MEMS Applications and Devices in IoT

AST Seminar Report

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Introduction

Micro-electromechanical (MEMS) systems are process technologies used to build small integrated devices or systems that integrate mechanical and electrical components. They are built using integrated circuit (IC) cluster techniques and can vary in size from a few micrometres to millimetres. These devices (or systems) can hear, control and activate on a small scale, and produce effects on a large scale.

Mems devices are generally divided into two categories:

1. Sensors
2. Actuators

- **Sensor** devices gather information from their surroundings.
- **Actuators** execute given commands or act through highly controlled movements.

MEMS Fabrication Techniques

MEMS has been identified as one of the most promising technologies for the 21st Century and has the potential to revolutionize both industrial and consumer products by combining silicon-based microelectronics with micromachining technology.
If semiconductor microfabrication was seen to be the first micro-manufacturing revolution, MEMS is the second revolution.

Silicon Micro Fabrication

The two most general methods of MEMS integration are:

1. Surface Micromachining

Surface Micromachining enables the fabrication of complex multi-component integrated micromechanical structures that would not be possible with traditional bulk micromachining.

2. Bulk Micromachining

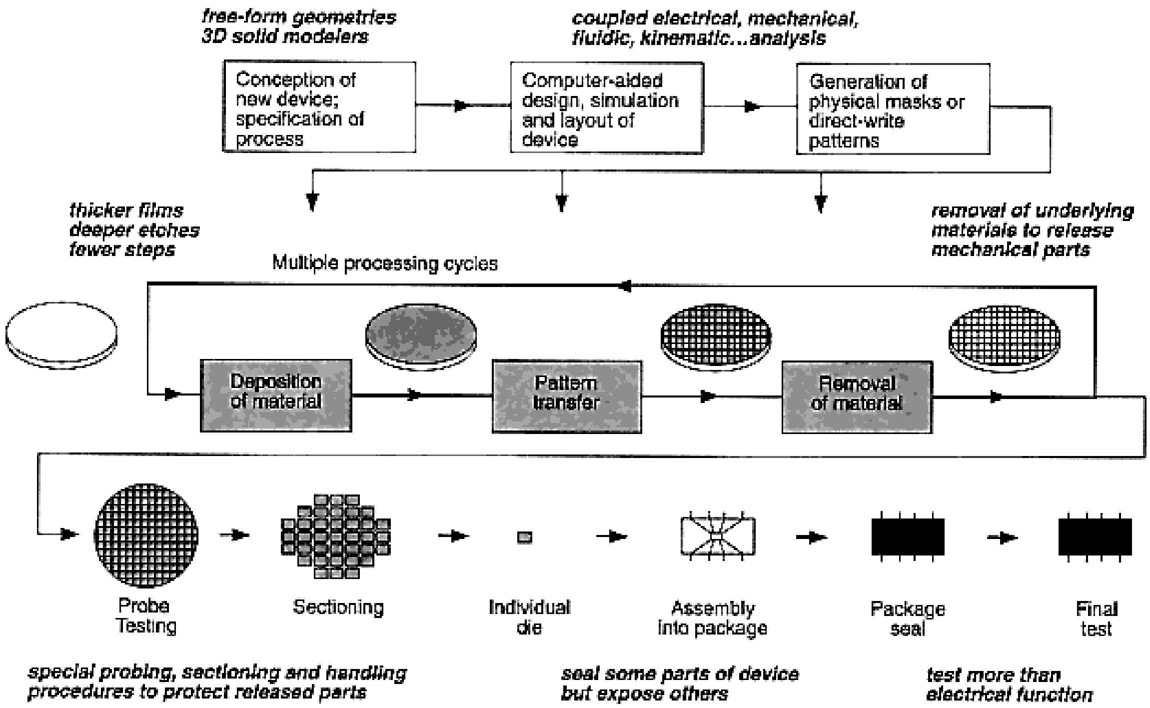
Bulk micromachining is an extension of IC technology for the fabrication of 3D structures. Bulk micromachining of Si uses wet-and dry-etching techniques in conjunction with etch masks and etch stops to sculpt micromechanical devices from the SI substrate.

Non-Silicon Micro Fabrication

1. LIGA

LIGA is a German acronym for lithographie, galvanoformung (plating), and abfromung (molding).
LIGA essentially stands for a process that combines extremely thick-film resists (often>1mm) and x-ray lithography, which can pattern thick resists with high fidelity and results in vertical sidewalls.

