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SENSOR TECHNOLOGY AND DESIGN

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Measure Any Parameter With a Single Platform

An exciting new sensing and measurement methodology uses a single platform to measure almost any physical parameter with extremely high accuracy.

Arik Ariav, Nexense, Inc.

Imagine monitoring a person's vital signs with a noncontact sensor placed beneath a mattress. Imagine an engine torque sensor with incredible accuracy that could save consumers billions of dollars by increasing fuel efficiency and reducing emissions. Imagine locating a brain tumor in 3D simply by using temperature measurements with an accuracy of $\pm 10^{-4}$ °C.



Nexense has made a scientific discovery that makes these measurements a reality.

At the core is a patented sensor technology that links the measurement of all physical parameters to time, one common basis for all physical phenomena. The resulting sensor technology has a signal-to-noise ratio (SNR) of up to 190 dB, 24-bit resolution, digital output without an ADC, and an ability to make measurements without direct contact, in a nonintrusive and nonemissive manner. All of these characteristics can be achieved without the cost implications typically associated with highly accurate instruments.

How Does It Work?

The Nexense measurement methodology relates to a technique of measuring any physical parameter that has a relationship to time. We measure the time it takes an energy wave to propagate through a given medium. Every physical measurement can be extracted from the time domain. A cyclically repeating energy wave is transmitted from a first location (a transmitter) in the medium to a second location (a receiver) also located in the medium. A predetermined reference point is detected in the cyclically repeating energy wave at the second location. The frequency of transmission of the energy wave is continuously and automatically altered in a closed loop controlled by the specific characteristic of the measured component. This change in frequency is used to produce a measurement of the physical parameter.

This is accomplished in two steps. First, the measured parameter acts upon the transit time of the wave, and in the second step, the transit time is converted to a frequency. In a typical application a transmitter and a receiver are placed on or within some type of medium. The transmitter can emit any type of cyclically repeating energy wave; depending on the application, this wave could be acoustic, radio, light, or magnetic and it can be transmitted through any medium, including air, silicone, metals, liquids, or gases.

The parameter acting on the medium (force, pressure, temperature, etc.) causes a minute displacement of the medium or a change in its natural velocity coefficient (the speed at which the energy wave travels through the medium) and thus causes an actual or virtual displacement of the transmitter and receiver. Virtual displacements can result from a temperature change, for example, an acoustic wave that travels in metal at 5000 m/s will experience a change in this velocity as the temperature changes. As the transducers shown in Figure 1 are displaced, the transit time of the frequency changes.

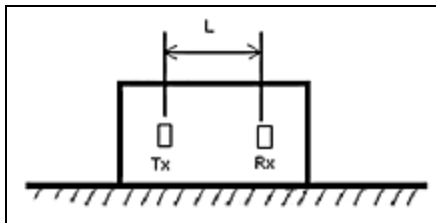


Figure 1. In most physical measurements, the transmitter and receiver are displaced. The minute displacement is measured with extreme precision.

Generally speaking, the transit time gives complete information regarding displacement and temperature. Measuring transit time directly presents some challenges, however. First, to directly measure the transit time of one pulse we need a resolution of a few picoseconds. Second, when sending the pulse signal, the received signal is strongly amplified to get a rectangular shape.

To obtain the time-stabilized signal, Nexense uses a specially designed time-to-frequency converter. Actually, this is an electrical oscillator with a delay line, i.e., the transmitter and receiver are connected to the electrical feedback loop. The receiver's signal is amplified and then passed to a high-speed comparator that produces a square signal. The comparator's output is connected to the transmitter. Immediately after receiving the signal, the transmitter sends it back through the medium (or channel), completing the feedback loop (see Figure 2).

