Investigations into the effects of illumination and acceleration on optical mouse sensors as contact-free 2D measurement devices[☆]

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Abstract

Since its introduction in 2000, there has been much interest in the use of optical mouse technology for displacement sensing and motion tracking. A conventional optical mouse configuration uses a single source of illumination but tests have shown that this can result in differences in sensor sensitivity in the x- and y-axes. This paper presents an investigation into the use of an optical mouse sensor for a two-dimensional, contact-free measurement device. It has been found that two-axis illumination can improve the accuracy of position measurement in two dimensions when compared with single-axis illumination. The effects of acceleration and deceleration on sensor accuracy have also been considered and it has been shown that sensor sensitivity is higher under conditions of acceleration than when decelerating.

Key words:
Optical mouse; Mouse sensor; Displacement sensor; 2D measurement

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1. Introduction

The computer mouse was introduced by the Stanford Research Institute (now known as SRI International) in 1963, with this first generation of devices designed to use external wheels which made contact with the working surface [1]. In 1971, a new mouse development was introduced by the Xerox Palo Alto Research Center (PARC), in which the external wheels were replaced with a rolling ball [1]. The rolling ball, which could rotate in any direction, was linked to two perpendicular wheels and an electronic commutator was used to translate motion of the rolling ball to position of the cursor on the screen.

Modern mechanical mice still use this concept of a rolling ball, however the contacting wheels have been replaced by two perpendicular shafts to determine motion on the x- and y-axes. Experience has shown that extended use of a mechanical mouse can result in the rolling ball becoming clogged with dust, lint or debris from the work place. As a result, the ball mouse requires periodic cleaning to maintain the sensitivity of the mouse to motion.

The optical mouse was introduced in the 1980s, however it was not until 2000 that optical mice became dominant in the computer mouse market [1]. With no moving parts, an optical mouse avoids problems of clogging with lint or debris. The early generation of optical mouse sensors used LED illumination, however they suffered from poor motion tracking capability. In 2004 laser illumination for optical mice was introduced to improve the operational performance [1].

An optical mouse performs a similar function to other two-dimensional position sensors and many researchers are interested in using the optical mouse as a cost effective position sensor solution. In Ref. [2], an optical computer mouse (OCM) was used to measure the elongation of polyethylene. The results showed that the OCM could provide reliable readings that were consistent with previous experimental tests on the properties of polyethylene.

The use of an OCM in vibration measurement was reported in Ref. [3]. An OCM was also used as a displacement sensor for optical microscopy to define and record a region of interest position [4]. This concept allows a microscope user to move back to the region of

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interest position more easily.

In Ref. [5], the OCM was used as a localization system for a mobile robot by attaching two optical mice on the underside of a robot. An investigation into the use of an optical mouse as an odometer for an automobile was presented in Ref. [6]. This research used the ADNS-3060 OCM as a vehicle tracking device. Using a different lens system from that of a standard mouse, it was reported that a speed of 7 km/h could be achieved. The use of an OCM as a displacement sensor for indoor mobile robots was reported in Ref. [7].

A detailed investigation into the performance of an OCM as a displacement sensor was presented in Ref. [8]. Sensor characteristics and the influences of surface texture, working distance and velocity were studied.

This paper presents an investigation into the characteristics of a mouse sensor under conditions of acceleration and deceleration. The work reported used an optical system consisting of a laser-based mouse sensor (ADNS-6010) in conjunction with a telecentric lens and laser illumination. This prototype non-contact displacement sensor (NDS) was designed with two lasers to allow an investigation into the influence of illumination placement on the performance of mouse sensors. In Refs. [2] and [7], the issue of bias in the readings on the x- and y-axes was discussed. It was stated in Ref. [2] that motion tracking capability in the x-axis reduced dramatically compared to that in the y-axis as variation in the z-axis direction was applied. In Ref. [7], the bias between measurements in the x- and y-axes was reported as an average error of 1.27%. This present paper investigates the causes of bias between the axes.