MEMS Design Process



MEMS Design Process
https://www.nap.edu/read/5576/chapter/13#58

There are three building blocks in MEMS technology, which are,

- Deposition Process

  The ability to deposit thin films of material on a substrate

- Lithography

  To apply a patterned mask on top of the films by photolithography imaging.

- Etching

  To etch the films selectively to the mask.

Thin layers of materials are deposited onto a base and then are selectively etched away leaving a microscopic three-dimensional structure.

In this way, MEMS processes construct mechanical as well as electrical components. The electrical elements on the chip process data while the mechanical elements act in response to that data hence a complete system on a chip integrated circuitry provides the thinking part of the system while the MEMS component complements this intelligence with active perception and control functions.

MEMS and IoT or say Why MEMS for Sensors?

The Internet of Things (IoT) can leverage several core functions and benefits of MEMS. MEMS devices can effectively meet the requirements of many IoT applications:

- Low Power Consumption

  IoT sensors and gateways are often required to be wireless and battery-powered. Due to low per-unit cost, it’s usually cheaper to replace the entire unit than to reinstall it with a new battery. Thus any reduction in power usage extends the life of the devices. Some MEMS face the same power requirements as their larger counterparts.

- Small Form Factor

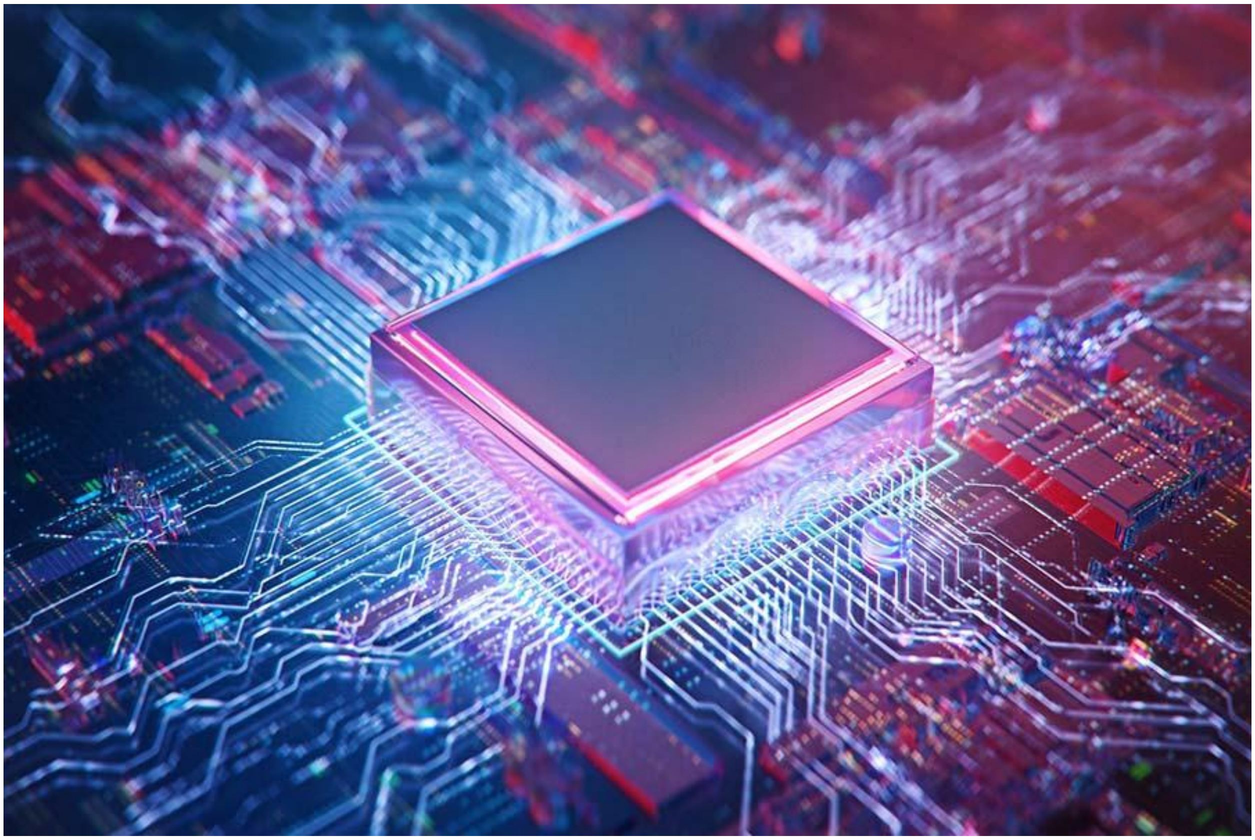
  MEMS are by definition unobtrusive. But beyond user needs, in some IoT applications, the device might need to be added to an existing machine—like a car—that has limited room for more hardware. In other cases like wearables and biomedical applications, small size is a critical requirement that must be met. Due to their small nature, MEMS meet and exceed these requirements.