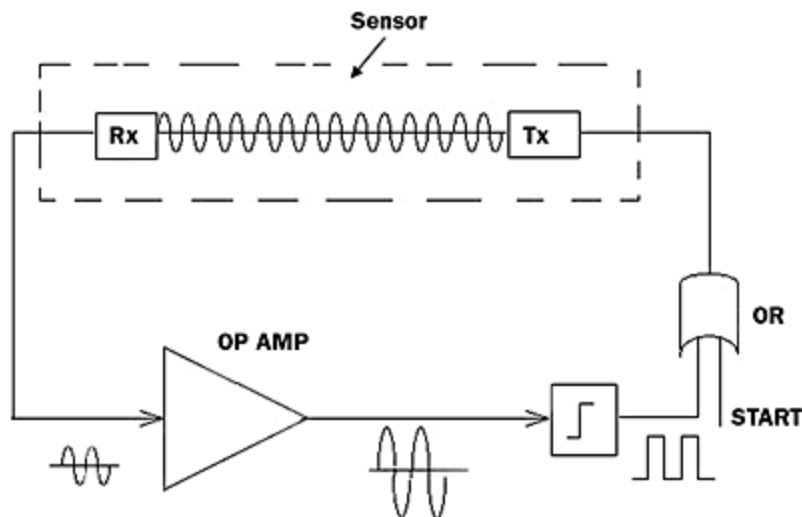


Figure 2. The comparator circuit converts the frequency to a square wave output.

Any electrical circuit has noise. If the hysteresis of the comparator is sufficiently low, the noise signal will pass through the feedback loop. However, the resonant transmitter and receiver loop will only select frequencies within their bandwidth.

There are two ways to initiate the oscillations in the loop: an artificial pulse or a pulse that appears when power is switched on. Because of the resonant features of the transducers, a group of several pulses will be obtained on the receiver output and then sent to the channel via the transmitter synchronizing the phase. On each following pass, the pulses will have greater duration until finally the continuous frequency (a standing wave) is established in the loop.

Regardless of the start conditions, only one frequency will continue to exist. This frequency is governed by the general rules of phase and amplitude balance:

- The amplification must compensate the energy attenuation in the channel, otherwise oscillation will stop after a short time.
- For the oscillation frequency, the total phase shift along with the propagation path and electronic unit must be equal to $2\pi N$ radians, where N is an integer.

The frequency is located within the bandwidth of the transducers. The distance between the transmitter and receiver is chosen to obtain one frequency only, which satisfies these conditions.

The phase shift of wave propagation, T , is equal to:

$$\Theta = 2\pi \frac{L}{\lambda} = 2\pi \frac{L}{cT} = 2\pi \frac{Lf}{c} \quad (1)$$

where:

λ = length of wave
 f = oscillation frequency
 T = period of oscillation frequency
 L = distance between transmitter and receiver
 c = velocity of energy propagation

When any distance, L , is changed, the oscillator frequency (and period) changes, too, because the total phase shift must be kept constant.

Consequently:

$$f = \frac{1}{T} = \frac{N - \frac{\Theta_E}{2\pi}}{L} c \quad (2)$$

Where T_E = phase shift in the electronic unit.

The frequency we get from the oscillator depends on the distance between the transmitter and the receiver. To measure the period of this frequency, the Nexense frequency meter contains two counters with corresponding latches (see Figure 3).

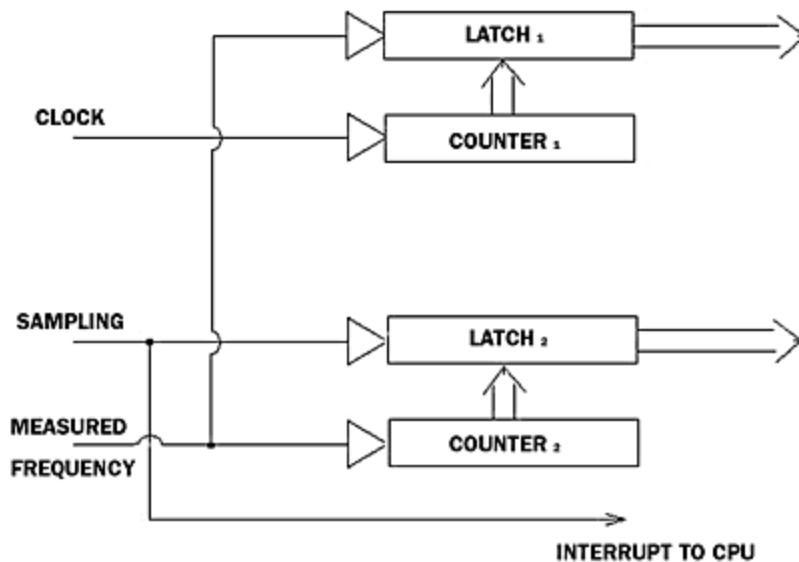


Figure 3. The measured frequency is referenced to a standard frequency clock and the CPU reads data from each latch.

