MEMS Technology & Application in Defense Navigation System

Ravish Gupta [1], Jigyasha Maru [2], N. Pannaga [3]

1. M. Tech scholar, Department of Electronics & communications, Rajiv Gandhi Proudyogiki Vishwavidyalaya ,
2. M. Tech scholar, Department of Electronics & communications, Dr. C V Raman University,
3. M. Tech scholar, Department of Mechanical, Mangalore Institute of Technology & Engineering (MITE)

Abstract: - Micro-electromechanical systems (MEMS) are Freescale's enabling technology for sensors. MEMS based sensor products provide an interface that can sense, process and/or control the surrounding environment. Freescale's MEMS-based sensors are a class of devices that builds very small electrical and mechanical components on a single chip. Silicon-based MEMS (Micro Electro-Mechanical Systems) devices have a high potential of making a new field of applications for defense equipment. The design of sensors has increasingly made use of micro electromechanical systems (MEMS) technology. In this paper *we focus on* personal navigation device for defense department. *Innovative approaches for improved* Accuracy in navigation research, and led to the development of the Global Positioning System (GPS).

Keywords— *Micro electromechanical devices, micromachining, radio* frequency (RF), Electrical and Computer Engineering, Robotics Engineering, inertial measurement units (IMUs), sensors, RF terrain relative velocity.

INTRODUCTION:-

The mechanical design of microscopic mechanical systems, even simple systems, first requires an understanding of the mechanical behaviour of the various elements used. While the basic rules of mechanical dynamics are still followed in the miniaturised world, many of the materials used in these structures are not well mechanically characterised. For example, most MEMS systems use polysilicon to build mechanical structures. Polysilicon is a familiar material in the IC world, and is compatible with IC manufacturing processes. Microelectromechanical systems (MEMS) devices are manufactured using similar microfabrication techniques as those used to create integrated circuits.

In the most general form, MEMS consist of mechanical microstructures, microsensors, microactuators and microelectronics, all integrated onto the same silicon chip. This is shown schematically in Figure .

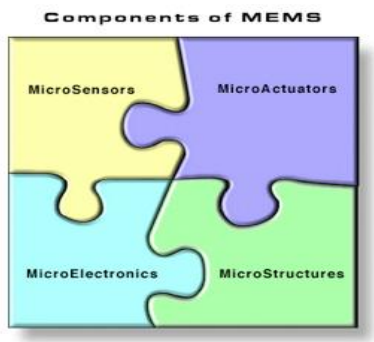

Figure: MEMS components.

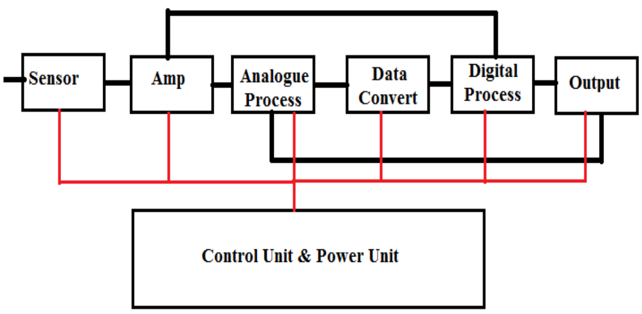

Figure: - MEMS Technology Diagram

MEMS fabrication techniques

MEMS fabrication uses many of the same techniques that are used in the integrated circuit domain such as oxidation, diffusion, ion implantation, LPCVD, sputtering, etc., and combines these capabilities with highly specialized micromachining processes. Production of a MEMS device consists of two phases - phase 1 involves the fabrication of structures and elements on the silicon wafer, and phase 2 involves packaging and assembly of individual silicon chips. The assembled chip products are mounted on PC Boards for insertion into electronics systems. Some of the most widely used micromachining processes are

- **Bulk micromachining -** whereby the bulk of the Si substrate is etched away to leave behind the desired micromechanical elements. Bulk micromachining involves the removal of part of the bulk substrate. It is a subtractive process that uses wet anisotropic etching or a dry etching method such as reactive ion etching (RIE), to create large pits, grooves and channels. Materials typically used for wet etching include silicon and quartz, while dry etching is typically used with silicon, metals, plastics and ceramics.

- **Wafer bonding -** Wafer bonding is a micromachining method that is analogous to welding in the macroscale world and involves the joining of two (or more) wafers together to create a multi-wafer stack. There are three basic types of wafer bonding including: direct or fusion bonding; field-assisted or anodic bonding; and bonding using an intermediate layer. In general, all bonding methods require substrates that are very flat, smooth, and clean, in order for the wafer bonding to be successful and free of voids.. permits an Si substrate (aka 'wafer') to be attached to another substrate, typically Si or glass, to construct more complex 3D microstructures such as microvalves and micropumps.