- Cost-Effectiveness

When deploying an IoT solution, scale is usually a major concern. For instance, when putting sensors to monitor weather and moisture levels on a farm field, there will need to be many devices seeded in each acre. Or consider an asset tracking solution in which there may be an extremely large (and variable) number of assets that need to be tracked. In other applications, such as shipping, a device may just be a one-time use. MEMS are made through a process called photolithography, which makes it easy and cost-effective to produce them in mass quantities.

Application of MEMS in IoT

The IoT has an enormous requirement for tiny, low-cost sensors to monitor all aspects of production; these sensors must communicate the information to other nodes in the factory network and must operate reliably in the harsh electrical and mechanical environment of the factory. MEMS devices are tailor-made for this purpose: they’re small, rugged, and lend themselves to the inclusion of additional circuit blocks in the same package for wired or wireless connectivity.



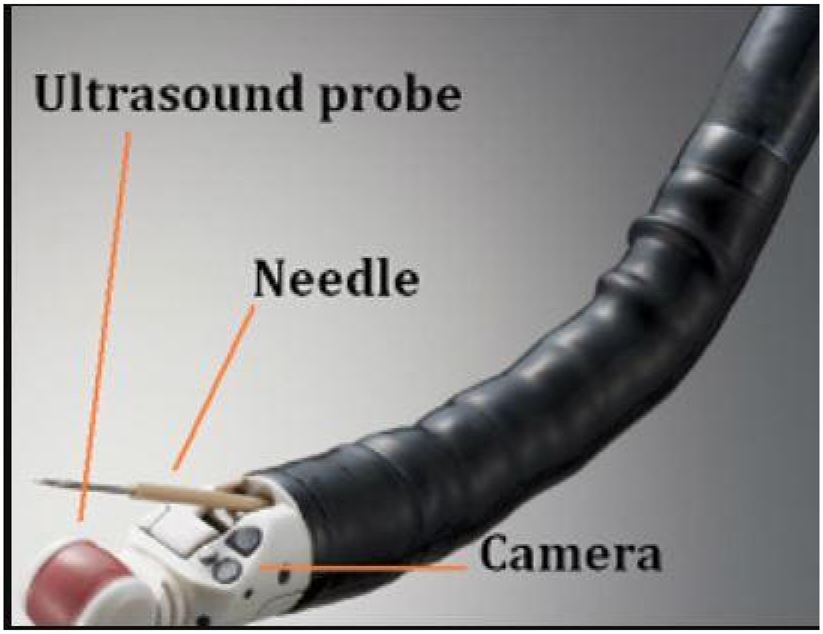
MEMS
https://www.pureairemonitoring.com/nitrogen-usein-the-fabrication-of-mems/

Medical Field

MEMS has allowed the medical industry to increase the precision and accuracy of medical devices. These devices are used to manufacture miniature and portable devices for surgical, diagnostic, and monitoring purposes. The demand for MEMS embedded devices has increased due to their high efficiency and compact design.

Endoscopy

Conventional Endoscopy



Conventional Endoscope
https://health.usf.edu/medicine/internalmedicine/digestive/eus

An endoscopy is a procedure where organs inside your body are looked at using an instrument called an endoscope. An endoscope is a long, thin, flexible tube that has a light and camera at one end.

- Can be used only to views the limited part of the small intestine
- Requires sedation of the patient
- Is an uncomfortable procedure

Lab on a Pill (IoT Based Smart Capsule) (Length 25 mm, Width Diameter: 10mm)

Lab on a Pill
https://www.iothub.com.au/news/smart-pill-brings-iot-to-digestive-health-413887

Components

- Digital Camera
- Light Source
- Battery
- Radio Transmitter
- Sensors (MEMS Tech)

Working

- The pill is intended to be swallowed like any normal pill.
- Once within the body, the pill's sensors sample body fluids and pick up "meaningful patient data" such as temperature, dissolved oxygen levels and pH.
- The pill is expected to retrieve all data over an a12-hour period.

