Available online at www.sciencedirect.com
SCIENCE DIRECT®

Sensors and Actuators A 107 (2003) 21–25

SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

The optical mouse as a two-dimensional displacement sensor

T.W. Ng*

Faculty of Engineering, Engineering Block EA-07-32, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Singapore

Received 24 July 2002; received in revised form 23 May 2003; accepted 3 June 2003

Abstract

Optical sensors are used extensively for displacement measurement. A cost-effective optical displacement sensor will be invaluable in applications where very high resolutions are not required. In this work, the optical mouse has been investigated to determine its suitability for two-dimensional displacement measurement. While the mouse worked only on objects with opaque surfaces, experiments conducted with a commercial unit with 0.0635 mm resolution showed that highly linear (average R^2-value of 0.9914) and low error (mean square error (M.S.E.) value below 0.018 mm^2) measurements could be attained. On the flipside, the unit could only operate if placed at a distance no greater than 1.25 mm from the object surface. Overall, the optical mouse has been found to be a viable two-dimensional displacement sensor. Its efficacy was demonstrated in measuring the viscoelastic elongation of polyethylene.

Keywords: Optical mouse; Displacement sensor; Viscoelasticity; Optical sensor

1. Introduction

A wide variety of displacement sensors have been developed based on the principles of capacitive, inductive, magnetic, ultrasonic and optical sensing. For displacement sensors based on the optical effect alone, designs have been reported employing the principles of triangulation [1,2], interferometry [3,4], moiré [5,6], diffraction [7,8], time-of-flight [9,10], and speckle [11–13]. Some of these schemes are able to provide measurements with sub-micrometer accuracy. Nevertheless, not all applications require such high degrees of measurement accuracy. In building drift monitoring and large-strain viscoelastic measurements, for example, mensurations in the range of 0.1 mm are generally sufficient. One major drawback with the majority of optical displacement measuring tools lies with their relative high cost. This arises primarily from the expensive components used in certain designs and the non-economics of scale associated with low volume manufacturing of such systems. There is, hence, an incentive to source for alternative cost-effective optical sensors for displacement measurement; in particular, when the demands of accuracy are not very high.

When computers were first developed, there was no need for pointing devices to be employed because crude interfaces like teletype machines or punch cards for data entry were used. Hence, many years (from mid 1960s to early 1970s) elapsed before arrow keys were found on most terminals. Full screen editors were the first devices to take real advantage of the cursor keys, and offered an initial, albeit crude way to point. Following this, light pens were used on a variety of computers. Graphics tablets, joysticks and various other interfacing devices also enjoyed popular adoption in the 1970s. However, none of these really became the pointing device of choice until the advent of the computer mouse. Compared with a graphics tablet, computer mice are inexpensive and occupy very little space on the desk.

Until recently, the operation of computer mice had been based almost exclusively on the rolling ball principle. Popularly called the mechanical mouse, it houses a rubberized ball that rolls according to the planar movement imposed on the mouse. Two rollers located within the mouse are in constant contact with the rubberized ball. One of the rollers detects for motion in the *x*-direction, whereas the other detects for motion in the *y*-direction. Quite naturally, the mechanical mouse suffers from the problems of wear and dirt accumulation over time. For this reason, it is common to find them incapable of registering movement after several months of heavy usage.

In 1999, Agilent Technologies unveiled the first optical mouse that was immune to the problems of wear and dirt accumulation. With resolutions currently reaching 0.03175 mm, optical mice are gradually replacing their mechanical predecessors as the pointing device of choice

---

* Fax: +65-777-3525.
E-mail address: engngtw@nus.edu.sg (T.W. Ng).

0924-4247/$ – see front matter © 2003 Elsevier B.V. All rights reserved.
doi:10.1016/S0924-4247(03)00256-5

in computers. Due to the economics of large volume production, the cost of an optical mouse is extremely low. Currently, it is possible to acquire a reasonably good quality unit for as low as US$ 20.

