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# A Computer Mouse Based on Highly Sensitive Micromachined Flow Sensors

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**Abstract**

A PC mouse based on micromachined calorimetric flow sensors is presented. Two cylindrical openings in the bottom of the device are equipped with highly sensitive flow sensors (for the *x*- and *y*-velocity components). Due to fluid adherence to the boundary (mouse pad), the device motion induces an air-flow vortex in the cavities. A microcontroller processes the sensor signals and sends the velocity information via USB interface to the PC. In order to obtain the optimum cavity dimensions, comprehensive 2D and 3D models of the device were developed. A mouse prototype was build as a plug-and-play device and characterized utilizing a specially developed measurement setup. The measured characteristics are in good agreement with the simulated behavior. The device features very low power consumption and functions independently of the reflectivity and surface roughness of the mouse pad.



*Keywords:* computer mouse; flow sensor; USB interface; FEM simulations.

## 1. Introduction

Since 1980s a computer mouse has become the most used pointing device for personal computers. The first widely available model was ball-mouse based on opto-mechanical read-out principle. However, its mechanical parts were prone to dirt and the power consumption due to LED as a light source was relatively high. In the 90s the ball mouse was gradually replaced by solely optical devices without any rolling parts. Optical mouse requires no maintenance but they generally can not track on glossy and transparent surfaces. Moreover, they have higher power demands than their mechanical counterparts, which is detrimental for battery-powered wireless devices.

To overcome these drawbacks we developed a PC mouse device based on micromachined flow sensors. The extremely sensitive calorimetric flow sensors register the air-flow generated by the device motion. Due to sensor miniaturization the device features very low power consumption and is independent of the reflectivity and surface roughness of the mouse pad.

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## 2. Device Principle and Sensor Layout

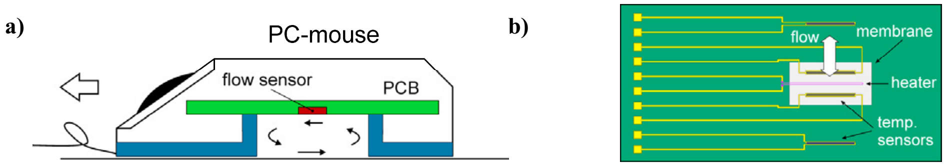


Fig. 1. (a) Schematic cross section of the PC-mouse with a cylindrical recess on the bottom. The induced air-flow circulation in the cavity is detected by a flow sensor mounted in a PCB (printed circuit board) which builds the bottom of the opening; (b) Layout of the calorimetric flow sensor.

Figure 1a shows a schematic cross section of the PC-mouse with a cylindrical recess at the bottom. Due to fluid adherence to the boundary (mouse pad), the device motion induces an air-flow vortex in the cavity. The flow velocity is sensed with a flow sensor mounted on the bottom of the opening.

The layout of the calorimetric flow sensor is depicted in Fig. 1b. Two thin film Ge-thermistors are placed symmetrically to a central chromium heater, both fully embedded in a micromachined membrane. The generated temperature profile around the heater is symmetrical at rest and consequentially both thermistors exhibit equal temperature. The convective heat transfer induced by mouse motion disturbs the thermal symmetry. This change can be converted into an output voltage which is related to the temperature difference of the membrane thermistors. Operating such flow sensors with constant heating power, a high sensitivity is feasible only within a limited flow range. Due to efficient convective cooling at higher flow rates (> 4 m/s), the output characteristic becomes non monotonic [1]. However, the maximum flow velocity induced by the mouse motion is far below 0.5 m/s. In this low flow range the sensor is highly sensitive with approximately linear output characteristic. The simple read-out electronic circuit consists of a Wheatstone bridge utilizing two membrane thermistors as active parts and two additional thermistors located at the rim of the silicon chip. The resistance of these substrate thermistors depends only on the chip temperature. If all thermistors have the same temperature characteristic, the bridge voltage in the first approximation does not depend on the ambient temperature. This is decisive since the mouse housing, and hence the sensor chip, are heated irregularly by the user's palm.

## 3. Simulations

Finite Element Method (FEM) simulations were utilized to study the sensor behavior and to obtain the optimal design (Fig. 2a). A memory intensive 3D model was used to simulate the dependence of the output signal on the movement direction. The simulation results reveal almost ideal cosine-shaped directional characteristic. In order to analyze the effect of the geometrical parameter variations (diameter and height of the cavity) on the sensor output signal, a 2D model was utilized.