- This data is transmitted wirelessly to a card attached to the wrist of the individual.

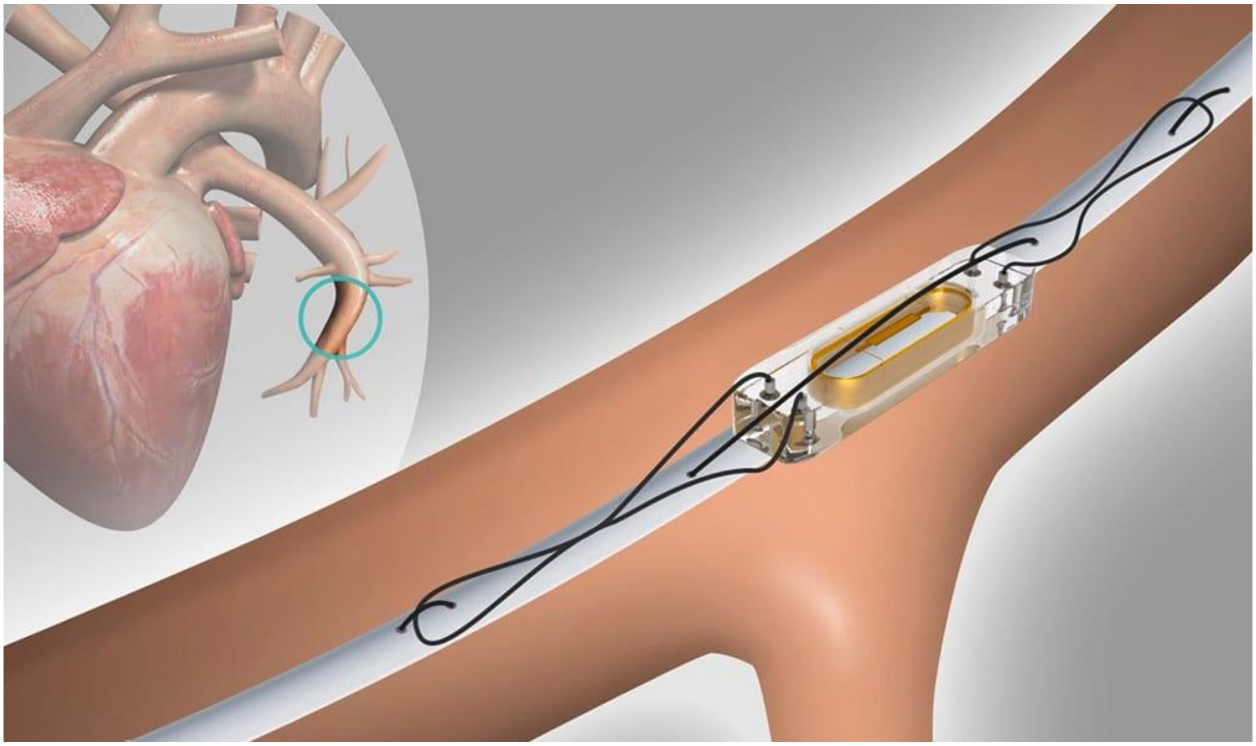
The advantage over conventional Endoscope

- Requires no sedation
- Can show views of the entire small intestine
- Can aid in early detection of colon cancer

Hearing Aid

A MEMS-based ear implant has been designed by the University of Michigan and looks like a cochlea. This appears to be the first hearing chip with integrated electronics and it uses micromachined cantilevered beams for sound interpretation. Beams of different lengths are used to distinguish frequencies. A piezoelectric vibrator will interact with the ear.

The Heart



Cardiomems-implant
https://cacvi.org/services/cardiac-procedures/cardiomems-implant/

Cardio**MEMS** has also been advancing its HeartSensor, a wireless device that measures intracardiac pressure in patients with congestive heart failure. Similar to the EndoSensor, the HeartSensor is inserted through a catheter in a non-surgical procedure. Patients receive monitoring electronics to take home which are used to conduct daily pressure readings. Then that data is transferred over a phone line to their physician. The HeartSensor enables doctors to monitor patients more closely and adjust medications as they see the disease progressing.

