Development of Ultrahigh-Sensitivity Vibration Sensor Technology for Minute Vibration Detection, Its Applications

SASAKI Yasuhiro, TAKAHASHI Masatake, AIMOTO Takashi, GENSHIN Akira

Abstract

The NEC Group has developed a piezoelectric vibration sensor that features sensitivity at about 20 times that of previous models. A vibration sensor is a device that corresponds to the auditory and tactile organs of the human body. The real world is flooded with vibration information generated by humans, goods and environments. Our recently developed vibration sensor can collect minute waveform data that has been hitherto undetectable and has therefore not been utilized. The device extracts the frequency components that present anomalies and analyzes their significance by means of cloud computing, so as to implement a safe and secure society by connecting accurate identification of situations and circumstances for the prevention of adverse events. This paper introduces features of the newly developed vibration sensor and discusses efforts being made for the development of its applications.

Keywords

vibration, sensor, piezoelectric ceramics, vibration amplitude magnification mechanism, high sensitivity, waveform, frequency band, noise, cloud computing

1. Introduction

The sensor is a key device that collects information dispersed and scattered in the real world and processes it into information of a higher quality level by means of cloud computing in order to initiate the creation and provision of new services.

There has been a strong need to identify the causes of abnormal vibrations and the nonstandard operation of electronic equipment and machine tools, to check the deterioration of structures including buildings and understand the daily health patterns of individuals easily. The piezoelectric vibration sensor recently developed by the NEC Group extends the potential for solving these issues in a simpler manner than has been available hitherto.

The development of the new sensor was initially started aiming at internal use in the development of other products. Vibration and acoustic technologies are indispensable in the development of electronic equipment such as for computers and mobile phones within the constraints of noise reduction and high audio quality requirements. Abnormal vibrations and the acoustic behavior of components used in electronic equipment have previously been determined using vibration sensors designed for scientific measurements. However, such traditional vibration sensors have not been widely used because they may be as expensive as 100,000 yen and also because their measuring ranges are limited.

Under these circumstances, we judged that the development of a new piezoelectric vibration sensor (hereafter referred to simply as "vibration sensor") with high sensitivity and low price would be possible by utilizing the proprietary technologies that have been previously developed by the NEC Group. Therefore, we have proceeded to develop the vibration sensor discussed in the present paper.

2. Piezoelectric Vibration Sensor

The newly developed vibration sensor achieves a high sensitivity at a world leading level of about 20 times that of previous vibration sensors that have been designed for scientific measurement. It functions in a wider frequency band of 10 to 15 kHz, and at a greatly reduced price of about 1/10th that of the previous sensors. The present device can detect an acceleration of only 0.0001 G, which is 1/10,000th that of the gravity acceleration of the earth, and over a broad frequency band (**Fig. 1**). This detection level is equivalent to the capability of detecting vibrations on a glass surface on which a drop of water falls.

The NEC group has been conducting R&D for more than half a century on piezoelectric ceramics devices such as communication device filters, speakers and actuators for use in our electronic equipment. The piezoelectric ceramics materials used in these applications feature a piezoelectric effect or an electromechanical transduction capability that converts an externally applied vibration into a voltage (**Fig. 2**). The combination of piezoelectric ceramic materials with machine mechanisms and electronic circuitry makes it possible to create a high-sensitivity sensor.

Our newly developed vibration sensor incorporates new technologies for obtaining electrical signals efficiently.

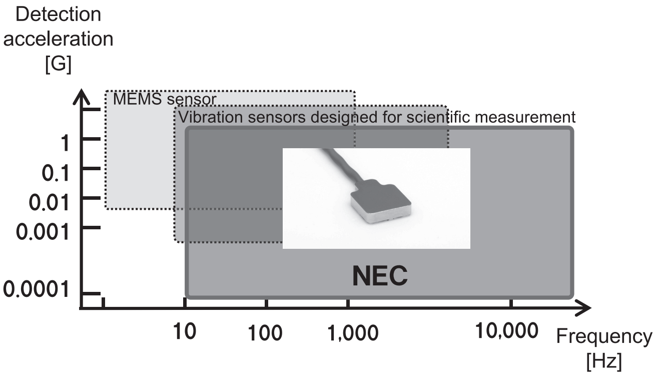

Fig. 1 Piezoelectric vibration sensor with ultrahigh sensitivity.

These include optimum composition of the piezoelectric ceramic material, a unique vibration amplitude magnification mechanism in the sensor mechanical part and the noise reduction technology and impedance converter that enables a high S/N (signal-noise ratio).

In the development of the piezoelectric ceramic material, we utilized our previously accumulated material database and discovered the optimum material composition for the sensor by repeating material syntheses based on perovskite crystals.

For the development of the unique vibration amplitude magnification mechanism we designed a precision vibrator structure by repeating simulations. It achieves a loss-free conversion into signals of the electrical charge generated on the piezoelectric ceramics material due to vibrations of the sensing target.

