A Test setup for Evaluating Long-Term Measurement Characteristics of Optical Mouse Sensors

Received 2nd April, accepted 2nd May.

Furkan A. Kanburoğlu, Ergin Kilic, Melik Dölen, Buöra Koku

Abstract:

Due to significant advancements in optical navigation technology, optical mouse sensors (OMS) are increasingly employed as low-cost motion sensors in personal computing and robot navigation. This paper proposes a new test bed to study the long-term measurement characteristics of emerging OMS devices. With the utilization of this set-up, the attributes of a high-resolution OMS (Agilent ADNS-2051) are investigated under various critical operating conditions like changing surface velocity and the pattern. The paper illustrates that despite the problems addressed, the positioning accuracy of an OMS could be quite sufficient for some basic process control applications.

Keywords: *sensors, control, navigation, test bed*

1. Introduction

Optical mouse sensors, which are originally intended to serve as pointing devices in personal computing, have gained considerable recognition in the past few years as low cost alternatives to conventional displacement sensors (optical position encoders) in "not-so demanding" applications such as mobile robotics, process control, and monitoring.

Not surprisingly, this new technology has drawn considerable attention in industry and academia. Most research efforts in this field [1-6] focus on the application of optical mouse sensors as odometers in mobile robotics, where one or more optical mouse sensors are utilized to determine robots' position (and their orientations). In [7], two sensors are utilized to measure three degree-of-freedom motions on various surfaces. Similarly, [8] employ the sensor as a displacement transducer to measure the elongation of polyethylene while [9-10] concentrate on the measurement of vibratory motions (with low frequencies and amplitudes). Despite the general interest of the scientific community, only a handful of the studies investigate the measurement attributes of optical mouse sensors as non-contact position measurement devices. For instance, [11] studies the basic measurement properties of such devices with an emphasis on the surface texture on the sensor's characteristics. Long-term static and dynamic measurement attributes of such devices are yet to be evaluated to their full potential not only to help the mechatronics engineers determine the proper application domain but also to lay out some design guidelines for this emerging technology. Consequently, the purpose of this study is to design a special test-bed to experimentally characterize the static and dynamic measurement attributes of up-coming devices with a major emphasis on their long-term state-state behavior.

The organization of the paper is as follows: After a short introduction, the paper summarizes the operating principles of optical mouse sensors (OMS). Section 3 describes a preliminary study on a high resolution sensor using the linear stage of a CNC machine tool. The next section proposes a new test set-up to evaluate the characteristics of such devices in the long run. Likewise, the following section concentrates on number accompanying tests to investigate the steady-state measurement attributes of OMS. Based on the information collected, the key points of the paper are discussed in last section.

2. Operating principles

The OMS is based on the pioneering technology developed by the Agilent Technologies Inc. titled *Optical Navigation*. The typical OMS utilizing this technology incorporates an Image Acquisition System (IAS), a Digital Signal Processor (DSP), and a serial communication interface. The sensor, whose cross-section is illustrated in Fig. 1, essentially makes good use of optical flow principle.

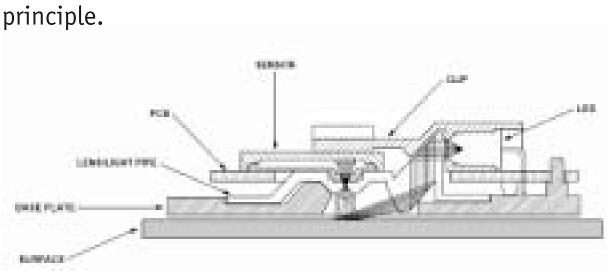


Figure 1. Assembly of OMS [12].

In this scheme, the IAS first acquires microscopic surface images at relatively high rates (500 – 6400 frames/sec) via the solid state camera, lens, and LED based illumination system. Fig. 2 shows sample gray-scale images acquired through the operation. Since the solid-state camera of the sensor is calibrated accurately for a height range, the physical dimensions of the features in acquired images can be indirectly determined *via* relevant transformations.

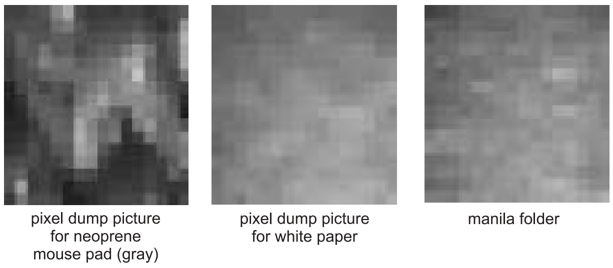


Figure 2. Pixel dump pictures for different surfaces [12].