The prototype NDS is described in Section 2. Section 3 presents the testing and calibration of the NDS and the test results are reported in Section 4. Finally, Section 5 provides conclusions from the testing.

2. System description

2.1. Components

At present, there are two types of optical mouse sensor; LED-based devices (e.g. ADNS-2610, -2620, -2051, -3060 and -3080) and laser-based mouse sensors (e.g. ADNS-6000, -6010 and -6030). An ADNS-6010 laser-based device was selected for the NDS prototype detailed in this paper. The ADNS-6010 is a compact device which embeds a digital signal processor (DSP) on the same chip as a tiny digital camera. It is shown in the data sheet [9] that an ADNS-6010 can reach an operating speed of 45 inches per second (ips) and an acceleration of 20G. The ADNS-6010 was specifically designed for use in gaming and therefore has a programmable frame rate of up to 7080 frames per second (fps) and a selectable resolution of 400, 800, 1600 or 2000 counts per inch (cpi).

The prototype NDS unit was constructed with a telecentric lens, TL10-65, which is a C-mount camera lens and has a specified working distance of 65 mm. In the NDS unit, the optical system was required to capture microscopic images in order to deal with smooth surfaces which have little surface texture therefore, the optical system was set to a magnification of 1 as is typical for optical mice.

Illumination in the prototype NDS unit was provided by two laser modules of wavelength 656 nm. Fig. 1 illustrates the placement of these lasers which are located in relation to the reading axes of the mouse sensor, i.e. x- and y-axes.

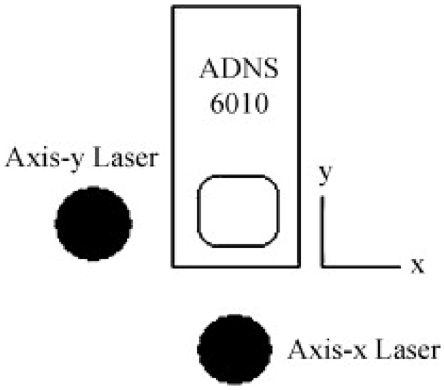

Figure 1: Laser placement (top view).

2.2. Construction

The arrangement of the NDS was based on the physical dimensions of the TL10-65 lens. Given the C-mount camera mounting requirements, the image plan of the ADNS-6010 had to be positioned 17.52 mm from the top of the TL10-65. Because of the thickness of the NDS housing, the actual working distance of the NDS was 51 mm although the distance from the end of the TL10-65 to the test surface was 65 mm. The lasers were positioned at 22° with respect to the optical axis (the centreline of the TL10-65) in order to ensure that the illumination was incident on the field of view (FOV) of the TL10-65.

The mouse sensor and electronic components were mounted on two separate printed circuit boards, the mouse sensor board and the microcontroller board. A Microchip PIC24FJ128GA006 was selected to process the optical sensor output data. An adaptor was constructed to hold the TL10-65 and the mouse sensor board. The TL10-65 was mounted to the bottom of the adaptor with the standard C-mount thread (32 tpi) and the mouse sensor board was fitted to the top of the adaptor. Details of this arrangement are shown in Fig. 2.

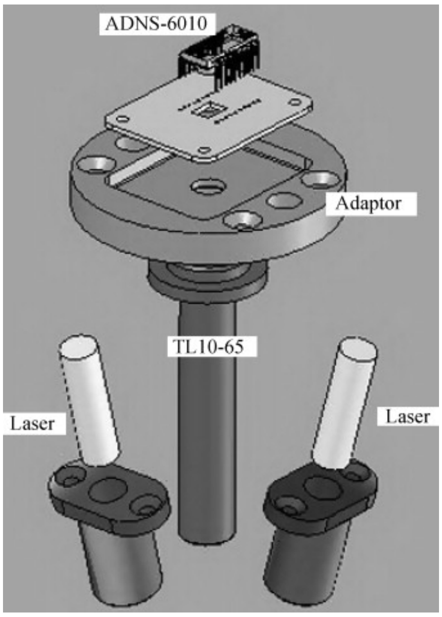

Figure 2: Layout of the NDS.