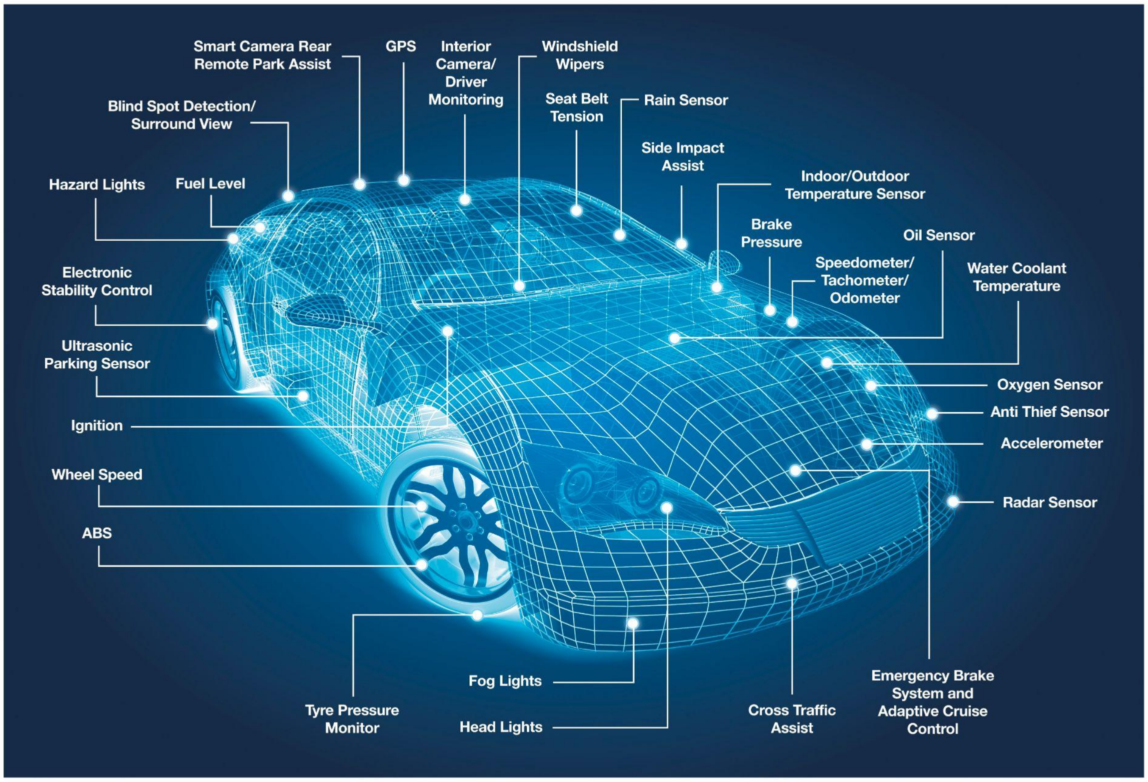
MEMS could also help improve pacemakers and defibrillators. The basic function of pacemakers hasn't changed a lot in 20 years. All pacemakers include a computer, some memory, and a telemetry link; additional sensors might provide more information to the user's doctor, such as blood oxygen measurements, pH level, or other information. People with pacemakers tend to be subject to other diseases as well, and a group of implanted sensors could provide early warnings about the patient's health. Maybe someday they will be implanted in healthy people.

Other MEMS-based IoT sensors are having medical-related applications being used in daily life like Smart Watches.

Automotive

The MEMS sensors most prevalent in today’s vehicles are:

- Inertial sensors (accelerometers and gyroscopes)
- Magnetometers
- Pressure sensors
- Thermal sensors
- Gas sensors
- Optical MEMS



High-performance MEMS sensors for smarter vehicles
https://www.cieonline.co.uk/high-performance-mems-sensors-for-smarter-vehicles/

Inertial sensors

Inertial sensors include accelerometers and gyroscopes, whether individually or combined in packages. These sensors are the dominant type in the automotive industry and are used in many key applications.

Accelerometers

Accelerometers measure static (gravity) and dynamic (motion or vibration) acceleration. MEMS accelerometers usually work on one of two principles: movement of a mass, or the piezoelectric effect. In the first principle, a weight is attached to a spring. Under acceleration, inertia tries to hold the mass in place, creating a force on the spring, which generates an electrical signal commensurate to the motion of the object. In the piezoelectric-based principle, the forces from acceleration act on a microscopic crystalline framework that generates a correlated voltage.

