An improved electrode structure for capacitive single-axis tilt sensors

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Abstract - This paper presents a novel design for a low–cost tilt-sensor system. Electrodes have been attached to a vial for use as tilt sensor with electronic read-out. The electronic signal processing has been realized using the Universal Transducer Interface (UTI) and a microcontroller. Experimental results show a standard deviation of 1.8 arcsec for a measurement time of 0.1 s and a rather linear behavior.

1. Introduction

With tilt sensors the angle is measured with respect to a reference plan, for instance the plane perpendicular to the gravity field. Up to now spirit levels belong to the most common instruments implemented for such measurements. Nowadays many tilt sensors have been implemented with electronic detection systems, which enables their application in control loops and improves the accuracy and allows data storage. These advanced instruments are applied in a lot of applications, such as: construction lasers, instruments for wheel alignment, optical systems and more in general in many applications in the field of mechatronics, geophysical monitoring, machine tool leveling, medical positioning – monitoring and many others. The research work presented in this paper concerns investigations for the design of sensor systems based on the use of low-cost vials and interface systems (Fig. 1).

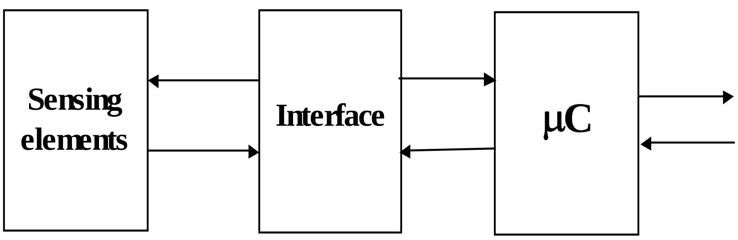


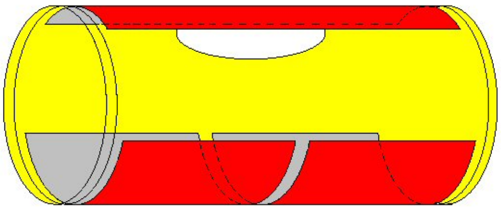
Figure 1 *Block diagram of the low-cost electronic system for tilt sensing.*

In the designed system a capacitive sensing element has been fabricated by attaching electrodes to an ordinary vial. In both cases, for the electronic signal processing a microcontroller and a universal transducer interface (UTI) [1] have been used. The system has experimentally been investigated.

2. The capacitive tilt sensing element

The vial [2] consists of a glass container filled with heptane and a gas bubble (Fig. 2(a)). Three electrodes have been glued at the surface, as shown in the schematic drawing of Fig. 2(b) and the photograph of Fig. 2(c). The common top electrode is placed above the gas bubble; two more electrodes are located at the bottom left and right side of the vial.

(a)

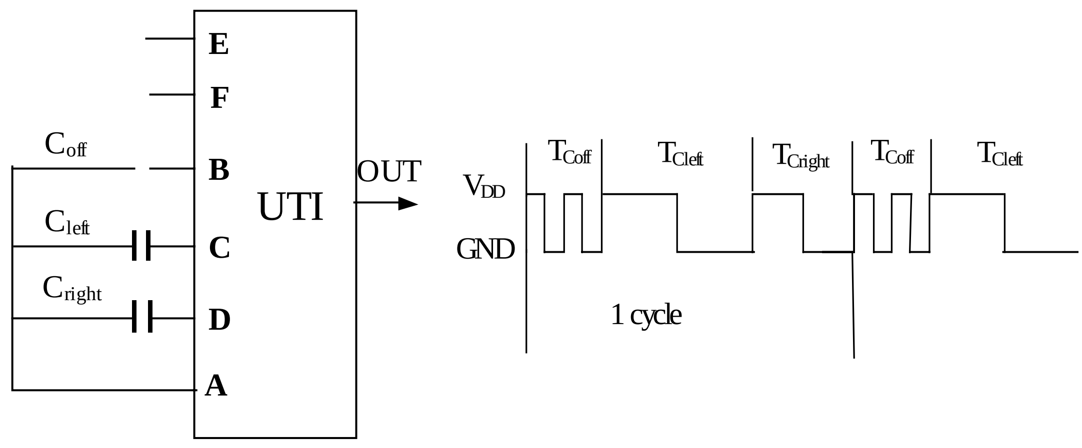


(b) (c)

Figure 2 *A capacitive tilt sensor: (a) An ordinary vial, (b) Schematic drawing of the position of the electrodes that has been glued at the wall of the glass container (c) Photograph of the vial with electrodes.*

In this way two capacitors C_{left} and C_{right} between the common electrode and the two bottom electrodes are formed. The value of these capacitors depends on the location of the gas bubble. The ratio C_{left}/C_{right} is an indirect measure for the tilt. When the gas bubble is in the center, both capacitors are equal to about 0.7 pF. For a tilt of 60 arcsec the differential capacitance $\Delta C = C_{left} - C_{right} = 3.6$ fF. With the universal sensor interface UTI such a small change can easily be detected, with a resolution as low as 50 aF. Figure 3(a) shows the way of connection with the UTI set-up.

Input pin A of the UTI is connected with the common electrode on top of the vial. The bottom electrodes are connected to pins C and D, respectively. The UTI generates a square wave output signal, which is used for excitation of the capacitors and, via an internal multiplexer, is transferred to the pins C and D, respectively. Pin B is open and is used to measure the offset value of a non-connected input terminal of the UTI.