The microcontroller board included external connections for the system power supply and for an RS232 serial line for communications. The lasers were powered directly from the microcontroller board without control from the ADNS-6010.

3. Experimental set-up

3.1. Test platform and test surfaces

3.1.1. Test platform

A linear table with stepper motor drive was used to evaluate the performance of the NDS. The stepper motor drive could be programmed to operate under controlled speed, acceleration or displacement. Specimen surfaces were mounted on the carriage and the NDS was located at the mid-point of the linear table. The NDS was mounted on a linear translation stage which allowed adjustment of the working distance, as illustrated in Fig. 3.

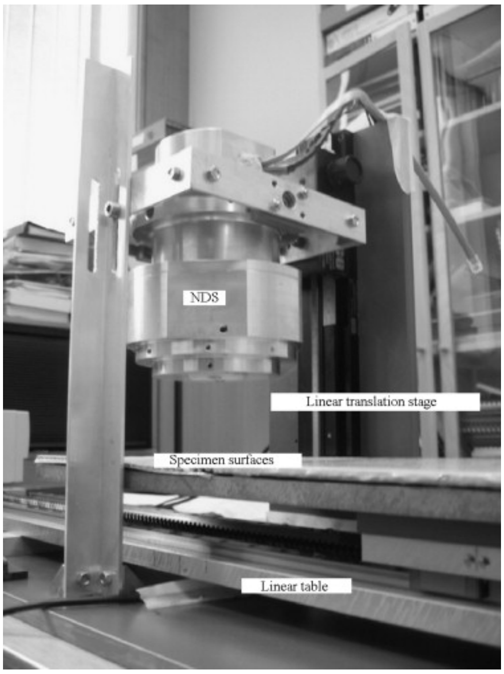

Figure 3: Test platform consisting of the NDS and linear table.

3.1.2. Specimen surface

A graph paper surface was used for tests with regard to the influence of illumination on the mouse sensor performance. Three specimen surfaces were then used for calibration of the NDS with respect to acceleration and deceleration: carpet, linoleum and wood. All surfaces were 100 mm × 600 mm and were attached to a 13 mm thick piece of PVC on top of the carriage of the linear table.

3.2. Data acquisition

Within the NDS, the PIC microcontroller was designed to communicate with the mouse sensor via an SPI serial connection. The PIC was programmed to read from and write to appropriate registers in the mouse sensor, for example, in order to acquire x- and y-axis displacement, read operations were transmitted to the Delta_X and Delta_Y registers, respectively. The PIC microcontroller communicated with a PC via an RS232 serial connection.

The distance travelled by the carriage of the linear table was determined by the use of an incremental 1000-line rotary encoder fitted on the shaft of the stepper motor. The carriage of the linear table moved 1 in. (25.4 mm) per turn of the motor shaft. The encoder generated two quadrature outputs which were decoded using a rising-edge detection circuit and a second PIC microcontroller to determine distance and direction of travel. This additional PIC microcontroller transmitted distance travelled by the linear table to the PC also via an RS232 connection.

Two serial communication ports on a standard PC were used to gather data from the test platform, COM1 for the NDS data and COM2 for the position data from the encoder. LabVIEW^{TM} was used both to generate a signal to initiate transmission of data on the two channels and to manipulate the position information. The two systems were sampled simultaneously at 50 ms intervals.

4. Results

4.1. *Influences of illumination direction*

Commercially available OCM devices use a single source of illumination, either a red or infrared LED or a laser. These light sources are located on the y-axis of the mouse sensor, as defined in the mouse sensor layout of Fig. 1.