In this work, the suitability of the optical mouse as an optical displacement sensor is first investigated. Next, it is demonstrated in an experiment to determine viscoelastic deformation of polyethylene.

The general behaviour of solids is one that exhibits an elastic response to external forces. Fluids, on the other hand, are generally categorised as exhibiting a viscous response to applied forces. Materials like polymers, however, exhibit both an elastic and viscous response to external forces. Such hybrid behaviour is described as viscoelasticity. While the viscoelastic behaviour of materials is well studied [14], it is still actively researched due to its importance in a wide spectrum of engineering applications [15,16]. Optical methods to determine the viscoelastic deformation of materials have often relied on expensive and complicated designs [16].

2. Working principle of the optical mouse

The basic working principle of an optical mouse is described in Fig. 1. A single light emitting diode (LED) illuminates the surface at an angle. A lens is used to image the surface of the mouse pad onto a CMOS sensor located in the camera chip. The off-axis illumination by the LED helps to put the tiny textures on the surface in sharp contrast. The CMOS sensor typically comprises 18 pixel × 18 pixel (324 pixels in total). The mouse works by comparing the images of the surface that are refreshed approximately every 1500th of a second. As it is too computationally taxing to compare the images at all 324 possible overlaps, a 5 pixel × 5 pixel window, taken from the center of the second image, is normally used for the overlap matching process. This window is moved relative to the first image and the chip rates how well each of the 324 pixels matches up. These ratings are added to an overall score for the overlap. Once the chip has found the best overlap, it checks the scores of the eight pixels surrounding the center of the window. Finally, it sends the actual value of the displacement to the computer. The measurement accuracy is typically limited to the pixel spacing of the imaging sensor located in the chip.

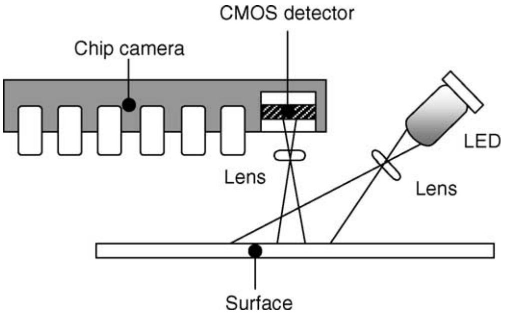

Fig. 1. Schematic description of the working components of an optical mouse.

In a typical displacement sensing application, the optical mouse has to be placed in close proximity with the moving object. In some cases, however, it may not be possible to do so due to physical constraints. Hence, the suitability of the optical mouse for displacement measurement has to be weighed according to its ability to register movement accurately when placed at some distance from the test object surface. Another important issue that has to be ascertained is the type of surface that the optical mouse can sense displacement from. In practical applications, an object to be sensed may be opaque, transparent, or reflective.

3. Experimental

In the experiment, movement is achieved via a *xyz* translation stage (Newport M-460A-XYZ model). The resolution

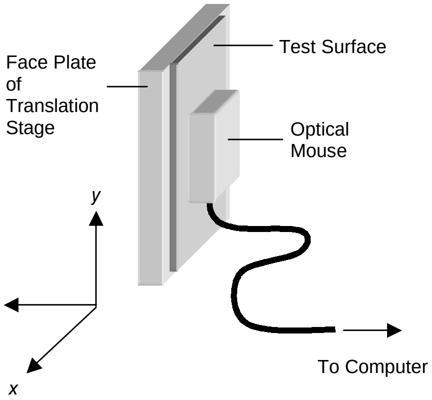

Fig. 2. Description of the experiment to determine the displacement measurement capability of the optical mouse.

