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# Application of the theory of micro switch group sensor (MSGS) to noise-affected switches

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**Abstract**

Although microsystem technology (MST) has facilitated the fabrication of a large number of small devices, such devices tend to have errors caused by the inaccuracy of the fabrication process and thermally induced noise fluctuations. In previous work, the concept of the Micro Switch Group Sensor (MSGS) was introduced using the example of a device that exploits the randomness of brittle material fracture, in particular the Weibull distribution. In this paper, the Gaussian distribution of noise signals is applied to the theory of MSGS. An MSGS device made of an electric circuit consisting of three noise-affected switches was built in the experimental work and its operational principles are discussed. The device's output signal was compared with the performance of each of the switches, and the theory of MSGS was verified.
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*Keywords:* Noise; Sensor; Statistic; Switch; Measurement theory

## 1. Introduction

Microsystem technology (MST) has made it possible to produce microsensors, such as accelerometers and gyroscopes that are just a few hundreds of microns in size with integrated signal processing electronics [1–3]. While this is a marvellous achievement, the nature of the sensing element and its mode of operation have changed little compared with conventional macroscopic sensors.

Traditionally in developing a sensor system one would develop a single sensor, which is designed to be both linear and devoid of any noise. However, in trying to exploit MST to fabricate microsensors, noise and non-linearity become much more prevalent. For the process to be economical a large number of sensors must be manufactured and therefore they must be very small. This leads to the sensors becoming subject to noise such as Brownian motion and displaying non-linear mechanical and electrical properties [4–6] and there also is the inherent randomness caused by the tolerance of manufacturing process.

Previous work has demonstrated the theory and operation of small MSGS. The authors introduced the concept of the MSGS using the Weibull distribution, the inherent randomness in breakable cantilever beams [7]. The MSGS is a new type of sensor which measures a physical quantity by observing the state of an array of non-linear switches which have an inherent randomness in their characteristics due to noise and manufacturing variability. The measured is simply determined by observing the number of switches either on or off. The number can be acquired with simple digital electronic circuits, avoiding the need for a conventional A/D converter. The MSGS may be regarded as a true digital sensor, as shown in Fig. 1.

In this paper a Gaussian noise is applied to a system of electronic noise-affected switches, which is more applicable to MST sensors. A theory is developed to relate the state of the outputs of the switches to the input signal. Three noise-affected switches were fabricated, using Zener diode noise sources and electronic comparators. The state of the comparator, taken as the number of switches turned on was determined as a function of the input voltage and the results compared to the theory developed. The analysis confirmed that the behaviour of these switches matches and verifies the MSGS theory.

## 2. MSGS theory for noise-affected switches

Currently, it is possible to fabricate small sensors, which are millimetre, micrometre, and even nanometre in dimension, using

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**Nomenclature**

$G_{noise}(V)$ probability density function of the noise voltage
$G_{sig}(V)$ probability density function of $V_{sig}$
$i(V_{in}, t)$ output signal from each of comparators described by high or low
$n$ number of switches turned on
$n(V_{in}, t)$ number of switches turned on as the function of $V_{in}$ and $t$
$N$ number of switches consisting the MSGS
$P_{Nn}(V_{in})$ probability of $n$ switches are turned on in $N$ switches
$P_{on}(V_{in})$ probability of a switch turned on by the input voltage $V_{in}$
$P_{on1}(V_{in})$ probability of the comparator 1 turned on
$P_{on2}(V_{in})$ probability of the comparator 2 turned on
$P_{on3}(V_{in})$ probability of the comparator 3 turned on
$P_{30}(V_{in})$ probability that 0 in 3 switches are turned on
$P_{31}(V_{in})$ probability that 1 in 3 switches are turned on
$P_{32}(V_{in})$ probability that 2 in 3 switches are turned on
$P_{33}(V_{in})$ probability that 3 in 3 switches are turned on
$t$ time
$T$ total measurement time
$T_n$ total length of time during which the number of switches turned on is $n$
$V_{allhigh}$ voltage when the states of all comparators are low
$V_{alllow}$ voltage when the states of all the comparators are high
$V_{cout}$ output signal from each of the comparators
$V_{high}$ voltage when the state of the comparator is high
$V_{in}$ input voltage
$\overline{V_{in}}(N, n)$ mean value of $V_{in}$ associated with $n$ and $N$
$V_{low}$ voltage when the state of the comparator is low
$V_{noise}$ noise voltage
$V_{sig}$ sum of the input voltage $V_{in}$ and the noise voltage $V_{noise}$
$V_{sout}$ output signal from the summing amplifier
$V_{th}$ threshold voltage of the switch