In order to assess the suitability of a mouse sensor for general position detection in the NDS, an investigation was conducted into the influence of surface illumination. As shown in Fig. 1, two lasers were fitted in the NDS, one on each axis of the mouse sensor. Three conditions of illumination were investigated, a single laser on each of the x- and y-axes and two lasers, one on each axis. All of the tests were conducted at a linear table speed of 50 mm/s, a nominal NDS working distance of 51 mm and each was repeated 10 times. For each illumination arrangement, the tests were conducted for motion in the x direction and then the NDS was rotated through 90° to carry out tests on y-axis motion. The linear table programming remained unchanged between the different tests. The tests used a graph paper surface to ensure that there was sufficient surface definition for consistent position detection.

The test results for x-, y- and dual-axis illumination are shown in Fig. 4, Fig. 5 and Fig. 6, respectively. These clearly show that the sensitivity of the optical mouse sensor is influenced by the direction of the illumination. Comparing Fig. 4 and Fig. 5, the sensitivity of the mouse sensor was shown to be higher when the direction of travel and the axis of illumination were aligned for the case of a single source of illumination. It should be noted that the sensitivity was always higher for a measurement axis that was coincident with the illumination axis.

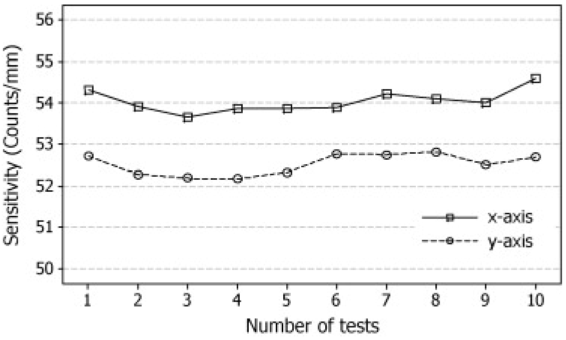

Figure 4: Influence of x-axis illumination on sensor sensitivity.

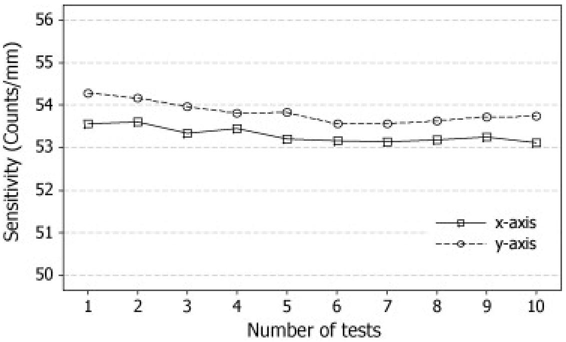

Figure 5: Influence of y-axis illumination on sensor sensitivity.

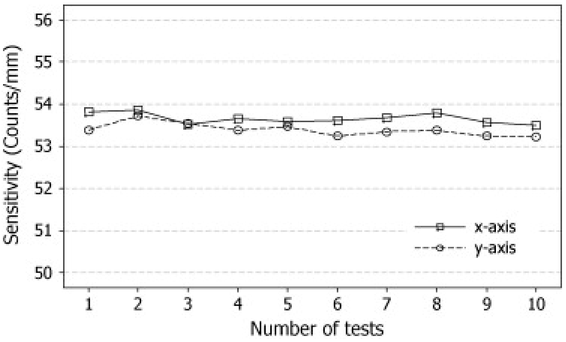

Figure 6: Influence of both x- and y-axes illumination on sensor sensitivity.

Fig. 6 illustrates the effect of using dual-axis illumination on the sensor sensitivity. It can be seen that with illumination provided on both axes there was much better correlation between the sensitivities on the two axes of the sensor. The difference in sensor sensitivity between the x- and y-axes, with respect to the y-axis values, (Fig. 4, Fig. 5 and Fig. 6) was 0.5% when using two illumination sources, as opposed to errors of 2.89% and −0.97% with single-axis illumination on the x- and y-axes, respectively.

Both Refs. [2] and [7] reported discrepancies between the x- and y-axes position readings of an optical mouse device. In both of these tests, a single source of illumination was used but as the above results suggest, it might be possible to reduce this error by the use of a second, quadrature light source.