Gyroscopes

Gyroscopes (or gyros) identify angular change. MEMS gyros use paired vibrating objects like a tuning fork. Vibrating objects want to maintain their motion in the same plane. If the paired objects are accelerated linearly, then the two objects move in the same direction with no noticeable difference between the two in how they move. However, if the tuning fork is rotated, then a force acts on each object pointed in opposite directions. This is due to the Coriolis effect as the objects are forced to move out of the plane. These forces can be converted into output voltages corresponding to the speed of the angular change.

Magnetometer

A **magnetometer** measures the strength and direction of a magnetic field. A MEMS sensor typically relies on the Lorentz force, which is felt when a charged particle (as in an electrical current loop) passes through a magnetic field. The mechanical deflection of the electrical structure proportionate to the strength of the field can be discerned either electronically or optically.

MEMS pressure sensors

MEMS pressure sensors assess the pressure difference across a silicon diaphragm. A fixed reference pressure is captured on one side of the diaphragm, while the other side is exposed to the environment to be measured. The effect on the diaphragm can be measured by the change in electrical resistance in the diaphragm materials due to mechanical strain (the piezoresistive effect mentioned above).

Thermal sensors

Thermal sensors measure temperatures. In MEMS, this sensing is typically accomplished using a resistance temperature detector. These detectors examine changes in the electrical resistance of a thin layer of test material (such as platinum, germanium, or polysilicon) in response to changes in temperature.

Gas sensors

Gas sensors assess levels of gases such as carbon dioxide and other volatile compounds. There are a variety of detection technologies in use today, including electrochemical, pellistor, and photoionization methods.

Optical MEMS

Optical MEMS direct and detect light, from visible light to infrared wavelengths. Lens arrays and microscopic mirrors gather and direct light, while the detection of light intensity is handled with photodiodes (which generate an electrical current, when exposed to light) or photoresistors (which exhibit a change in electrical resistance under light).

AR/VR Technology

AR/VR Technology
https://www.power-and-beyond.com/mems-ultrasonic-sensor-pushing-the-boundaries-of-arvr-technology-a-918416/

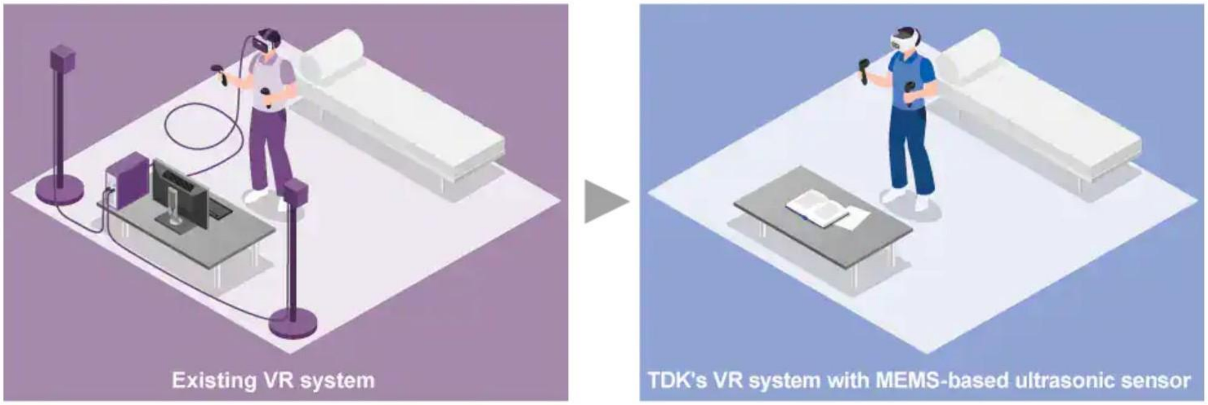
AR/VR systems are becoming increasingly popular in a variety of industries, including entertainment, education, healthcare, and other industrial uses. Users can utilise them to do difficult jobs or procedures in a virtual environment. Through advanced and accurate location/motion detection, sensing technology allows users to have a genuine experience in a virtual area. Ultrasonic sensors are receiving a lot of interest in recent AR/VR systems that employ Time-of-Flight (ToF) to measure the distance to an object.

