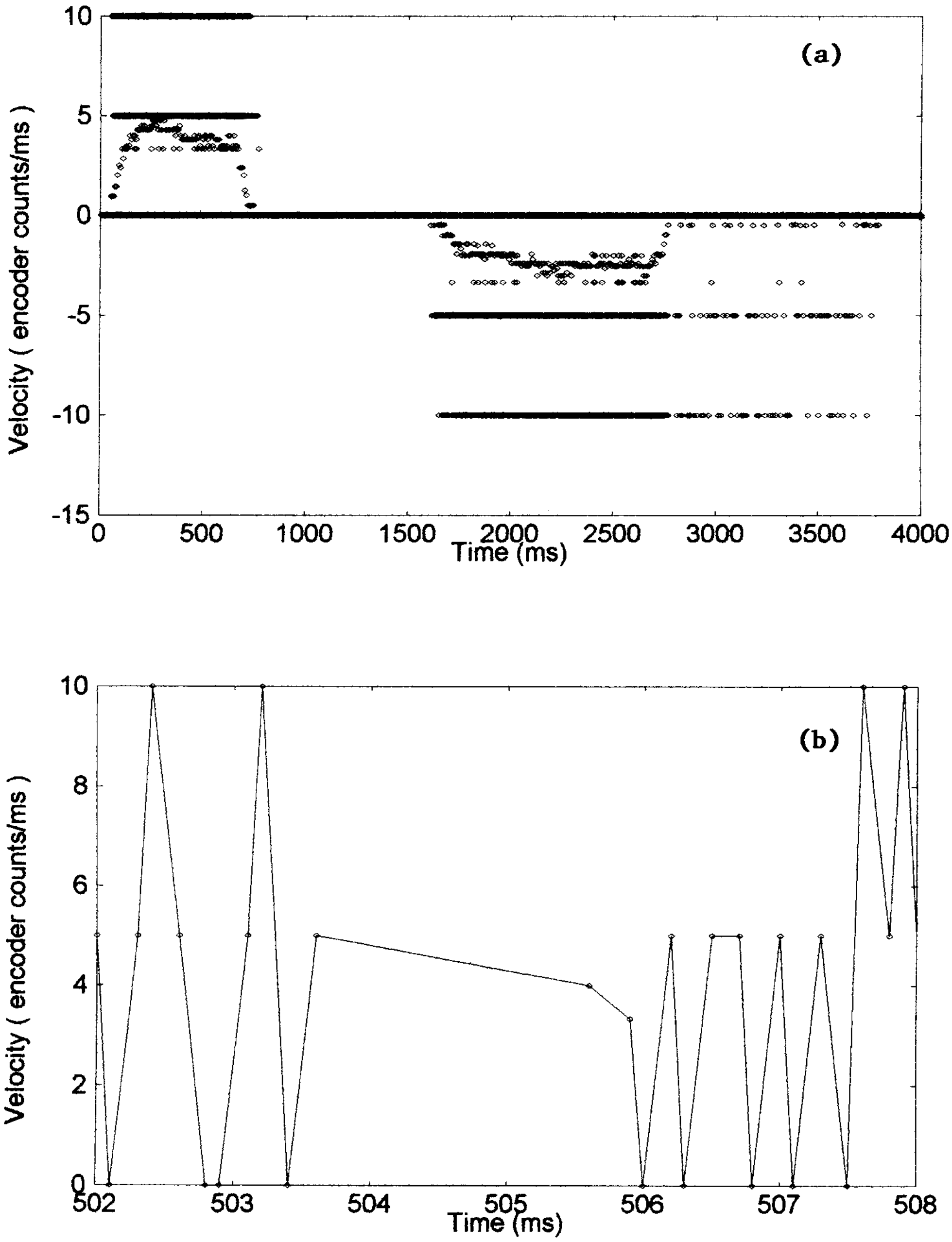

Fig. 6. (a) Velocity calculation using 2-point regression. (b) Close-up of the speed.