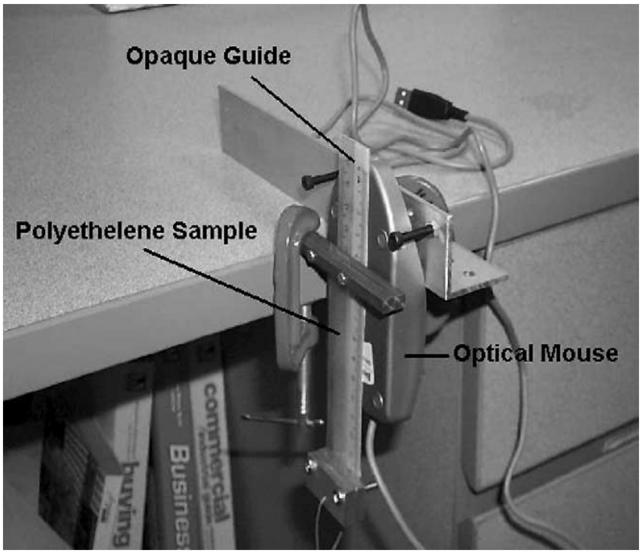

Fig. 3. Description of the experiment to determine the viscoelastic deformation of polyethylene.

of the translator along each axis is 10 μm. The test surface is attached to the vertical faceplate of the translator (see Fig. 2). In the experiment, three types of surfaces were applied for testing: a diffusely white painted plate, a plexiglass sheet, and a square mirror. Each was meant to represent an opaque, transparent, and reflective object, respectively. An optical mouse with a resolution of 0.0635 mm was employed for testing. On the computer, any imaging software (e.g. Windows Paint) may be used to determine the mouse's position. In the experiment, the value of *z* (see Fig. 2) represented the position that the optical mouse was placed from the object's surface. For each setting of *z*, displacements in the *x*- and *y*-axis, as registered in the computer due to the optical mouse's movement, were compared with actuations from 0 to 1 mm at intervals of 0.05 mm on the *xyz* translation stage. The same procedure was repeated for values of *z* from 0 to 1.5 mm at increments of 0.25 mm. The experiment to determine the viscoelastic deformation of polyethylene is described in Fig. 3. A polyethylene film specimen of 20 mm width, 0.1 mm thickness and 100 mm length was suspended