CH-101 combines PMUTs, a power-efficient DSP (digital signal processor), and a low-power CMOS ASIC in a small-sized package measuring 3.5 x 3.5 x 1.25 mm, with one-thousandth the volume of a traditional ultrasonic ToF sensor.
https://www.tdk.com/en/featured_stories/entry_007.html

TDK has developed a solution to this challenge, however: a new ultra-small ultrasonic ToF sensor named CH-101. It boasts one-thousandth of the volume of a traditional ultrasonic ToF sensor, and it is the world's first one to be MEMS-based.

The PMUT is responsible for emitting piezoelectric ultrasonic sound and receiving echoes from objects within the sensor's field of view. When it is combined with the DSP—a specialized microprocessor designed to process digital signals—it can be used for a broad range of new and more specialized AR/VR applications, including the sensing of an object's prevision, collision detection, and distance measuring.

CH-101, an ultrasonic sensor that supports "VR wherever you are"

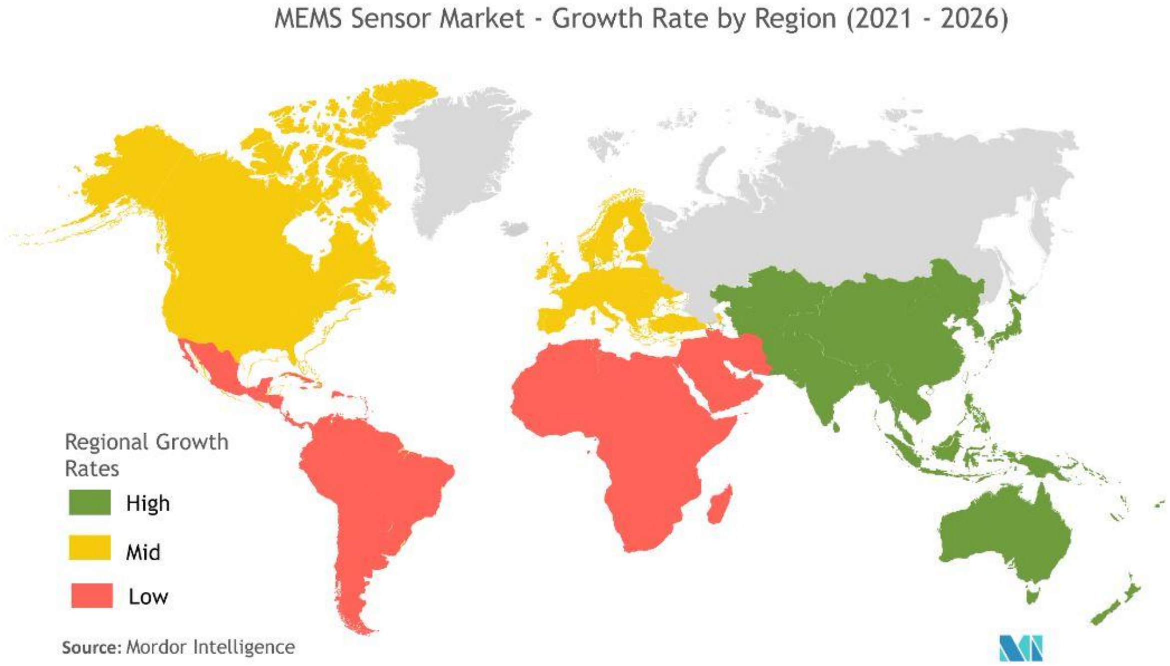


VR System with MEMS-based sensor
https://www.tdk.com/en/featured_stories/entry_007.html

Existing optical sensor-based VR systems combine external sensors to send out infrared rays with a wired headset and controllers that respond to the infrared rays to locate the position of the user. A VR system with CH-101 allows the users to experience VR using just a headset and a controller.

MEMS Sensors Market

The global MEMS sensors market was valued at USD 11,686.2 million in 2020 and is expected to reach USD 16,857.0 million by 2026, registering a CAGR of 6.5% during the forecast period (2021-2026). Due to the COVID-19 pandemic, certain types of MEMS sensors have significantly spiked in demand. For instance, the demand for thermopiles and microbolometers used in temperature guns and thermal cameras has increased because of the need for contactless monitoring of people's temperatures.



https://www.mordorintelligence.com/industry-reports/mems-sensor-market

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