- **Surface micromachining -** Surface micromachining involves processing above the substrate, mainly using it as a foundation layer on which to build. It was initiated in the 1980's and is the newest MEMS production technology. where the structures are built on top of the substrate and not inside of it, enabling fabrication of multi-component, integrated micromechanical structures not possible using bulk micromachining

- **Micromolding -** a process using molds to define the deposition of the structural layer, and enabling the manufacture of high aspect ratio 3D microstructures in a variety of materials such as ceramics, glasses, metals, and polymers

- **LIGA -** LIGA is an important tooling and replication method for high-aspect-ratio microstructures. a micromolding process that combines extremely thick-film resists (>1 mm thick) and high-energy x-ray lithography, to enable the manufacture of high-aspect-ratio 3D microstructures in a wide variety of materials

- **High aspect ratio micromachining (HAR) -** combines aspects of both surface and bulk micromachining to allow for silicon structures with extremely high aspect ratios through thick layers of silicon. HARMEMS technology provides over-damped mechanical response and exceptional signal-to-noise ratio to address customer requirements.

Application

Guidance and navigation have been critical for military success since the dawn of civilization. Accuracy was the focus of in the Defense navigation research, and led to the development of the Global Positioning System (GPS). The current focus in the Defense is the development of portable localization systems, particularly for GPS-denied or -compromised environments. These include mountainous or urban environments, situations in which there are dismounted soldiers, and with unmanned aerial vehicles.

In the Electrical and Computer Engineering & the Robotics Engineering has been combining radio frequency (RF) velocity and range sensors with miniaturized microelectromechanical systems (MEMS) inertial measurement units (IMUs) to achieve superior navigation accuracy. This paper includes the development and demonstration of such micro and nano scale low-power navigation sensors, MEMS IMU technology and integrated navigation systems techniques that allow long term (hours to days) GPS-denied precision navigation.

"This is an exciting vertically integrated research project that involves both sensor development of the MEMS and RF sensors as well as system integration to demonstrate the gains these sensors will enable for localization applications," said Electrical and Computer Engineering Professor Tamal Mukherjee, who heads this research project.

The primary focus of their research is applying personal navigation systems to a situation in which a soldier is dismounted. In this case, the navigation sensor is placed in the soldier's shoe or boot sole in order to determine his or her location with high accuracy. Other applications of this research include navigation for unmanned aerial vehicles (UAV), specifically the relative navigation for "flocks" of small UAVs, allowing them to navigate together without colliding like a flock of birds.

Shoe-Based Sensors: Working

The team is building on a decade of research by ICES Director Gary Fedder and Mukherjee on chip-scale inertial sensors that meet the power and size requirements for portable applications. However, they suffer from a rapid growth in position error due to inherent bias drift and noise in the sensors. To limit this error growth, Fedder and Mukherjee are teaming with Electrical and Computer Engineering professors Dan Stancil and Jeyanandh Paramesh on developing a RF velocity sensor that detects when a shoe touches the ground. This is used for zero-updating (ZUPting) the navigation system that Robotics Institute professor and National Robotics Engineering Consortium researcher Alonzo Kelly is developing to bound this error growth.

Figure: - Smart Shoe

As seen in the pictures on the following page, three kinds of shoe sensors are implanted in a shoe. The RF terrain-relative velocity (TRV) sensor mounted on the heel and toe is used for ZUPting the position computed from the accelerometers in the MEMS-based inertial measurement unit (IMU). The magnetometers in the IMU are used for ZUPting the heading computed from the gyroscope on the IMU. Shoe relative sensors (SRS) on one shoe form a constellation which can then be used to find the location of a moving shoe with respect to a stationary shoe. The team anticipates initial demos using the IMU and TRV sensor, with the SRS sensor used to meet the final project goal of accuracy down to 1 m after 10 hours in a GPS-denied environment. “This is a very challenging goal, one that took about a dozen years for GPS to get close to; we hope to get there in just 3 years” said Tamal Mukherjee.

Figure: - ▼ TRV Terrain-Relative Velocity Sensor

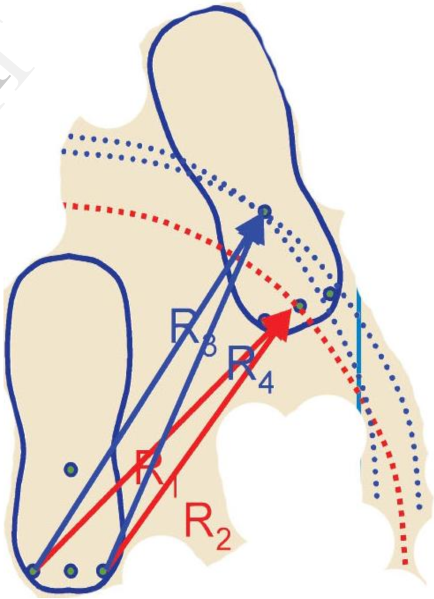

Figure: - SRS Shoe Relative Sensors

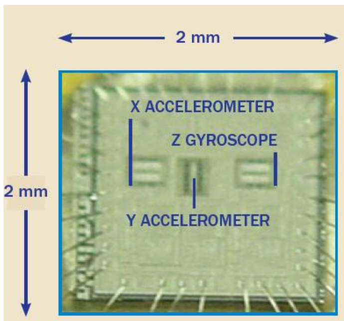

Figure: - IMU Inertial Measurementunit

SUMMARY

Automotive sensors and actuators represent a major market for the MEMS technology. However, there are many development issues that must be brought into balance for a sensor technology to be commercially viable for many applications. This paper has examined the sensor development issues unique to the Defense industry. The future is bright for even greater penetration of these devices in Defense products.

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