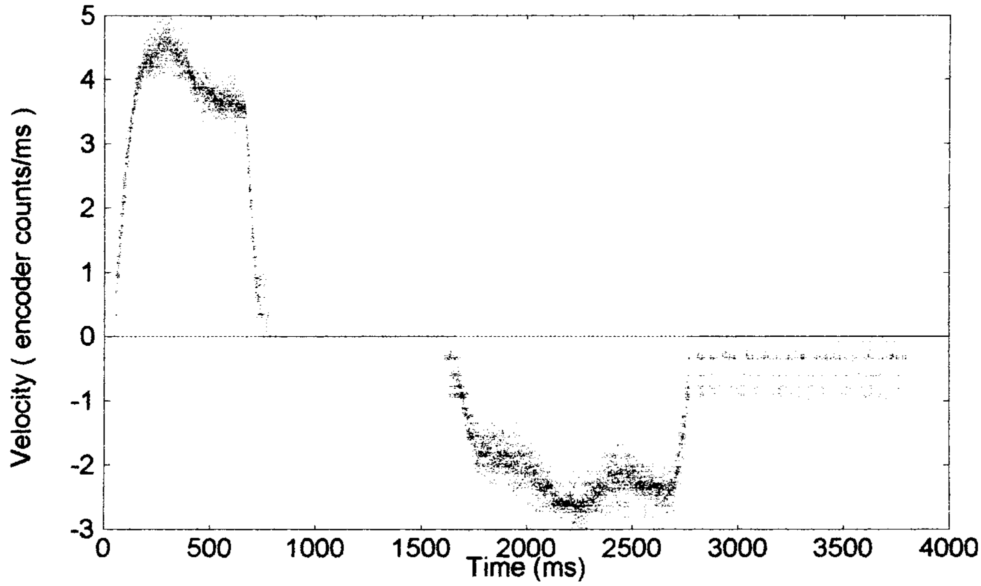

Fig. 7. Velocity calculation using 10-point regression.

observations can be made. Firstly, the computer records the location of the encoder approximately 6 times in a millisecond. The relatively large gap in data points seen on the time displacement close-up (Fig. 5b) is attributed to the computer transferring the recorded data into the virtual disk drive. In addition, the plot has a staircase appearance because the sampling rate of the computer exceeds the resolution of the optical encoder, for a given velocity. Thus, the computer takes two or more recordings while the encoder is still in transition from one stage to another. At such points, the apparent velocity is zero, since the slope of displacement versus time is zero. On the other hand, when data points jump vertically, the apparent velocity is large and is in the range of 5000 encoder points per second. This indicates that if the speed is determined by considering only two adjacent points, the calculated speeds may be described as: zero, large, zero, large . . . . This is clearly shown in Fig. 6 whereby the velocities are obtained using two adjacent points. The students are asked to read the velocities at certain times from Fig. 6a, and compare them with the ones determined directly by manually measuring the slope of the displacement curve in Fig. 5a. The students are informed that, due to the high ratio of sampling frequency to pneumatic axis velocity and low resolution of the encoder, the computer most often records zero changes in displacement. Thus, when comparing between only two points, the computer either detects zero velocity or a sharp

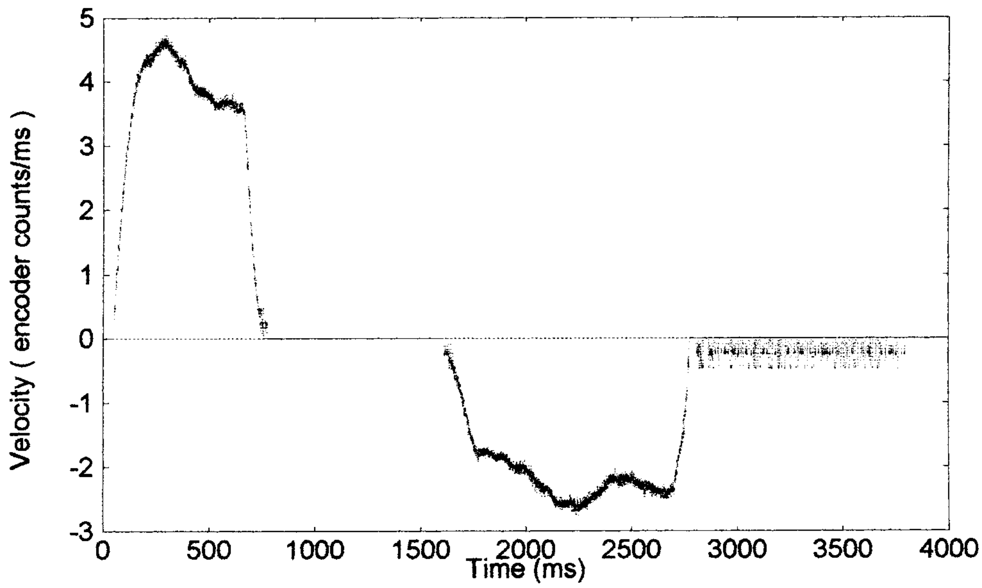

Fig. 8. Velocity calculation using 20-point regression.

