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Research on the Cutting-edge Applications of MEMS Technology in Inertial Sensing Systems

Chunyi Ji[1, *]

[1]School of Electronic and Optical Engineering, Nanjing University of Science and Technology, Nanjing, 210000, China

[*]hmyljj@zhengyan.com.cn

Abstract:

MEMS technology is a high-tech that has developed rapidly in recent years, the technology integrates multiple components such as microsensors, microactuators, signal processing, and control circuits, and has significant advantages such as small size, low power consumption, high accuracy, and low cost. In this paper, the cutting-edge applications of MEMS technology in inertial sensing systems are discussed. The design principles and technical classification of MEMS inertial sensors are introduced. Some application examples of MEMS inertial sensors in navigation, positioning, control, and other fields are analyzed. The development trends and challenges of MEMS inertial sensing systems are discussed. The cutting-edge application of MEMS technology in inertial sensing systems has far-reaching technical, economic, and social significance. With the continuous progress of technology and the continuous expansion of application fields, MEMS inertial sensing technology will play a more important role and make greater contributions to the progress and development of human society.

Keywords: MEMS; Inertia sensor; Accelerometer; Gyroscope.

1. Introduction

With the rapid development of science and technology, MEMS technology has become an important branch in the field of modern science and technology, and its application in inertial sensing systems has made remarkable progress. Since the 90s of the last century, there has been an increasing number of inertial devices targeting MEMS [1]. MEMS inertial navigation technology is one of the research hotspots and future development directions in the field of inertial navigation in recent years [2]. The purpose of this paper is to discuss the cutting-edge application of MEMS technology in inertial sensing systems and to analyze its principles, characteristics, and latest research progress in depth.

MEMS technology is an emerging technology integrating mechanical, electronic, optical, chemical, and other disciplines. It integrates miniaturized devices such as microsensors, microactuators, and signal processing circuits on silicon substrates through mi-

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crofabrication technology to form a miniature system with specific functions. Due to its advantages of lightweight, low cost, and small size [3], it has been widely used in inertial sensing systems.

Although MEMS technology has been widely used, some key mechanisms are still unclear, and the research and development of MEMS technology still faces the problem of imperfect technical routes. In the field of MEMS, performance indicators are an important basis for measuring the performance of sensors. However, the current review articles often have the problems of unclear indicators and a lack of unified standards when describing performance indicators.

In this paper, an in-depth study on the cutting-edge application of MEMS technology in inertial sensing systems is conducted. First, Provide an overview of the basic principles and characteristics of MEMS inertial sensors, including how they work, performance indicators, and applications. Explore the cutting-edge applications of MEMS technology in inertial sensing systems, including high-precision navigation and positioning. Finally, summarize the problems and challenges existing in the current research, and propose corresponding solutions and development directions.

2. MEMS Technology Overview

2.1 Basic Principle of MEMS Technology

MEMS is a technology that integrates miniature sensors, actuators, signal processing and control circuits, interface circuits, communications, and power supplies into a chip using semiconductor microfabrication technology and ultra-precision machining technology. It is a combination of microelectronics and mechanical technology, which realizes the miniaturization and integration of mechanical systems. It covers almost all fields of natural and engineering sciences and is a multidisciplinary and cutting-edge research field. It involves a variety of disciplines such as electronics, machinery, materials, manufacturing, information and automatic control, physics, chemistry, and biology, and is a typical multidisciplinary cutting-edge research.

2.2 MEMS Technical Characteristics and Classification

MEMS technical features: 1). Miniaturization; 2). Microelectronics integration; 3). High-precision mass manufacturing.

MEMS technical classification: 1). microsensors; 2). Microactuators; 3). Micro-optical devices; 4). RF-MEMS (Radio Frequency Microelectromechanical System) class; 5). Biological MEMS.

MEMS Inertia sensor classification: MEMS gyroscope, MEMS accelerometer, MEMS magnetometer, and MEMS-IMU.

3. MEMS Technology Applications in Inertial Sensing Systems

3.1 Accelerometer Based on MEMS Technology

MEMS accelerometers were one of the first sensors to begin research in the field of MEMS. Accelerometers are sensors that sense axial acceleration and convert it into a signal that can output. It is a miniature accelerometer made using micro-nano technology that measures the acceleration of an object in three directions and converts it into an electrical signal output. The working principle of MEMS accelerometers is based on two main effects: piezoelectric effect and capacitive effect. By measuring the change in capacitance, it is possible to infer the acceleration experienced by the object.

3.2 Gyroscope Accelerometer Based on MEMS Technology

MEMS Gyroscopes are sensors that can sense the angular velocity of a moving body relative to inertial space. This gyroscope uses micromachining technology to create tiny mechanical structures on silicon wafers that perform their functions by sensing and measuring changes in angular velocity. The working principle of MEMS gyroscopes is mainly based on the Coriolis Force effect. In MEMS gyroscopes, they typically contain one or more tiny vibrating elements that are driven to vibrate at a certain frequency and amplitude. When the system in which the gyroscope resides rotates, the vibrating element is subjected to the Coriolis force, producing a lateral displacement or vibration proportional to the angular velocity of rotation.