Consequently, the DSP processes them to estimate the direction- and (incremental) distance of motion via making comparison among the images acquired sequentially. Relative displacement values in the fundamental directions are generated; then to be accessed through the serial output interface (typically SPI) [12].

The optical mouse sensor technology is actually on fast track, generating new and improved sensors in every few months or so. Table 1 illustrates the properties of commercially available optical mouse sensors. The latest (high-end) devices, which employ coherent light source (laser LED), adaptive IAS, and advanced processing algorithms, promise to yield higher resolution (up to 2000 counts/inch), better dynamic performance, and higher reliability/stability.

The next section carries out a preliminary study on the position measurement characteristics of a high-resolution OMS with a major emphasis on its consistency (repeatability).

3. Preliminary study

As preliminary study, Agilent ADNS-2051, whose properties are listed in Table 1, is tested using a (modified) CNC electro-discharge machining center. The sensor, which is attached onto the electrode housing of the machine, is moved along a linear path back and forth several times. Figure 3 shows this test bed while Table 2 summarizes all the relevant test conditions.

Table 1. Properties of commercially available optical mouse sensors.

Sensor (ADNS-)	Type	Resolution (cpi)	Proc. Speed (fps)	Max. Speed (ips)	Max. Acc.
2030/2051	LED	800	2300	14	0.15g
2610/2620	LED	400	3000	12	0.25g
3040	LED	400 / 800	Vary	20	8g
3060/3080	LED	400 / 800	6400	40	15g
5020/5030	LED	500 / 1000	Varies	14	2g
6000	Laser	400 / 800	6400 / Varies	20	8g
6010	Laser	400 / 800 1600 / 2000	7080 / Varies	45	20g
6030 / 6530	Laser	400 / 800	Varies	20	8g

Table 2. Summary on the preliminary tests.

Machine	Makim Kompak K3 CNC EDM
Res. of Lin. Scales	5 μm
Controller	Galil DMC-2153
Travel Distance	50 mm
No. of Repetitions	2×25
Acc./Dec.	5 mm/s^2
Speed	10 mm/s
Surface	Polished CI surf.

Table 3. Summary of preliminary test results.

(mm)	Mean (μ)	Std. Dev. (σ)
Linear Scale	50.0194	0.0073
Optical Mouse	49.5974	0.0657
Error	0.4220	0.0651

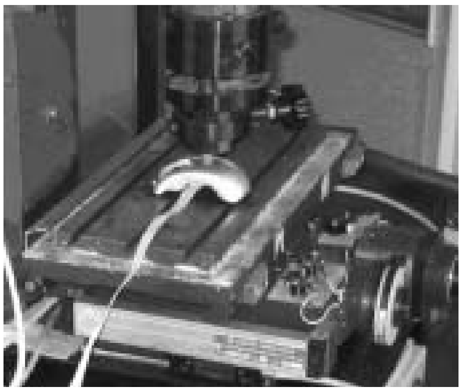


Figure 3. Test set-up used in preliminary study.

First of all, the displacement between two successive stops (aka relative positions) is considered. The difference between the position counts (of either linear scale or mouse) essentially yields the travel span at each repetition. Table 3 tabulates the critical results obtained. Note that the error in this table is defined as the difference between the linear scale measurement (travel span) and that of the optical mouse. Similarly, Figure 4 illustrates the position error characteristics of the sensor.

To study the absolute measurement characteristics, the position counts at the beginning of the test are taken as the reference. Hence, the absolute coordinates of all points are calculated with respect to this reference point. Note that the error is again defined as the difference between the linear scale measurement (absolute coordinate) and that of the optical mouse. Figure 5 illustrates the absolute position errors of the optical mouse sensor. In the figure, the "reverse" label denotes that the mouse is at the starting point of the motion while the "forward" label signifies that the sensor is located at the farther end.

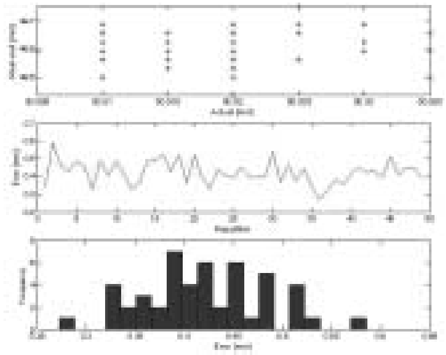


Figure 4. Preliminary test results on incremental displacements.