4.2. Acceleration and deceleration

Tests were carried out to assess the effects of acceleration and deceleration on the sensitivity of the NDS. For the acceleration tests, the linear table was programmed to run under constant acceleration over the majority of its track and then to decelerate rapidly. Conversely, for the deceleration tests, the carriage accelerated rapidly at the start of its run and then decelerated at a fixed rate to the end of the table. Given the size limitations of the table (550 mm length), acceleration and deceleration rates were limited to the following settings: 50.8, 101.6, 152.4, 203.2, 254.0, 304.8, 355.6, 406.4 and 457.2 mm/s^2. The tests were conducted at the nominal working distance of the NDS with two-axis illumination and each test was repeated 10 times. Three test surfaces were used, carpet, linoleum and wood, as shown in Fig. 7, Fig. 8 and Fig. 9, respectively. The y-axis of these graphs shows average sensor sensitivity (in counts per mm) over the 10 test runs for each axis. The standard error of the average is also shown. It should be noted that the standard error of the mean was calculated by dividing the standard deviation by the square root of 20 samples, 10 for the x-axis and 10 for the y-axis.

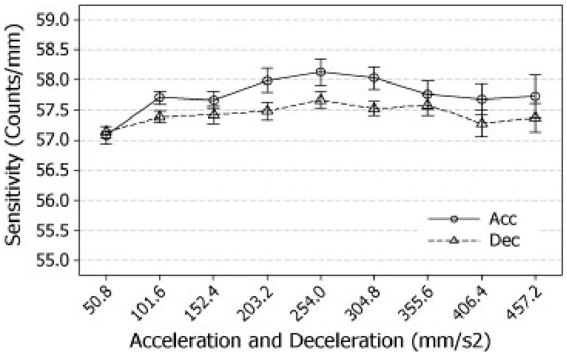

Figure 7: Influence of acceleration and deceleration using a carpet surface.

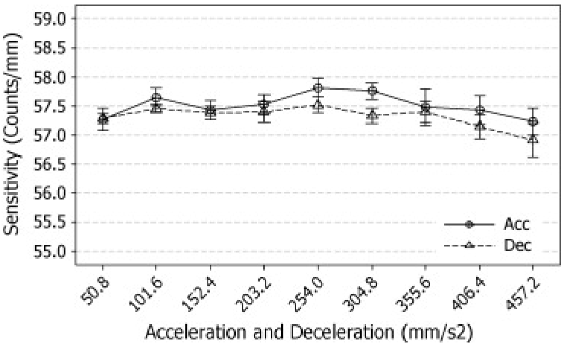

Figure 8: Influence of acceleration and deceleration using a linoleum surface.

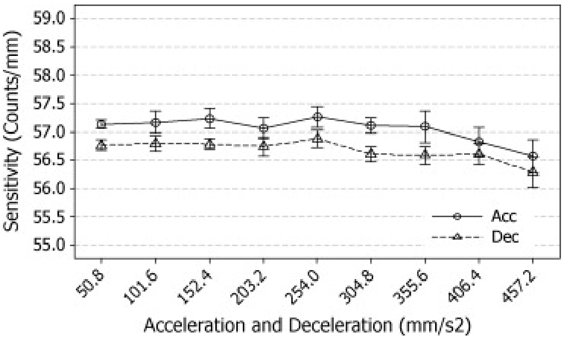

Figure 9: Influence of acceleration and deceleration using a wood surface.

Note that the range of sensitivity values was higher for the acceleration/deceleration tests (generally between 57 and 58) than for the constant speed tests of Fig. 4, Fig. 5 and Fig. 6 (generally 53–54). This was because the latter were carried out at a speed of 50 mm/s which, as shown in Fig. 10, gave lower values of sensitivity for a range of surfaces than did speeds between 100 and 450 mm/s.