*Greek letters*
$\mu$ mean value of the noise voltage
$\sigma$ standard deviation of the noise voltage
$\sigma_{Nn}$ standard deviation of each state
$\sigma_{\mu}$ standard deviation of $\mu$

micromachining technology. However, such sensors tend to have large errors caused by thermal noise and manufacturing tolerance. The traditional principle of sensing is to transduce some physical property into an electrical quantity, such as voltage. The concept of the MSGS, however, is to transduce the physical quantity into the state of a large array of micro switches, the state of the array being the number of switches on or off. Large arrays of microswitches make it possible to reduce the errors of measurement by making them work together as an ensemble, exploiting the microswitches' stochastic features. In this section, the performance of an array of noise-affected switches is derived, based upon MSGS theory and assuming that noise signals have a Gaussian distribution [8,9].

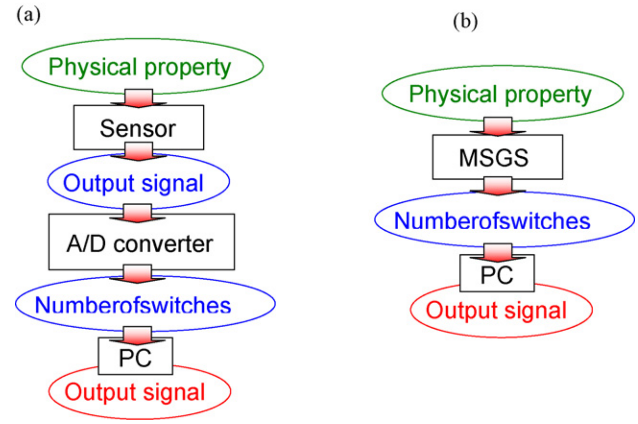


Fig. 1. The comparison of (a) traditional sensor system and (b) MSGS.

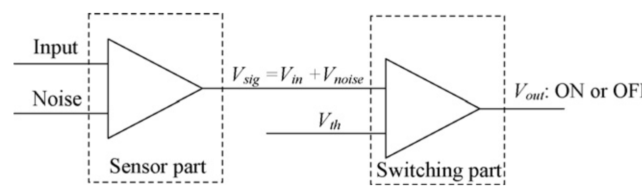


Fig. 2. Block diagram of a noise-affected microswitch.

The block diagram of a noise-affected microswitch is shown in Fig. 2. The input quantity and noise are converted into a voltage signal. The output of the sensor $V_{sig}$, is a function of the sum of the input voltage $V_{in}$ and the noise voltage $V_{noise}$. When $V_{sig}$ exceeds the threshold voltage $V_{th}$, the output of the switch is turned on. The Gaussian noise signal shown in Fig. 2(a) has a standard deviation $\sigma$ and mean value $\mu$. The probability density function of the noise signal is described as:

$$G_{noise}(V) = \frac{1}{\sqrt{2\pi}\sigma_n} \exp\left\{-\frac{((V-\mu)/\sigma_n)^2}{2}\right\}, \tag{1}$$

and is shown in Fig. 3(b).

The probability density function of $V_{sig}$, $G_{sig}(V)$, is expressed in Eq. (2).

$$\begin{aligned} G_{sig}(V) &= G_{noise}(V - V_{in}) \\ &= \frac{1}{\sqrt{2\pi}\sigma_n} \exp\left[-\frac{\{V-(\mu+V_{in})/\sigma_n\}^2}{2}\right] \end{aligned} \tag{2}$$

The performance of $V_{sig}$ and the probability density are shown in Fig. 4.

Because the switches are turned on when $V_{sig}$ is larger than $V_{th}$, then the probability that the switch is turned on by $V_{in}$, $P_{on}(V_{in})$ is given by the shaded area under the curve of $G_{sig}(V)$ above $V_{th}$, as shown in Fig. 5. Hence, $P_{on}(V_{in})$ is expressed as

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