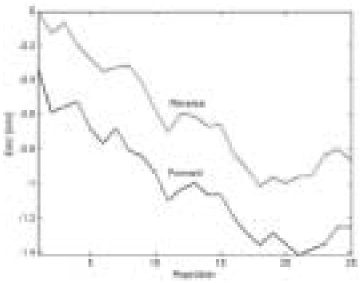


Figure 5. Preliminary test results on incremental displacements.

This preliminary result shows that despite its low accuracy, which is not acceptable for most CNC applications; the device exhibits relatively good repeatability (i.e. consistency in the output). Actually, the fast transitions in the motion (acc/dec) tend to introduce a DC offset to the OMS measurements due to the fact that the IAS of the unit apparently loses the continuity from one image to another at various instances. Note that the acceleration threshold of the device tested is quite low (0.15 g). Despite the fact that the best efforts are made to keep the axis acceleration rates lower than this threshold, the device obviously exhibits "sliding" due to many unaccounted factors. Hence, a special test setup considering all the dynamic constraints of the OMS must be designed and utilized to reveal the true potential of such devices.

In fact, steady-state measurement properties of the optical mouse sensors are of special importance to mobile robotics applications. In spite of some positive features associated with linear stages, such setups are not suitable for investigating the measurement attributes of such devices at the steady state for extended periods in time due to their finite travel spans. Hence, the design of a specialized test setup is becoming a necessity. The next section introduces a new test setup for all intensive purposes.

4. Proposed test setup

The proposed experimental setup, which is illustrated in Figs. 5 and 6, is composed of a well-balanced disk supported on pre-loaded precision ball bearings, which in turn yield wobble-free rotation of the disk. The disk, which is driven by a DC servomotor, serves as a mobile surface to study the characteristics of the OMS under test. Note that a high-resolution optical encoder at the rim is utilized to verify the apparent "linear" displacement of the sensor. The mouse station, which is to be housed right above the rotating disk, constitutes graduations to control not only the elevation of the sensor but also its orientation. As can be seen in Fig. 6, the whole test set-up is controlled by a custom-built micro-controller card, which is interfaced to a PC where the data will be collected and analyzed. Table 4 summarizes the important elements employed in the test-bed.

Figure 6. General view of the setup.

The test setup has the main advantage of testing the measurement characteristics of the device without ever interrupting the process. Hence, the mouse can be tested for elongated periods in time and the steady-state attributes of the device can be assessed rigorously.

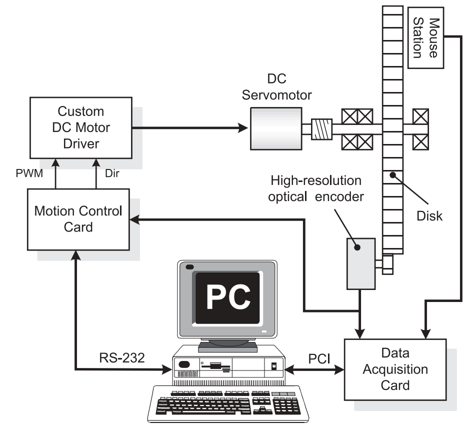


Figure 7. Schematic of experimental setup.

Table 4. The summary of elements used in the experimental setup.

Elements	Type / Model	Remarks
Motor	50 W Brush-type DC motor	Built-in gearbox
Motor Driver	Trans-conductance amplifier	800 W / MOSFET
Controller	PIC16F877A @ 20 Mhz	8-bit RISC controller
Motor Encoder	Hohner quadrature optical encoder	10000 pulses/rev (ea. quad. channel)
Dat a Acquisition Board	Humusoft MF-614	4 enc. inputs, 4 DAC, 16 ADC, 8 DI, 8 DO.
Software	Matlab Real-time Windows Target	Dat a capture, analysis, and visualization

To demonstrate the capabilities of the proposed setup, the OMS (Agilent ADNS-2051) used in the preliminary tests are again taken into consideration. Although there are several different factors affecting the measurement accuracy of an OMS, the surface speed along with texture are known to be the most critical ones. Hence, the effect of six surface patterns along with four different surface speeds (100, 200, 300, 470 mm/s) are investigated in the experiments. The above-mentioned test patterns are illustrated in Figure 8. Notice that since the speed of the sensor is limited to 14 ips (356 mm/s), two of the velocities (300 and 470 mm/s) are specifically selected to test the operating boundaries of the OMS. All experiments are conducted for elongated periods (10…15 minutes). The following section presents the results of these tests.