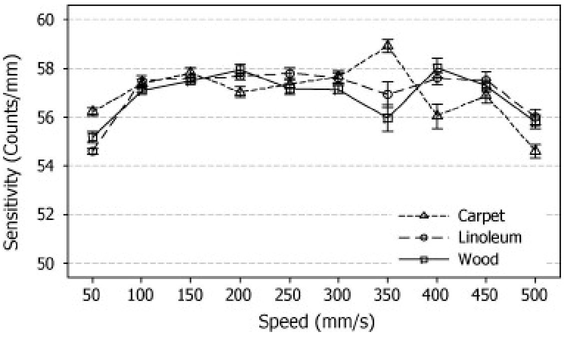

Figure 10: Sensitivity values for operation at constant speed over carpet, linoleum and wood surfaces.

The results show that rates of acceleration and deceleration have a significant influence on the sensitivity of the mouse sensor. The sensor operated with a higher sensitivity under acceleration conditions than for deceleration. However, there was also greater variation in the sensitivity under acceleration than deceleration. Comparing the results for the three surfaces, the maximum difference between acceleration and deceleration sensitivities was 0.9%. Table 1 summarises the standard deviations for readings taken on the three test surfaces. It can be seen that the mouse sensor performs more consistently under conditions of deceleration than acceleration.

	Standard deviation	
Surface type	Acceleration	Deceleration
Carpet	0.308	0.162
Linoleum	0.196	0.186
Wood	0.211	0.178

Table 1: Standard deviation of sensor sensitivity under acceleration and deceleration for the test surfaces.

Fig. 7, Fig. 8 and Fig. 9 clearly show a decline in sensor sensitivity once the rate of acceleration or deceleration exceeds the test point at 355.6 mm/s^2. A reduction in the sensor sensitivity equates to a reduction in position tracking capability. The rate of 355.6 mm/s^2 equates to approximately 0.335G. However, the specification for the ADNS-6010 gives a maximum acceleration rate for operation of 20G [9]. There are three possible reasons for the difference between the test and specification values. Firstly, the optical arrangement used in the NDS might have had a negative impact on the tracking capability of the mouse sensor. Secondly, although the sensor sensitivity starts to fall at around 355.6 mm/s^2, this does not mean that the mouse sensor has entirely lost its tracking capability. A third factor that must be taken into account is the change in sensor sensitivity with speed, as reported in Ref. [8]. In the current work, the linear table was programmed to operate up to a maximum speed of 600 mm/s however, as shown in Ref. [8], the sensitivity of the sensor used in those tests (the ADNS-2051) began to reduce at speeds in excess of 400 mm/s. Given the length of the linear table, the acceleration and deceleration rates of up to 203.2 mm/s^2 ensured that the table speed remained below 400 mm/s, however the higher acceleration and deceleration rates resulted in speeds of 400–600 mm/s which were shown in Ref. [8] to result in significant reduction in sensor sensitivity for one particular device. Further work is required to investigate the separate effects of acceleration and speed at the higher rates of acceleration for the mouse sensor used in this work.

Looking at the influence of surface texture on sensor sensitivity, comparing Fig. 7, Fig. 8 and Fig. 9 the carpet surface showed the greatest variation in sensitivity. The three surfaces were physically quite different with the carpet being pale and relatively rough, the linoleum grey with reflective spots and fairly smooth texture and the wood had a sand papered finish. From Fig. 7, Fig. 8 and Fig. 9 it can be seen that there was significant fluctuation in the sensor sensitivity under both acceleration and deceleration for the rough surface. With smoother surfaces there was much less variation in the overall sensitivity. Also, the average sensor sensitivity was lower with smoother surfaces; on average the sensitivity was higher for carpet than for linoleum and for linoleum than for wood. The natural finish of the wood surface was less reflective than either of the other two surfaces, hence it resulted in the lowest sensitivity of the three.