The electrical noise generated by the external environment and/or sensor circuitry adversely affects sensors that handle very low detection signals. When the very low signals are buried in noise, they become mutually indistinguishable. We succeeded in minimizing the effects of noise by determining the penetration paths and causes of noise via scientific analyses and by applying optimum countermeasures.

In order to facilitate the embedding of the sensors in the equipment of the users the sensor incorporates an impedance converter circuit. This arrangement maximizes the transmission efficiency of the detection signals by matching the impedance with the equipment to which the vibration sensor is connected.

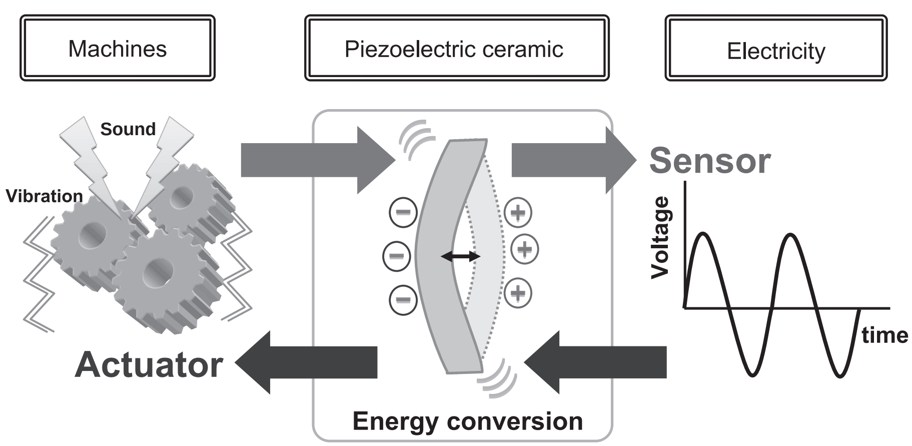

Fig. 2 Electromechanical conversion capability of piezoelectric ceramic materials.

3. Applications of Vibration Sensors

To respond to the needs for a safe and secure society, we are conducting R&D into vibration sensor application technology with a view to a cloud-based service that detects anomalies via the data collection of the sensors, and issues early notifications.

The next generation vibration sensors will be capable of the real-time collection of a large amount of data, such as the waveform data of minute vibrations e.g., representing abnormal operations of electronic equipment, cracking and creakings of buildings or the condition of human blood circulation. When this technology is combined with the vibration waveform analysis technology, it will be possible to identify conditions accurately by extracting the frequency components representing the anomaly and analyzing their significance. This will lead to the possibility of highly accurate prediction of serious events and on to the creation of new information services.

In the following subsections, we review the possible applications of the vibration sensor in the field of information services for infrastructure surveillance/diagnoses and healthcare by taking buildings diagnoses and human pulse detection experiments as examples.

3.1 Visualization of Building

We installed newly developed vibration sensors in a model of a building with columns and beams in which we had also intentionally introduced a mechanical abnormality, in the form of rattling to some of the columns located on the upper floors of the building. We then applied vibration stress externally to the building, collected the detection signals of the sensors and analyzed them.

The sensor outputs the vibration time waveform data as electrical signals according to the vibration stress applied to the building. We converted this data into frequency spectra in order to extract various frequency components. We then integrated the frequency components by applying a statistical information processing technique and visualized the building situation by creating an animation showing the mode of its vibrations. We were thereby able to confirm that some frequency components of minute vibrations that had not previously been detectable in fact represented the actual column rattling vibrations (**Fig. 3**).

In this way, remote monitoring of an infrastructure component such as a building or bridge by attaching several sensors to it and by then applying cloud computing technology can enable accurate identification of the deterioration status of a structural component. This leads to the early discovery of deterioration and permits efficient repair based on the obtained information. It is expected that this will help to ensure the safety of residents as well as assisting in the prevention of economic losses.

3.2 Identification of Blood Flow Condition by Human Pulse Vibrations

We equipped both traditional and a newly developed vibration sensors at the extremities of plastic rods and by applying each rod on a human carotid artery observed the detected vibration waveforms (**Fig. 4**).

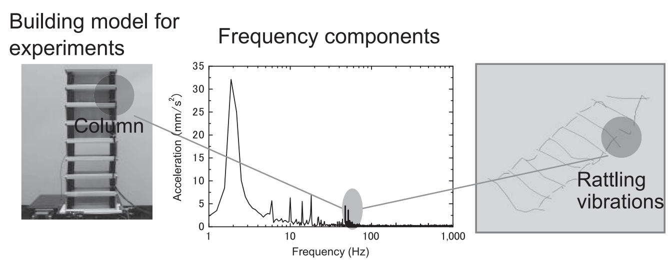

Fig. 3 Visualization of building defects by collection/analysis of minute vibrations.