3.3 Application of Inertial System Based on MEMS Inertial Sensors

MEMS Inertial sensors are widely used in inertial systems, and they are mainly used to sense and measure the motion state of objects, including acceleration, angular velocity, attitude angle, and other data. It has a wide range of application prospects and important technical value in the fields of spacecraft navigation, automobile crash testing, ship navigation, and so on.

3.3.1 MEMS inertial sensor-based spacecraft navigation application

MEMS inertial navigation technology has been a research hotspot in the field of inertial navigation in recent years, and its application in spacecraft navigation is very extensive and important, which is

MEMS inertial navigation technology has been a research hotspot in the field of inertial navigation in recent years, and its application in spacecraft navigation is very extensive and important, which is mainly reflected in the following aspects: The gyroscope is one of the core elements of the inertial navigation system, which is used to measure the angular rate of rotation of the spacecraft around each axis and form the navigation coordinate system. For example, satellite attitude control: after the satellite is launched into orbit, the gyroscope is used to monitor the attitude change of the satellite in real time, and adjust the attitude of the satellite through the attitude control system to ensure that the satellite can stably point to the intended target. Xi'an Institute of Automatic Flight Control of Aviation Industry Corporation of China has proposed a dual-quality tuning fork MEMS gyroscope [4], and Nanjing University of Science and Technology has proposed a MEMS gyroscope with low vibration sensitivity and wide dynamic range [5], which can meet most of the application requirements. 2. The research on MEMS accelerometers in China began at the end of the 80s of the 20th century, and the representative research and development units include: Tsinghua University, Nanjing University of Science and Technology, Northwestern Polytechnical University, Southeast University, 33 Aerospace Institute, 13 Aerospace Institute, Aerospace Long March Rocket Technology Co., Ltd., etc. [6] Accelerometers are used to measure the magnitude and direction of acceleration of a spacecraft. For example, orbit determination: Combined with gyroscope measurements, the accelerometer is able to calculate the velocity and position changes of the spacecraft to determine its orbital parameters. This is essential for tasks such as orbit maintenance, maneuvering, orbit change, and rendezvous and docking with other spacecraft.

3.3.2 Automotive crash test applications based on MEMS inertial sensors

MEMS Sensors are the mainstream sensors used in automotive electronics [7], and they are widely used in automotive electronics, including anti-lock braking systems, body stability programs, electronically controlled suspension, electric handbrakes, engine anti-stops, and vehicle inclination measurement [8].

Its application in automobile crash testing is mainly reflected in its ability to record and analyze various data in the collision process in real time as a key sensing element, providing an important basis for the improvement of vehicle safety performance. They are able to record all the key data during a collision in a very short time, including signals such as the amount of body deformation, the degree of impact on the human body, voltage, and switching quantity.

3.3.3 MEMS inertial sensor-based ship navigation applications

It has been a hundred years since the world's first gyroscope was first used in navigation in March 1908 [9]. The complex and ever-changing marine environment, such as bad weather, obstacles in the ocean, meteorological conditions, etc., all bring challenges to ship navigation. Therefore, ship navigation systems need to have high reliability, high precision, and strong anti-interference capabilities. MEMS inertial sensors provide accurate attitude information in ship navigation, assist GPS navigation, and adapt to complex environments.

3.3.4 Application of MEMS inertial sensor in seismic monitoring

MEMS Inertial sensors have attracted extensive attention in the field of international earthquake early warning because of their low cost and small size [10]. Earthquake early warning system: MEMS inertial sensors can be used to build an earthquake early warning system. Seismic Data Recording and Analysis: MEMS inertial sensors can also be used to record seismic data. Local Monitoring and Supplementing Traditional Networks: MEMS inertial sensors are small and affordable, making them easy to deploy locally or as a supplement to traditional monitoring networks.

3.4 MEMS Navigation Research Challenges and Future Prospects

3.4.1 Challenges Faced in MEMS Navigation

The main challenges of MEMS navigation development: accuracy and stability, environmental adaptability; Reducing power consumption on the premise of ensuring transmission performance; Data processing and fusion (the data generated by MEMS sensors needs to undergo complex processing before they can be used for navigation and positioning, and efficient data processing algorithms and fusion technologies are the key); cost control; Cost control remains an important issue in mass production and application.

3.4.2 Future prospects of MEMS navigation

In the future, there are four main directions for the development of MEMS navigation: high precision to meet the needs of increasingly refined and intelligent applications; Miniaturization to achieve portability, distribution, and application requirements; High level of integration to complete the high-density combination of multiple functions; Strong adaptability to adapt to complex application environments and broaden the scope of application [11].