The first counter counts pulses produced by a high-frequency clock (~100 MHz) and each rise in measured frequency results in data storage from the counter to its latch. The second counter counts periods of measured frequency. Data from the second counter are stored in the second latch with a predetermined sampling rate that depends on the application. At the same time, an interrupt request is generated every 1 ms and the CPU reads the data from both latches and calculates the increments of both counters between two samples. After each interrupt we know the integer number of periods and the

integer number of clocks corresponding to that number of periods. By dividing these numbers we obtain an average number of clocks per period of measured frequency. This method provides very high resolution, e.g., for a 10 ms sampling rate and 100 MHz clock the resolution is 1 Hz for a 1 MHz measured frequency, corresponding to ~10 nm resolution for displacement.

A typical application may be defined as a device consisting of the displacement sensor and an ASIC (containing an electronic feedback part of an oscillator), a frequency meter, a CPU, and an output driver (e.g., CMOS open drain).

Potential Applications

Our measurement method enables the measurement of any physical parameter, including acceleration, angular velocity, density, distance, displacement, elasticity, flow, mass, pressure, shape, strain, temperature, tilt, torque, vibration, viscosity, volume, and weight.

Nexense's patented technology is generic, adaptable, and capable of measuring any physical phenomena with very high precision. The sensor's ability to work in a noncontact, nonintrusive manner opens the door to unlimited opportunities.

Imagine the possibilities: Noninvasive core temperature measurements with an accuracy of $\pm 10^{-4}$ °F, household bathroom scales that can measure heart rate from the feet, precise engine performance and noninvasive wing integrity testing for aircrafts, and noncontact vital-sign monitoring from beneath the patient's 21 in. mattress. The potential applications are endless.

A recent project conducted by Nexense involved determining whether a person was occupying a car seat. Clearly, the weight of an occupant will compress the seat and sensors currently detect and accurately measure this weight. However, since the goal was to detect whether the occupant was a human rather than a heavy box or set of golf clubs, measuring only weight was inadequate. Nexense designed a sensor system that used the same hardware to detect a passenger's weight as well as his or her heartbeat.

By mounting a transmitter and receiver on to the seat's anchor bolt, the bolt becomes the sensing mechanism (see Figure 4).

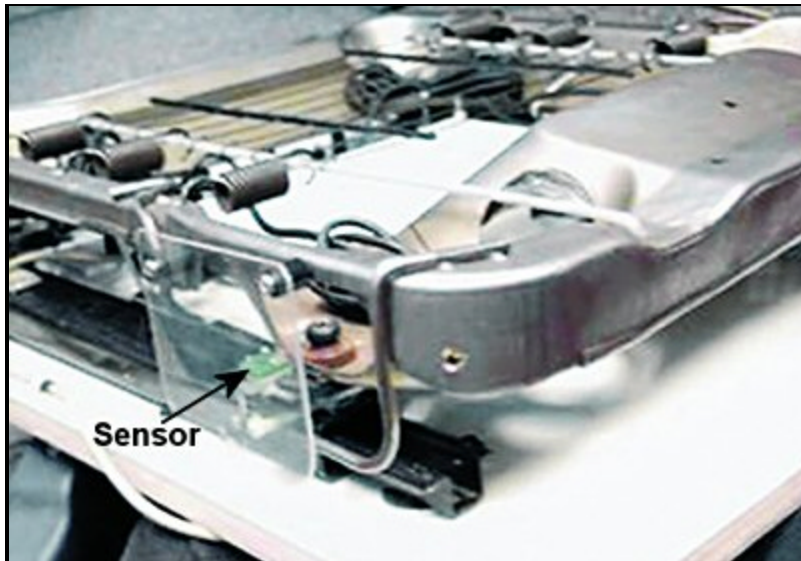


Figure 4. In this photograph a bolt is used as the sensor, with no additional tooling required.