(a) (b)

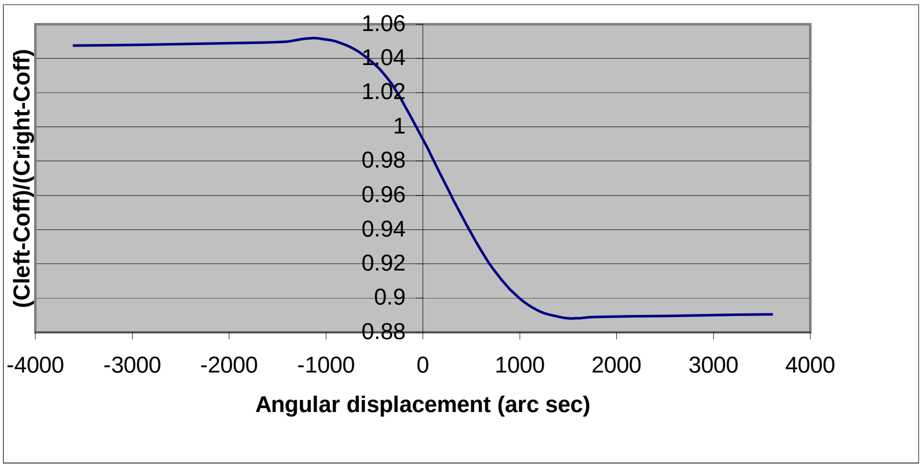
Figure 3 *(a) The connection to the universal transducer interface UTI; (b) output signal of the interface [1].*

The period length of the square-wave output signal is proportional to the value of the selected capacitor. The microcontroller measures the lengths of the various period times T_{off}, T_{left} and T_{right} for the different phases. Afterwards, using the program LabView in a PC, the capacitor ratio (C_{left} - C_{off})/ (C_{right} - C_{off}) is calculated according to the equation:

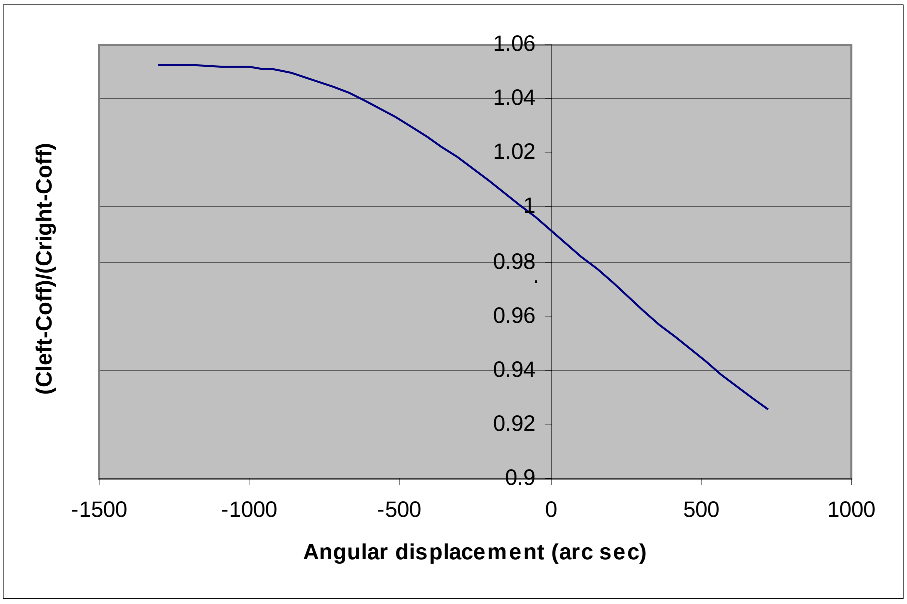
$$M_C = \frac{T_{left} - T_{off}}{T_{right} - T_{off}} = \frac{C_{left} - C_{off}}{C_{right} - C_{off}}$$

3. Experimental results

The capacitive tilt-sensor system has been measured over a range of ± 4000 arcsec. Figure 4 shows the measured capacitor ratio (C_{left} - C_{off})/ (C_{right} - C_{off}) of the total capacitive sensor system. The results show that the system has a good linearity over a range of about ± 500 arcsec. With a measurement time of 0.1 s a standard deviation of 1.6 arcsec has been found. For a measurement time of 10 s this standard deviation is reduced to 0.16 arcsec.



(a)



(b)

Figure 4 *(a)The measured ratio* (C_{left} - C_{off})/ (C_{right} - C_{off}) *of the capacitive sensor system; (b) a detail of Fig.4(a).*

4. Conclusions

A capacitive tilt-sensor system has been developed, fabricated and tested. The sensing element can be made using of a conventional vial to which external electrodes have been attached in a non-invasive way. The electronic signal processing can be performed with a universal sensor interface and a microcontroller. Over a range of ± 500 arcsec a good linearity has been found. The resolution amounts to about 1.6 arcsec for a measurement time of 0.1s.

5. References

[1] UTI Evaluation Board, Smartec, *www.smartec.nl*, The Netherlands, 2004.

[2] Precision vials, Level Developments lim., *www.leveldevelopments.com*, GB, 2005.