While facing many challenges, MEMS navigation re-

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search also shows broad development prospects. Through technological innovation, integration, intelligence, and the development of integrated navigation technology, MEMS inertial navigation technology will be applied in more fields and bring more convenience and safety to people's lives.

4. Conclusion

In this paper, the application of MEMS technology in inertial sensing systems is discussed in depth by combining comprehensive analysis and case studies. Firstly, through a literature review, the working principle, technical characteristics, and current status of MEMS inertial sensors in various application fields are comprehensively sorted out. Subsequently, combined with specific cases, such as spacecraft navigation and automobile crash testing, the application prospects and technical advantages of MEMS inertial sensors in these fields are analyzed. The research results of this paper are mainly reflected in the following aspects: Significant technical advantages: MEMS inertial sensors show strong application potential in inertial sensing systems due to their technical advantages of high precision, high stability, low power consumption, and easy integration. Broad application prospects: MEMS inertial sensors have shown a wide range of application prospects in many fields such as navigation and positioning, unmanned driving, to deep space exploration, and have promoted the rapid development of related industries. Driven by technological progress: The cutting-edge application of MEMS technology in inertial sensing systems not only improves the performance of sensors but also promotes the rapid development of related technologies, providing the possibility for a wider range of applications. Significant economic value: Through technological innovation and application expansion, MEMS inertial sensors have played an important role in promoting economic growth and enhancing industrial competitiveness. This study deeply analyzes the application status, technical advantages, and future trends of MEMS technology in inertial sensing systems, which is of great significance for understanding the development direction of MEMS technology and promoting the innovation and application of related technologies. For example, the details of some cutting-edge technologies and the latest research results may not be comprehensive; Due to time and resource constraints, this study did not allow for a detailed case study of all application areas; In addition, the challenges and solutions of MEMS inertial sensors in future applications need to be further discussed. Future research will continue to focus on the following aspects: first, to further improve the accuracy and miniaturization level of MEMS inertial sensors to meet the needs of increasingly refined and intelligent applications; The second is to explore new materials and process technologies to reduce production costs and improve the reliability and durability of sensors; the third is to strengthen interdisciplinary cooperation and promote the integration and innovation of MEMS technology and other advanced technologies; Fourth, expand the application field, especially in emerging fields such as the Internet of Things, wearable devices, etc.; Finally, future research pay attention to and deal with the new challenges and problems that may be encountered in the application of MEMS technology, and put forward effective solutions and strategies.

References

[1] Bian Yumin, Hu Yingjie,Li Bo, Xu Shujing, Yang Yongjun. Current situation and development trend of MEMS inertial sensors. Sensors & Applications Special, 2019, 39(4):50-56.

[2] Wang Siyuan, Han Songlai, Ren Xingyu.Luo Shilin. MEMS inertial navigation technology and its application and prospect. Control and information technology, 2018, (6):21-49.

[3] Xiaoyang Li, Weikui Wang, Shouli Wang, Yongqing Peng, Xiaofeng Jin. Research Status and Development Trend of MEMS Inertial Sensors.Journal of Telemetry, Tracking and Command, 2019, 40(6):1-21.

[4] Wang Yuchao, Wang Yong, Meng Bing, et al. Research progress of high-precision tuning fork type silicon microgyroscope.Chinese Society of Aeronautics and Astronautics.Proceedings of the 2019 (4th) China Conference on Aeronautical Science and Technology. Chinese Society of Aeronautics and Astronautics: Chinese Society of Aeronautics and Astronautics, 2019: 7.

[5] Shi Qin, Zhao Yang, Xia Guoming, et al.A wide range dynamic range MEMS gyro with low vibration sensitivity(English).Journal of Chiense Inertial Technology, 2019, 27(1):89-94.

[6] Wang Jiangtao.Research and design of a capacitive MEMS accelerometer interface circuit chip. Xi'an: Xidian University, 2018.

[7] Liu Xuejun, Ma Shihui. Talking about the application of MEMS sensors in automotive electronics. Automobile Applied Technology, 2019, (2): 112-113.

[8] Cai Huanhuan. Application of MEMS sensor in automotive electronics. Electronic components and materials, 2014, 33(05): 97-98.

[9] Zhang Yanhua, Wang Liduan, Zhan Xingqun, Zhai Chuanrun: New Progress and Development Trend of Inertial Navigation Technology. Shipbuilding of China. 2008, 49(183): 134-143.

[10] Liang Ruobing, Li Mei, Liu Zhongfu. A review of the application of MEMS accelerometers in seismic monitoring. Shanxi Electronic Technology. 2023(3): 105-107.

[11] Yin Yi, A Review of the Development of Intelligent Sensor Technology. Microelectronics, 2018, 48(4): 504-519.