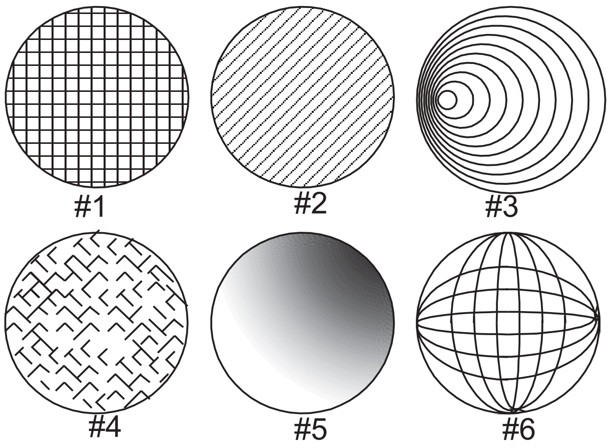


Figure 8. Surface patterns used in the tests.

5. Results and discussion

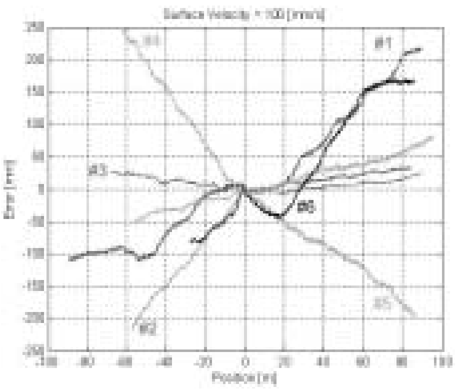
The results of the experiments are presented in Figure 9. To make a comparative evaluation among different cases, Table 5 summarizes the results in which the error values (in mm/m) are to be interpreted as relative position error introduced by the OMS per each meter of travel. Note that in Table 5, the columns "fwd" and "rev" indicate the cases where the disk rotates in the forward- (clockwise) and reverse (counter-clockwise) direction respectively.

Table 5. Summary of results.

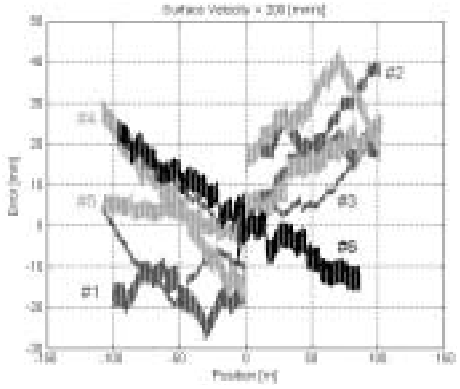
Error [mm/m]	v = 100 [mm/s]		v = 200 [mm/s]		v = 300 [mm/s]		Mean Error [mm/m]
	fwd	rev	fwd	rev	rev	fwd	
Surf. #1	2.50	1.25	0.29	5.16	0.28	218.6	38.01
Surf. #2	0.41	3.76	0.40	3.45	0.04	24.70	5.46
Surf. #3	0.28	0.06	0.25	68.30	0.19	574.7	107.30
Surf. #4	0.86	0.08	0.27	45.90	0.16	40.00	14.55
Surf. #5	0.02	0.96	0.43	53.50	0.06	54.40	18.23
Surf. #6	1.98	3.04	0.09	63.30	0.02	61.10	21.59

Close examination of the error patterns in Figure 9 reveals critical points about the attributes of the system under investigation:

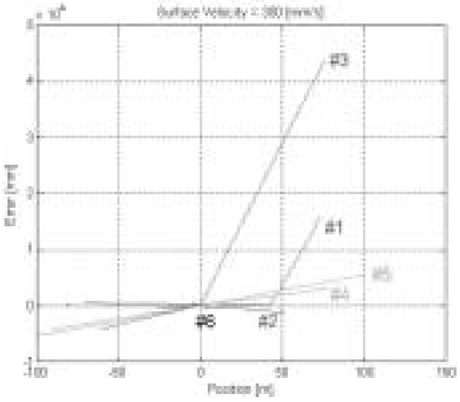
- At low speed (100 mm/s), no matter which pattern is used, the relative position errors of the OMS are quite insignificant. In fact, the sensor yields the best performance at 200 mm/s that lies in the middle of its safe operating zone.
- At high to moderate speed (300 mm/s), the sensor's performance degrades dramatically under certain conditions as indicated by sharp changes in the slopes of Figure 9(c). That is, the sensor apparently becomes unstable even the speed is lower than the max. speed (356 mm/s) specified by the manufacturer [12]. At high speed (470 mm/s), the sensor, not surprisingly, fails to yield meaningful results as indicated by Figure 9(d). Hence, the operating region of the device seems to be smaller than the one indicated by the chip producer.
- Judging by the mean error value in Table 5, the pattern #5 apparently leads the best measurement values owing to the fact that this rotating pattern gives the IAS the opportunity to collect highly contrasting images enabling easy comparison and feature extraction.