Because the sensor has such large bandwidth and high resolution, we could measure not only the weight of the occupant, but also the minute displacement caused by the occupant's beating heart. Essentially, the occupant's ~150 lb. weight remained constant, but the beating of his heart caused a continual change in his center of gravity. This change was significant enough to change the propagation time of the wavelength transmitted through the seat's anchor bolt.

Nexense designs custom sensors and sensor systems for specific applications because each application presents a unique measurement challenge when applying this technology. The company has developed a biosensor that allows patient vital signs and various physiological data to be measured and monitored in a noncontact, nonintrusive, and nonemissive manner. Based on the biosensor, here's a selection of applications that are now possible.

Medical / Healthcare

- Noncontact, nonintrusive patient monitoring for hospitals and long-term living facilities (see Figure 5)
- Bed-exit monitoring for hospitals and long-term living facilities
- Baby monitoring for heart activity and respiration
- Wearable heart-rate monitor for athletes and fitness enthusiasts
- Heart-rate monitoring for health- and fitness-club equipment
- Household or medical scale that detects heart rate via the feet
- Nonintrusive respiratory monitor (apnea, asthma, hyperventilation, etc.)
- Portable sleep lab for home apnea screening

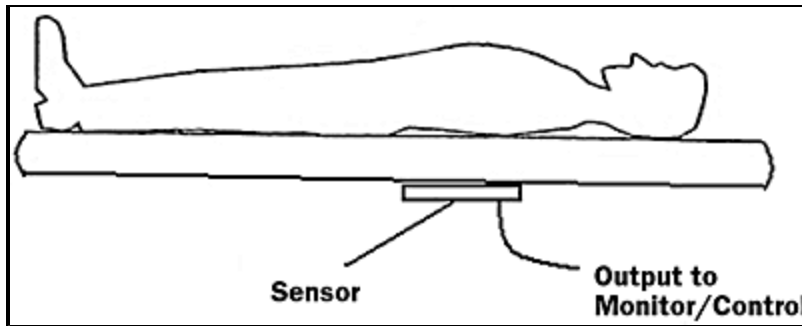


Figure 5. Current initiatives include various health and well-being monitoring devices, some wearable and some placed beneath a mattress.

Automotive

- Seat occupancy for smart airbag deployment
- Vehicle occupancy for forgotten-child alert
- Vehicle occupancy for intruder detection

Communications and Electronics

- Wireless "health phone" that detects and displays various physiological data
- Bedside "health clock" that displays heart rate, respiratory rate, apnea events, snores per hour, etc.
- Nighttime vital-sign monitoring linked to phone/security system or sent wirelessly to doctor or data center

Aerospace and Aviation

- Noninvasive integrity testing
- Vital-sign monitoring of pilots
- Precise distance measurements for wing strain

The precision, accuracy, and resolution achieved reach the near theoretical limit with an SNR of 190 dB. Cost is a key factor when assessing sensor technology, as sensors are often a small component of a much larger application. Typically, increasing the sensitivity, precision, accuracy, resolution, or any other defining characteristic of a sensor directly correlates with increased cost. The method discussed here is based on a generic technology platform in which the most precise measurements can be calculated for a fraction of what it would cost using today's measurement techniques. Often the only correlation to cost with this method is with regard to the design of the measurement system itself and the cost of raw materials. The relationship between precision and cost is virtually imperceptible.

Though Nexense has focused much of its attention to date on the health and medical applications, its technology is not limited to any one or two industries. This technology also represents unique business opportunities for the automotive, aerospace, aviation, communications, security, gas, and oil exploration sectors. For the first time, one platform enables the measurement of any physical parameter.

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Comments/Updates

To put it bluntly, the Cover Story "Measure Any Parameter with a Single Platform" is pretty much of a joke. Like all miracle cure-alls it is too good to be true. It basically winds up being a 'time-of-transmission' measurement strategy that is the basis of lots of instruments that are out there. But worse, it purports to measure anything. However, like most transducers, it relies on a mechanism to transduce the physical phenomenon of interest into a change of dimension (length). However, length of a material is dependent on all of the parameters involved: Force, acceleration, temperature, pressure, phase of moon.. etc. The challenge for the transducer developer is to separate these effects.. and the article does not discuss this. In fact, the example of the seat hold-down-bolt that measures the body weight and heart rate simply could not work in practice. There are simply too many things going on to separate out the effects.