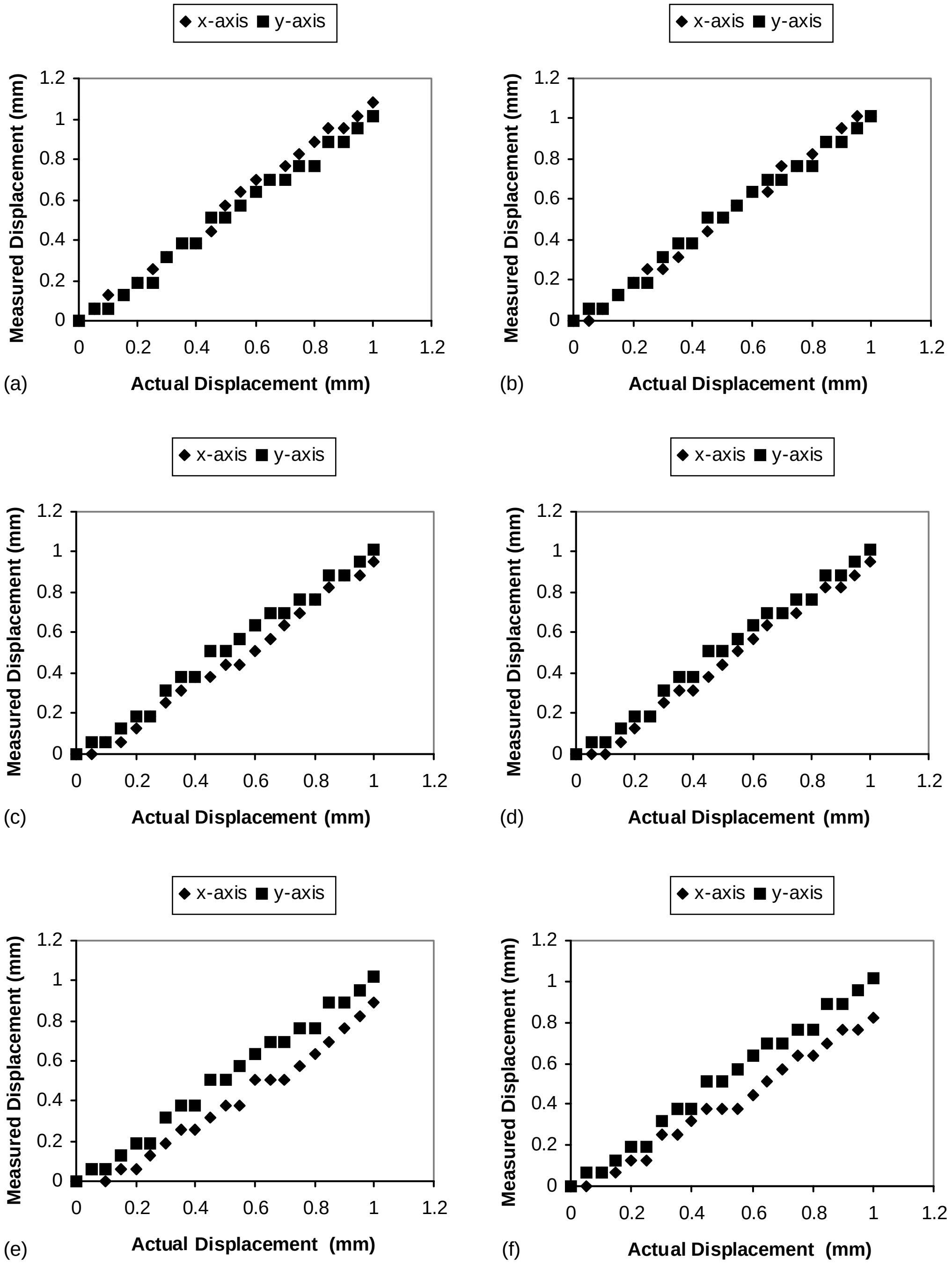

Fig. 4. Plot of *x*- and *y*-direction displacements recorded using the optical mouse against displacements introduced using the translator for *z*: (a) 0 mm, (b) 0.25 mm, (c) 0.5 mm, (d) 0.75 mm, (e) 1 mm, (f) 1.25 mm.

by a 1.5 kg weight. Its elongation in relation to time was recorded by the optical mouse.

4. Results and discussion

The optical mouse was found to only able to register displacements when the diffuse white painted plate was used as the test object. This result simply confirms that transparent and reflective objects are unsuited for displacement measurement using optical mice.

Fig. 4 shows the graphs of x- and y-direction displacements recorded using the optical mouse and plotted against displacements introduced by the xyz translator for various values of z. From visual inspection, it can be seen that a positive trend exists between the displacements detected on the optical mouse in relation to the translations introduced. No measurements could be obtained when z exceeded 1.25 mm. This is likely to be caused by complete defocusing. Together with the observed linear trend, this result implies that the optical mouse is generally suited for two-dimensional displacement measurement provided that z does not exceed 1.25 mm.

The issue of accuracy is considered next. Accuracy in this work is considered from the standpoint of linearity and error. Fig. 5 gives a plot of the R^2-value (which is based on a transformed regression model) determined from each of the plots in Fig. 4. In all cases, it could be seen that the R^2-values were close to the theoretical limit of 1. That the R^2-values (mean = 0.9914) were close to the theoretical limit of 1, demonstrates close conformance to the linear trend desired of any displacement measurement sensor. Fig. 6 gives a plot of the mean square error (M.S.E.) values calculated from each of the plots in Fig. 4. The upper limit was found to be restricted to 0.018 mm^2 for all measurable cases of z. This relatively low value connotes low errors when using the optical mouse for displacement measurement. Upon closer examination of the graph, it can be seen that the M.S.E. upper limit for measurements in the y-direction was in fact bounded to within 0.006 mm^2 for all measurable cases of z. However, the M.S.E. upper limit for measurements in the x-direction was restricted to within 0.006 mm^2 only for z from 0 to 0.75 mm.