Figure 2b illustrates the dependence of the bridge unbalance voltage on the height of the cavity for fixed diameter value. The sensor output and the linearity of the characteristic increase with decreasing cavity height. Typically, the maximal mouse velocity does not exceed 0.4 m/s. For this velocity the dependence of the bridge unbalance voltage

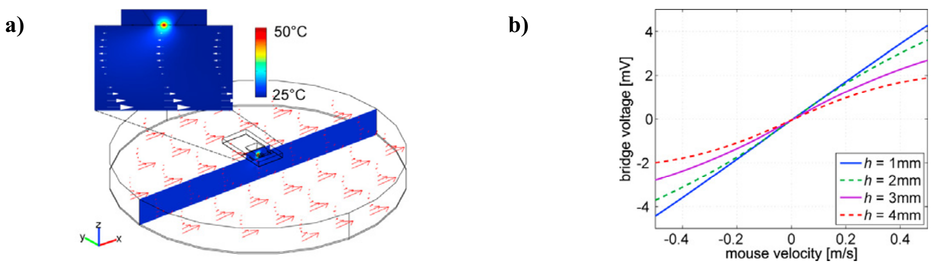


Fig. 2. (a) 3D FEM model of cavity and sensor. Arrows indicate the flow velocity relative to the flow sensor (mouse movement in $-x$ direction). 2D model arises from the central cross section (inset). The colors illustrate the distortion of the temperature profile due to flow which gives rise to the sensor output signal; (b) Simulated sensor output for a cylindrical cavity with 20 mm diameter and up to 4 mm recess depth.

on the geometrical parameters of the cavity was analyzed (Fig. 3a). For the proper mouse operation it is essential that the cursor follows the rapid hand movement of the PC user. This can only be achieved if the reaction time of the sensor is in the order of 10 ms, which is the period of the data transfer between mouse and PC. Figure 3b depicts the 10-90% rise time of the output signal after a step-like change of the mouse velocity as a function of cavity geometry. The minimum rise time is approximately 8 ms and increases with the volume of the cavity. The simulation results indicate that a small cavity volume is advantageous. However, a cavity height less than 2 mm is not recommended in order to avoid sensor damaged. Thus, the optimal cavity height amounts to 2 mm. Moreover, for this value the simulation results do not depend on the cavity radius. For experimental confirmation of the simulation results, two prototypes with 10 mm and 20 mm cavity diameter were built.

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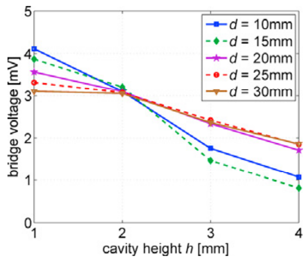


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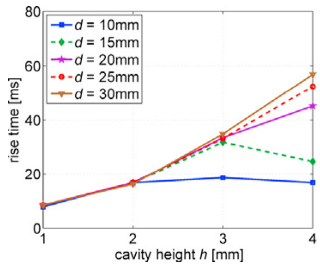


Fig. 3. (a) Simulated bridge voltage at $v = 0.4$ m/s mouse velocity as a function of cavity height for five different cavity diameters; (b) Simulated rise time of the output signal (10-90%) after a step like change of the mouse velocity (from 0 to 0.4 m/s) as a function of cavity height and diameter.

## 4. Device Layout

In order to obtain direction and velocity of the mouse movement, two sensors mounted orthogonal to each other in separated cavities are needed (Fig. 4a). Since the sensors feature approximately cosine-characteristic, their output signal for low flow velocities is directly proportional to respective velocity component ($v_x$ or $v_y$).