Strether Smith
Structural/Signal Analysis Consultants (S/SAC)
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Author's response:

Dear Mr. Smith,

Your analysis of the Nexense phenomenon is very good, but not exact. Please allow me to address the issues you have raised.

1. Transducer mechanism – Nexense can use any wave. The wave can be produced by many sources, transducer is one of them, while light and electromagnetic are others.
2. Time of transmission – Basically we are talking about propagation delay, but unlike other state-of-the-art techniques, Nexense technology doesn't depend on a precise clock reference. Instead, it relies upon the free time of flight within a given material while using a phase-front, pseudo-standing wave mechanism.
3. Dependency on different parameters is a significant issue that is addressed with multiple sensor arrays. I'll use your example of the seat occupancy system (only because it was used in your letter as an example). We do not provide a transducer. The screw in the seat occupancy is able to measure in two different ways, one is by the elongation and contraction of the screw but this, as you noted correctly will also be influenced by temperature. The way to overcome this issue is rather simple; we measure length but also shear. The shear wave and the longitudinal waves have two different propagation coefficients in the same material, each one of the results carry information about the length and the temperature. This leaves us with two unknowns and two equations... Car vibration may also appear as a disturbance, but one must keep in

mind that the integral of a vibration over time... is zero. If however the measurement needs to be taken faster, another linear Nexense accelerometer can be integrated and its result is subtracted from the screw dimension sensor. That solves the problem.

Thank you for your interest in Nexense.

Sincerely,
Arik Ariav
CEO

Dear Barbara,
I read with interest the cover story, "Measure Any Parameter with a Single Platform." I confess that I looked at the front cover several times to be sure it was a November and not an April Issue.

The article makes claims of dynamic range (190 dB) that I have never seen in a physical measurement system in 30+ years. the article had no data to back up the claims. I looked at the Nexense website and I was unable to find any real data, just potential applications.

Did *Sensors* magazine observe this or is it just a theoretical idea or a joke?

Sincerely,

Jeffery C. Gannon
Director of System Engineering
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<http://www.colibrys.com>

Author's response:

Dear Mr. Gannon,

Although you may be skeptical, Nexense holds worldwide patents (#s 6,621,278 and 6,856,141), with others pending. In addition, after thoroughly evaluating the technology, GE Healthcare offered the following assessment: "A revolutionary and complete technology and product development breakthrough which holds the potential to change the current sensor and measurement technology industry by possessing the ability to create unimaginable measurement solutions and replace many existing measurement solutions with a more accurate and cost effective measurement approach."

Thank you for your interest in Nexense technology.

Sincerely,
Arik Ariav
CEO

This is too much. Is this article for real? I really had to consult my calendar to make sure it's not April 1st!!!

Sensors magazine can do us all a favor and submit all articles to a peer review. This may filter out a few of these jokers out there!

Beyond words!

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Basically, I think you are on to something I have been promoting since 1995 (10 years). I was introduced to a technology called Electrical Signature Analysis (ESA), first brought forth by Dr. Steven Smith, et. al. from Oak Ridge National Labs. With ESA, which treats an electrical motor as it's own sensor, by evaluating the "noise" (same theory as yours, but not as precise) one can measure faults [information] that may lie down stream of what the motor is driving. For example, I monitored an industrial electric sewing machine's AC motor current with ESA software available from Framatome ANB corp. I could easily measure the effects of needle sharpness, through the gear train and drive mechanism, just with a electrical current probe attached to the drive motor! Easily !! Fantastic! So, going even deeper into what I refer to as the "noise", there exists an entire world of information, free for the picking. This can revolutionize the world of sensors and data.

We just have to take the time to grab it and investigate what it means! People I try to explain this to JUST do not understand what is available and what the possibilities are. I think your article helps to bring this to light. Congratulations!

Daniel L. Simon
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