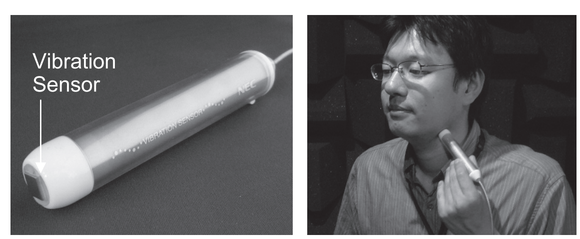

Fig. 4 Blood flow condition measurement using vibration sensor.

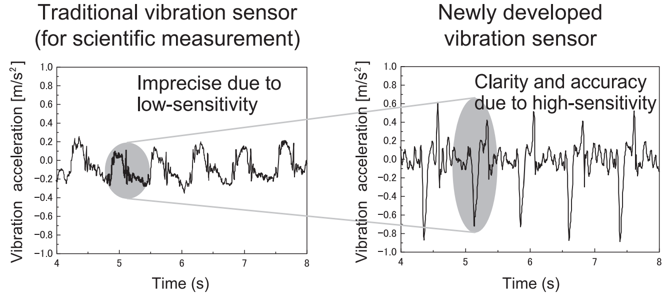

Fig. 5 Accurate determination of blood flow condition.

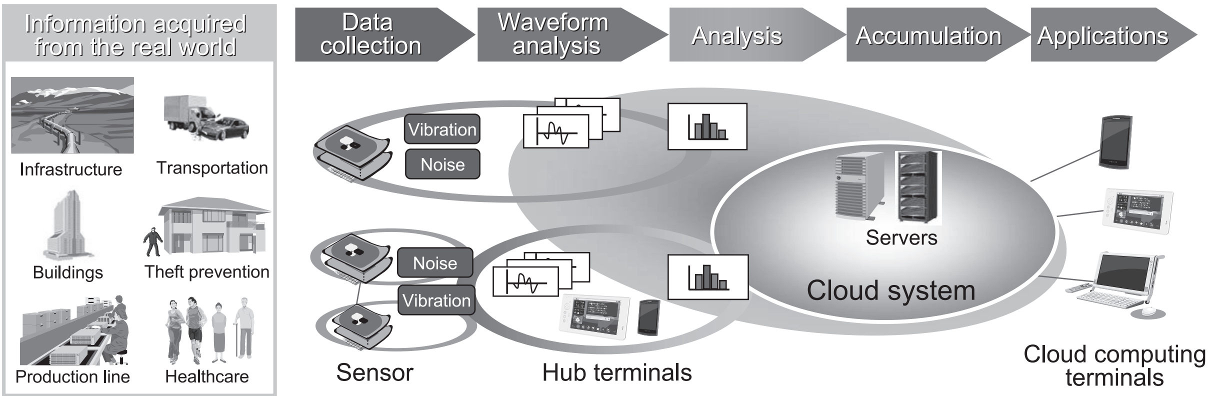

Fig. 6 Cloud computing-based sensor network system.

The vibration waveform observed with the traditional sensor was not clear while that obtained with the newly developed high-sensitivity vibration sensor was sharp and precise. The time interval between the vibration time waveforms represents the pulse according to the heartbeats and the peak values represent the pressure levels of blood circulation locally at the position the sensor is applied (**Fig. 5**).

By measuring blood circulation in a simplified manner, accumulating the collected data and analyzing its significance minutely in a time series makes it possible to identify changes in health condition on a daily basis. This information can be used in giving advice to each individual according to his or her lifestyle in order to provide satisfactory support for individual needs.

4. Conclusion

In the above, we introduced features of the newly developed vibration sensor and discussed efforts being made for the development of its applications. We then described our attempts to develop a sensor network system based on the use of cloud computing, in which the sensors, hub terminals, a cloud system and a communication network are connected organically to enable smooth operations for the collection of data and the provision of value-added information for our customers (**Fig. 6**).

The vibration waveform data collected from the sensors is analyzed in real time by the hub terminals, and the extracted significant information is transmitted to the cloud system. The cloud system performs detailed statistical information analyses and provides value-added information that can be understood by customers easily. Compression of the information in the real world into value-added information also contributes to reducing loads on the cloud system and information communication networks and optimizes the energy requirement for performing the information processing.

Looking forward, we will proactively continue the R&D of sensor technology in collaboration with the group and partner enterprises with the aim of realizing a safe and secure society.

Authors' Profiles

SASAKI Yasuhiro
Principal Researcher
Green Platform Research Laboratories
Central Research Laboratories

TAKAHASHI Masatake
Assistant Manager
Green Platform Research Laboratories
Central Research Laboratories

AIMOTO Takashi
Senior Manager
Sensors and Modules Business Development Promotion Division
NEC TOKIN Corporation

GENSHIN Akira
Assistant Manager
Sensors and Modules Business Development Promotion Division
NEC TOKIN Corporation

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