The sensor output signals must be first filtered and amplified. After the digitalization, a microcontroller performs subsequent data processing (Fig. 4b). Because it is impossible to fabricate completely identical thermistors and to place thin film structures perfectly centered on the membrane, the sensor output signal has an offset at zero flow velocity. This offset is temperature dependent and drifts during the mouse operation. Thus, the microcontroller must acquire the periods without mouse motion in order to continuously compensate the offset. Beside already mentioned manufacturing tolerances of the thermistors and the minor asymmetries of the thin-film structures an asymmetry caused by sensor mounting also influences the output characteristic. As a consequence, the magnitude of the bridge voltage for an arbitrary movement direction φ and φ+180° differs. Also the velocity transduction efficiency is slightly different for each sensor. As these are systematic errors, they can also be taken into account by means of subsequent data processing. The microcontroller transfers the data via USB interface using the format needed for

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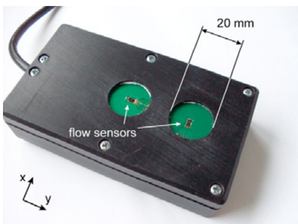


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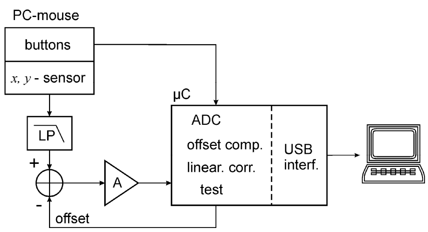


Fig. 4. (a) The bottom side of the PC-mouse prototype. Two flow sensors mounted orthogonal to each other in two separated cavities measure $x$- and $y$-component of the mouse velocity; (b) Block diagram of data acquisition and processing. After digitalization a microcontroller performs closed loop offset compensation, correction of the output characteristic linearity, and system tests. The communication with PC runs over USB interface using standard HID-protocol.

evaluation of the cursor position (standard Human-Interface-Device-protocol). Hence, the prototype is realized as a plug-and-play device and can be used on any PC independent of the actual operating system.

## 5. Measurement and Characterization

The device was characterized utilizing commercial A3 pen plotter. Placing the mouse at the pen position, it is possible to translate it in any direction at adjustable velocity. The controlling of the device movement and evaluating the data can be done conveniently applying a PC program. In order to assess the quality of the 2D and 3D numerical models, the measurements were compared with simulation results. The directional characteristic can be well fitted by a cosine function (Fig. 5a), whereas the output characteristic features an almost linear course up to 0.4 m/s mouse velocity (Fig. 5b). The acquired experimental data are in good agreement with characteristics predicted by our FEM simulations.

The correction of the nonlinearity of the sensor characteristic by a data processing algorithm was evaluated by a position-test. Thereby, the mouse is translated in one direction for 30 cm and than drawn back to the starting position with the same constant velocity. Ideally, the calculated distances in both directions should be the same, i.e., the cursor should come back to the same position on the display. The maximal obtained relative error amounts to only 3%, which is practically not perceptible by the PC user.

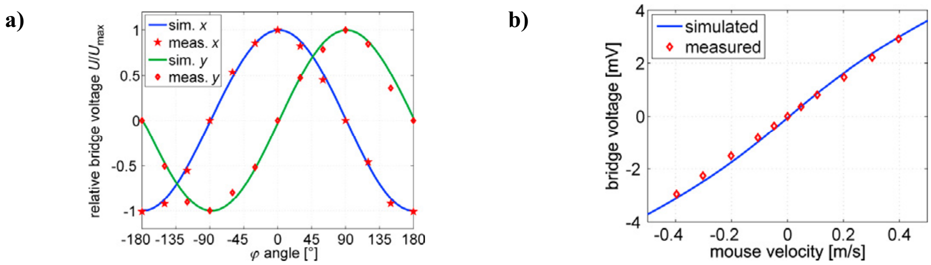


Fig. 5. (a) Output characteristics of the sensors for *x*- and *y*-component as a function of the mouse direction at 0.4 m/s mouse velocity (comparison between 3D simulation and measurement result; φ is angle between mouse movement direction and *x*-axis); (b) *x*-sensor signal as a function of the mouse velocity. The mouse motion is in *x*-direction (φ = 0° and 180°; comparison between 2D simulation and measurement results).

## 6. Conclusion

We developed a PC mouse utilizing flow sensors mounted in separated cavities on the bottom of the device. The air-flow generated by the device motion is detected by extremely sensitive calorimetric flow sensors. They use a thin film heater and two Ge-thermistors as sensing elements with a power consumption of only 3 mW [2]. Due to the bridge circuit of active sensor elements and closed-loop compensation of the offset drift, the mouse is independent of the variation of the ambient temperature. Thus, realized as a plug-and-play device with low power consumption it outperforms similar devices reported in the literature [3]. Tests on commercial PC's confirm that the presented device is a good low-power substitute for a common optical mouse.

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