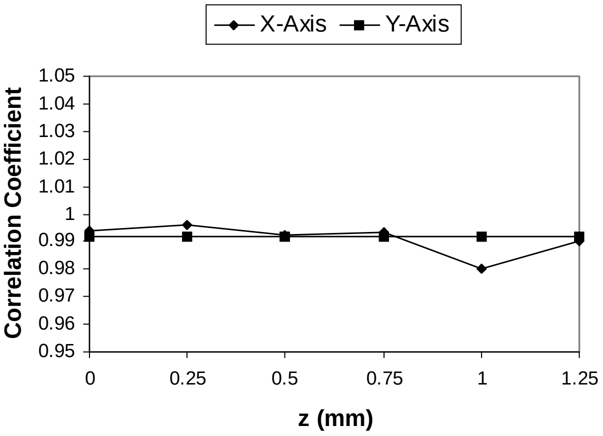

Fig. 5. R^2 distribution of the graphs in Fig. 4.

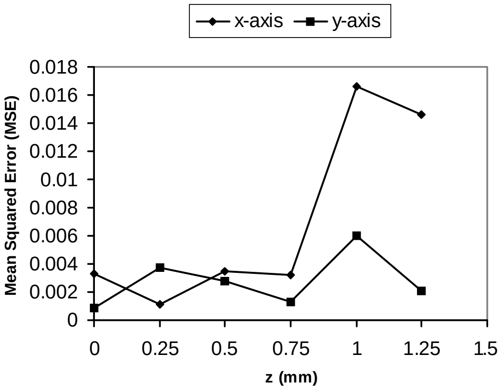

Fig. 6. Mean square error distribution of the graphs in Fig. 4.

The marked increase in M.S.E. values in the x-direction for z >0.75 mm is very likely due to the design of the mouse that has illumination in the x-direction. It is well known that oblique illumination functions as a form of spatial frequency filter [17]. One example where this effect has been successfully applied was in the reconstruction of shearograms [18]. Since illumination is restricted to the x-axis in the optical mouse design, the image sensor should only record x-axis features of an object at a relatively narrow spatial frequency range (see Fig. 7). Higher values of z essentially result in greater defocusing. Defocusing, in turn, degrades the transfer function of the higher spatial frequencies more markedly than the lower spatial frequencies. In other words, the image sensor will register a more marked loss of features in the x-direction than in the y-direction when z is increased. This, therefore, accounts for the trend of M.S.E. values found.

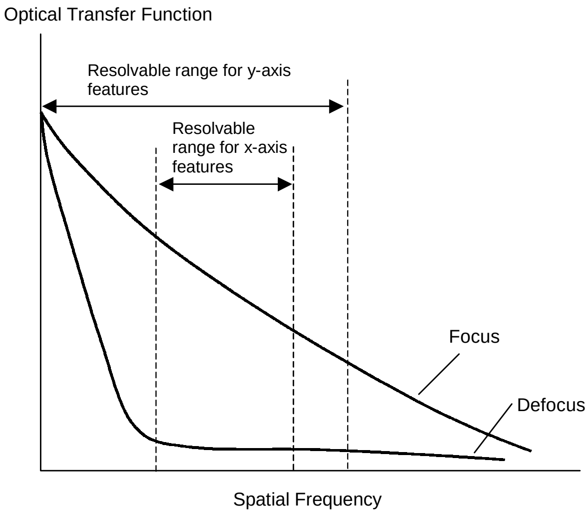

Fig. 7. Description of the optical transfer function for focusing and defocusing and its impact on the probable resolvable range of x- and y-axes features recorded on an optical mouse's image sensor.

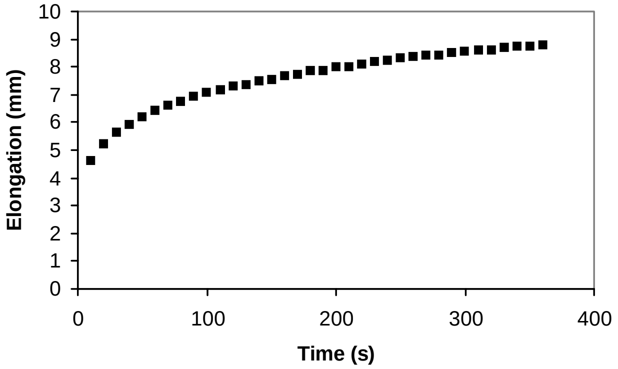

Fig. 8. Plot of elongation against time of the experiment to illustrate the viscoelastic deformation of polyethylene.