As was shown in Fig. 7, Fig. 8 and Fig. 9, the sensor sensitivity changes with acceleration and deceleration rates, however in the NDS in practice, an average sensor sensitivity is likely to be used. Fig. 11 and Fig. 12 show the displacement of motion over a carpet surface for acceleration and deceleration rates of 254.0 mm/s^2, respectively. The rate of 254.0 mm/s^2 was selected as it represented the largest difference between the sensor sensitivity for acceleration and deceleration. The two figures each show three curves: mouse sensor output using the sensor sensitivity at 254.0 mm/s^2, the mouse sensor output using an average sensor sensitivity and the linear table position. The sensor sensitivity for 254.0 mm/s^2 was determined from Fig. 7 to be 58.13 under acceleration and 57.67 for deceleration. The average sensor resolution was calculated using the values for acceleration and deceleration at the selected rate.

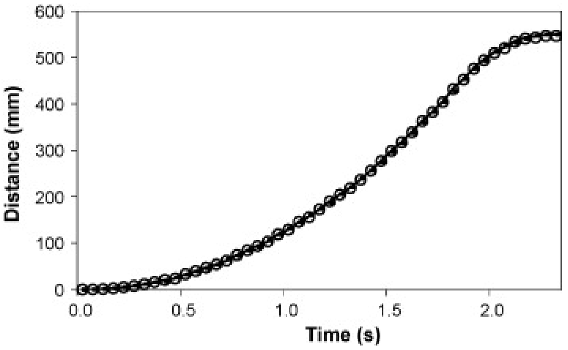

Figure 11: Displacement of motion under an acceleration rate of 254.0 mm/s^2 over carpet: with sensor sensitivity based on acceleration (○), with average sensor sensitivity (—) and linear table (– – –).

The errors between the mouse sensor readings with average sensitivity and with acceleration and decel-

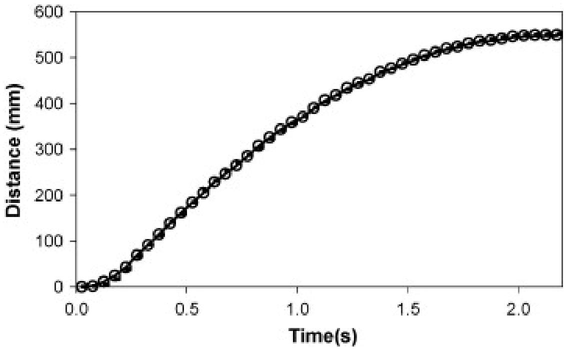

Figure 12: Displacement of motion under a deceleration rate of 254.0 mm/s^2 over carpet: with sensor sensitivity based on deceleration (○), with average sensor sensitivity (—) and linear table (– – –).

eration sensitivities were approximately 0.395% and 0.398%, respectively. These error figures suggest that an average sensor sensitivity could be used for general positioning operation, however if high precision position control is required, separate sensor sensitivities for acceleration and deceleration should be used.

5. Conclusions

Tests have shown that the use of a single light source with an optical mouse can result in poor correlation between the sensor sensitivity of the two axes. Illumination in the axis of motion always results in higher sensor sensitivity than when the illumination is at right angles to the direction of travel. An investigation into the use of two light sources has shown that by providing illumination on both x- and y-axes, the correlation between the position readings in the two axes is greatly improved with respect to single-axis illumination. However, further investigation will be required to determine whether locating the sources of illumination along the axes provides an optimum solution.

Acceleration and deceleration have been shown to have a significant influence on the sensitivity of a mouse sensor. The surface characteristics have also been shown to have an effect on sensor sensitivity during acceleration and deceleration. It was seen that the sensor sensitivity was higher under conditions of acceleration than for deceleration. However, an error around ±0.4% was found between displacement conversions using an average sensor sensitivity and those using separate sensor sensitivity based on acceleration and deceleration.

Based on the results, a mouse sensor could be used to detect displacement of motion under acceleration and deceleration conditions. An average sensor sensitivity could be used to convert between sensor counts and distance in millimetres, however if high precision measurement is required then calibration would be necessary both for the given surface and separately for the cases of acceleration and deceleration.

It has been shown that the use of a mouse sensor as a 2D displacement sensor is practical although initial calibration work must be performed. A mouse sensor could readily be used for predictable applications, i.e. ones with known surface texture and speed and acceleration and deceleration requirements.

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Biographies

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