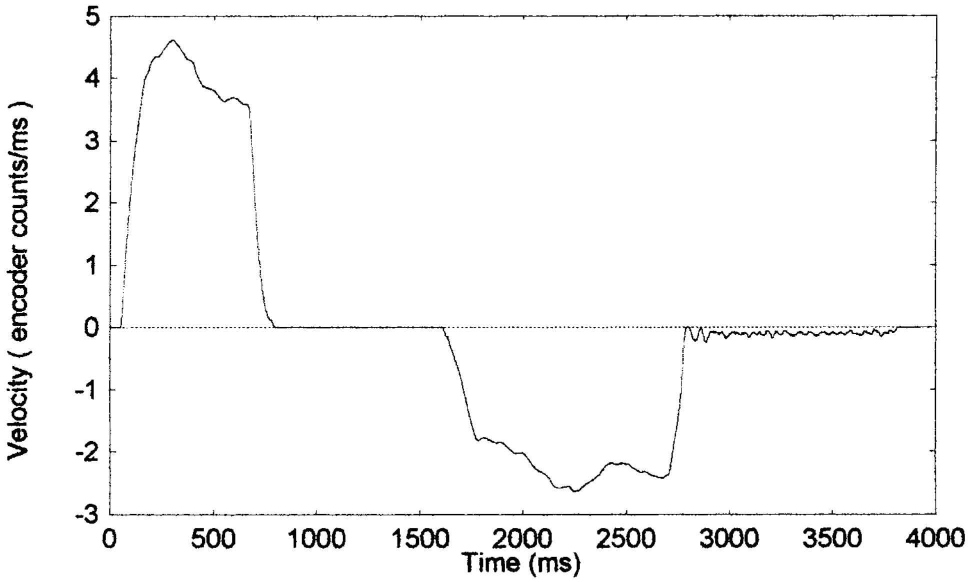

Fig. 9. Velocity calculation using 100-point regression.

spike in velocity as seen in the close-up plot in Fig. 6b. Therefore, the computer seldom sees the actual velocity. Clearly, there is need to adopt a better strategy for obtaining a meaningful velocity profile.

Next, the students use regression, using 10, 20 and 100 adjacent data points (see Figs. 7 to 9). Essentially, the n-point regression looks at the last set of n data points and fits a least-squares line. The slope of the line, calculated by Equation (2), then indicates the speed at the particular time. With reference to Fig. 7, the 10-point regression velocity curve shows a better velocity profile, since it uses more than just the last displacement point to determine the slope. However, it still appears to have scattered points. The 20-point and 100-point regression curves progressively improve the clarity of the velocity profile. The 100-point regression velocity profile (see Fig. 9) appears to be single valued. However, as one might expect, as more data points are used, the graph is shifted to the right. This shift may result in lower responsiveness of a control system using such data. Furthermore, the time overhead required for the necessary calculations also increases.

To make the point more clear, the students are asked to compare the 100-point regression to the 999-point regression. On this scale, the time lag is very apparent (see Fig. 10). It is also apparent that larger regression can smooth the velocity profile excessively, obscuring details (such as slight oscillations at the end of the stroke).

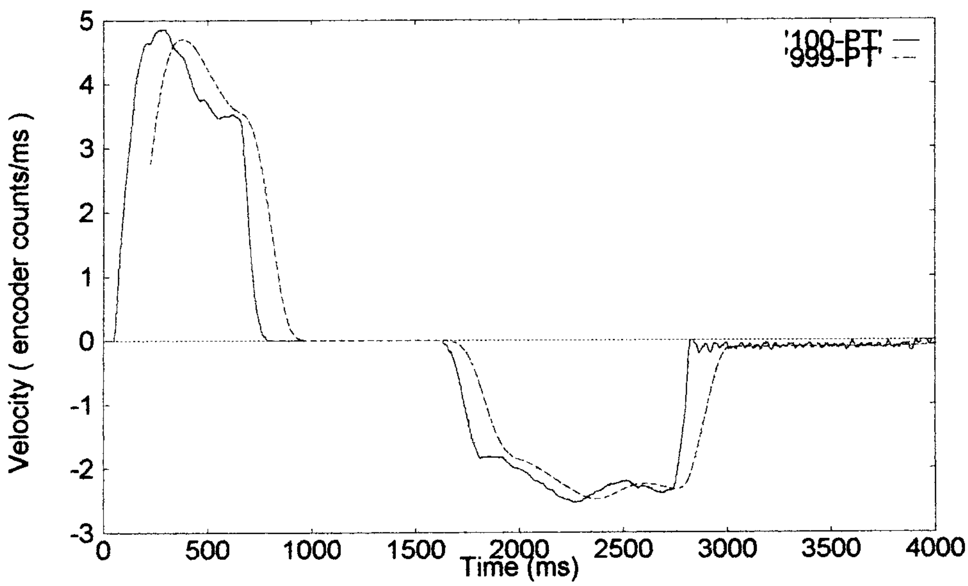

Fig. 10. Comparison between 100-point and 999-point regression results.

CONCLUSIONS

This paper presents an overview of a laboratory experiment developed as part of a senior-level undergraduate automatic control course. The experiment is related to integration between mechanical systems, sensors and computer software. It provides a unique training tool for engineering students to observe an aspect of mechatronics that deals with extracting accurate and reliable information from sensory data. This was illustrated by studying the displacement versus time profile of a computer-controlled pneumatic cylinder, equipped with an optical encoder with low resolution. Necessary software tools were all developed in-house.

An important lesson that students learned from this experiment was that the resolution of the sensing device should be chosen to correspond with: (1) the operating speed of the physical system being controlled, and (2) the rate at which the data are sampled. Choosing a sensing device with inadequate resolution operating with fast computers can result in false data interpretation. It was shown that, with a sampling rate exceeding the encoder resolution, apparent zero velocities may result in many points. Conversely, choosing too many regression points can lead to time lag and excessive smoothing of the velocity profile. Through this experiment, the students understood the concept faster, since they can see what happens rather than having to imagine what should happen (a 'do-and-see' approach).

The author would welcome inquiries and be pleased to furnish more information to faculty members of other institutions.

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