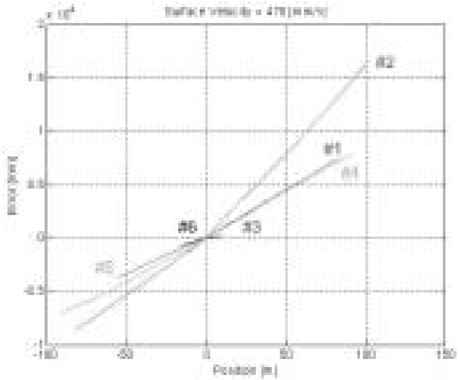
(a) Surface velocity: 100 [mm/s]



(b) Surface velocity: 200 [mm/s]



(c) Surface velocity: 300 [mm/s]



(d) Surface velocity: 470 [mm/s]

Figure 9. Relative position errors for various conditions.

6. Conclusion

This paper proposes a new test set-up to study the measurement characteristics of optical mouse sensors. The setup, which is based on a rotary table, enables the study of long-term measurement characteristics of such devices. In the near future, the study will concentrate on both the improvement of test setup and comparative analysis of emerging sensors using this system. To be exact, the attributes to be investigated using this setup shall be as follows:

- Drift,
- Surface and illumination effects (Laser/LED control),
- Linearity / Repeatability,
- Effects of the ambient conditions (temperature),

- Influence of other sensors parameters (frame rate, resolution, etc.).

ACKNOWLEDGMENTS
This work has been partially supported by the Turkish Scientific and Technical Research Council (TÜBİTAK)) under the project MISAG-257 and partially by METU/BAP under contract.

AUTHORS
Furkan A. Kanburoğlu, **Ergin Kilic** and **Buöra Koku** – Middle East Technical University, Department of Mechanical Engineering, Ankara, 06531, Turkey.
Melik Dölen*– Middle East Technical University, Department of Mechanical Engineering, Ankara, 06531, Turkey. Tel. [+90] (312) 210-5272, Fax: [+90] (312) 210-2536, e-mail: dolen@metu.edu.tr.
* corresponding author

References

[1] F. Santos, V. Silva, L. Almeida, "A Robust Self-localization system for a Small Mobile Autonomous Robot," in: *Proc. of the IEEE International Symposium on Robotics and Automation*, Toluca, Mexico, 1-4 September 2002.

[2] S.P.N. Singh, K.J. Waldron, "Design and evaluation of an integrated planar localization method for desktop robotics," in: *Proc. of the IEEE International Symposium on Robotics and Automation*, New Orleans, 26 April – 1May 2004.

[3] J.A. Cooney, W.L. Xu , G. Bright, "Visual dead-reckoning for motion control of a Mecanum-wheeled mobile robot", *Mechatronics*, 2004, vol. 14, pp. 623–637.

[4] J. Palacin, I. Valganon, R. Pernia, "The optical mouse for indoor mobile robot odometry measurement", *Sensors and Actuators*, 2006, vol. 126, pp. 141–147.

[5] Sooyong Lee, "Mobile Robot Localization using Optical Mice", *Proc. of the IEEE International Conference on Robotics, Automation and Mechatronics*, Singapore, December 2004, pp. 1192-1197.

[6] A. Bonarini, M. Mattencci and M. Retselli, "A Kinematic-independent Dead-reckoning Sensor for Indoor Mobile Robotics", P*roc. of the IEEE International Conference on Intelligent Robots and Systems*, Sendai, Japan, 28 September – 2 October 2004, pp. 3750-3755.

[7] K.-M. Lee, D. Zhou, "A real time optical sensor for simultaneous measurement of three-DOF motions", *IEEE/ASME Trans. Mech.*, 2004, no. 9, pp. 499–507.

[8] T.W. Ng, "The optical mouse as a two-dimensional displacement sensor", *Sensors and Actuators*, 2003, vol. 107, pp. 21–25.

[9] T.W. Ng, K.T. Ang, "The optical mouse for vibratory motion sensing", *Sensors and Actuators*, 2004, vol. 116, pp. 205–208.

[10] T.W. Ng, K.T. Ang, "The optical mouse for harmonic oscillator experimentation", *Am. J. Phys.*, 2005, vol. 73, pp. 793–795.

[11] Umberto Minoni, Andre a Signorini, "Low-cost optical motion sensors: An experimental characterization", *Sensors and Actuators*, Article in Press, 2006.

[12] Agilent Technologies, Datasheet of ADNS-2051.