The elongation behaviour of the polyethylene film in relation to time is given in Fig. 8. The trend of the curve follows that reported in literature [14]. This demonstrates the ability of the optical mouse to serve as a displacement sensor in actual engineering applications. It should be noted that the manner in which the experiment was set-up prevented movement in the *z*-direction whilst the film was loaded. Hence, the *z* distance limitation mentioned earlier was not operational in this experiment.

5. Conclusions

In this paper, the optical mouse was studied for its capability to function as a two-axes displacement sensor. It was found that measurements could only be obtained for opaque objects and if the distance between object and mouse was limited to 1.25 mm. Within this range, the experimental measurements obtained correlated closely with the displacements introduced using a scientific optomechanical *xyz* translator. The mean square error of measurements obtained was limited to 0.018 mm^2 and the mean R^2-value was 0.9914. These values indicated that the readings made possessed low levels of error and high degrees of linearity. It was found that the mean square error for measurements in the *x*-axis increased significantly when the distance between optical mouse and object was >0.75 mm. This behaviour was likely to be caused by the illumination direction of the mouse. In an experiment to determine the viscoelastic deformation of polyethylene, the elongation against time curve recorded was found to be consistent with that reported in known literature. Overall, it can be concluded that the optical mouse functions effectively as a two-dimensional displacement sensor.

References

[1] K.C. Kim, J.A. Kim, S. Kim, Y.K. Kwak, Rev. Sci. Instrum. 71 (2000) 3220–3225.
[2] E. Higurashi, R. Sawada, T. Ito, Appl. Opt. 38 (1999) 1746–1751.
[3] M. Wang, G.M. Lai, Rev. Sci. Instrum. 72 (2001) 3440–3445.
[4] T. Bosch, N. Servagent, S. Donati, Opt. Eng. 40 (2001) 20–27.
[5] B. Han, D. Post, P. Ifju, J. Strain Anal. Eng. Des. 36 (2001) 101–117.
[6] S.T. Lin, Opt. Eng. 40 (2001) 822–826.
[7] E.W. Bae, J.A. Kim, S.H. Kim, Meas. Sci. Technol. 12 (2001) 1495–1502.
[8] S.B. Oh, K.C. Kim, S.H. Kim, Rev. Sci. Instrum. 72 (2001) 2822–2826.
[9] A. Makynen, T. Rakhonen, J. Kostamovaara, Sens. Actuators Part A: Phys. 65 (1998) 45–53.
[10] T. Bosch, M. Lescure, D. Roviras, J. Opt. 23 (1992) 117–123.
[11] P. Zhou, K.E. Goodson, Opt. Eng. 40 (2001) 1613–1620.
[12] T.W. Ng, Opt. Lasers Eng. 26 (1997) 449–460.
[13] T.W. Ng, W.B. Yong, Meas. Sci. Technol. 13 (2002) 1–4.
[14] J. Gittus, Creep, Viscoelasticity and Creep Fracture in Solids, Applied Science, London, 1975.
[15] R.N. Haward, Macromolecules 26 (1993) 5860–5869.
[16] E. Kontou, P. Farasoglou, J. Mater. Sci. 33 (1998) 147–153.
[17] J.W. Goodman, Introduction to Fourier Optics, McGraw-Hill, New York, 1968.
[18] T.W. Ng, Rev. Sci. Instrum. 68 (1997) 3125–3129.

Biography

T.W. Ng is Assistant Professor at the National University of Singapore. His research interests are in optical engineering and engineering education development. He has published over 50 journal papers and is editor of Optical Testing Digest. Dr. Ng's homepage is at http://twng.eng.nus.edu.sg/course/twng/twng.html.