

Invited commentary

Academician Zheng You: Why It's Important to Focus on Developing High-End Sensor Technology

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Introduction

From the vast starry sky to the boundless ocean and the expansive land, sensors, as the primary source of information acquisition, are the bridge connecting the physical and digital worlds. They have become one of the most essential pillars of the information-driven society. The main function of sensors is to convert various physical, chemical, or biological quantities into detectable and digitized electrical signals, making them our primary tools for perceiving the world. Sensors play a crucial and indispensable role in modern society, including scientific research, industrial production, national security, and healthcare.

Today, sensors have evolved from early discrete devices composed of sensitive components and processing circuits into integrated intelligent sensor microsystems. These advanced sensors integrate information acquisition, processing, communication, and power supply functions, with prominent digitalization, miniaturization, and intelligence features. However, precisely because of these high-end sensors' advanced and cutting-edge nature, they have become core "chokepoint" technologies we are currently facing.

High-End Sensors: A Crucial "Chokepoint" Technology

Why are high-end sensors considered a critical "chokepoint" technology? What benefits do they bring, and how far is China from becoming a global leader in this field?

High-end sensors are notable for several characteristics. Firstly, they involve new principles,

materials, and devices closely tied to breakthroughs in fundamental sciences and foundational technologies. These sensors are directly integrated into equipment or serve end-users, making them highly relevant across numerous industries and sectors. For example, many advanced integrated circuit (IC) equipment sensors are considered key core technologies. Secondly, high-end sensors bring together cutting-edge advancements from various disciplines such as physics, chemistry, electronics, mechanics, and design. This interdisciplinary fusion is a defining characteristic of sensor technology and requires significant investment. The manufacturing of sensitive structures in high-end sensors often relies on micro-electromechanical systems (MEMS) technology, underscoring their capital and technology-intensive nature. Thirdly, the broad application of sensors adds to the complexity of this field. The technological range is vast, with products and solutions spread across industries. For instance, pressure sensors alone have thousands of solutions, each tailored to specific needs in water management, transportation, industrial automation, aerospace, and many other fields.

In the industrial landscape, sensors are seen as fundamental components, as the interface between the physical and digital worlds and the primary source of information acquisition. Their importance is twofold: they act as the "cornerstone of industry," essential for the survival and advancement of modern industries; at the same time, they are also key functionalities determining the performance and quality of major equipment and systems. However, due to the foundational and critical nature of sensors, they have created bottleneck issues and dependency. China's heavy reliance on foreign technology or products severely impacts domestic industries and even threatens national security and

strategic interests. High-end sensors, vital to key sectors, economic development, and national defence, have become a "chokepoint" technology that China must urgently overcome due to the major technical bottlenecks and reliance on imports.

What Can High-End Sensors Offer Us?

In cutting-edge technological innovation, sensors act as the "pioneers." Throughout the history of technological development, the emergence of global scientific centres has often been driven by breakthroughs in core sensor technologies and the important scientific instruments based on these advancements. Statistics show that 72% of Nobel Prizes in Physics, 81% in Chemistry, and 95% in Physiology or Medicine have been awarded thanks to advanced sensors and instruments. Additionally, 38 Nobel Prizes have been awarded directly to over 60 individuals for inventing scientific instruments based on new principles. Scientific instruments play a crucial role in detecting and characterizing phenomena and obtaining scientific data, with high-end sensors being the key to this process. For example, they are integral parts of instruments like X-ray diffractometers, CT scanners, super-resolution fluorescence microscopes, and electron microscopes, where they function as photodetectors, electron detectors, and temperature sensors. Similarly, displacement and force sensors are essential in mass spectrometers and scanning tunnelling microscopes. In modern scientific instruments, high-end sensors are decisive, directly reflecting the analysis, detection, and characterization level.

In the main arena of the national economy, sensors serve as "multipliers." The application fields of sensors are extensive, permeating almost every aspect of social production and daily life. For example, traditional mobile phones, which originally had only communication functions, have been transformed into smart devices with the integration of numerous sensors: image sensors, gyroscopes, accelerometers, proximity sensors, ambient light sensors, magnetometers, capacitive sensors, temperature sensors, humidity sensors, barometric sensors, and more. These sensors have transformed traditional phones into smart devices, significantly enhancing their functionality and performance, especially in terms of interaction with users. As a result, the development of the mobile phone industry has not only "multiplied" but has also entered a whole new era.

Moreover, the sensor industry boasts a market scale that should not be underestimated. According to data from the German company Statista, the global sensor market size was valued at \$251.29 billion (approximately 1.79 trillion RMB) in 2022. China's sensor market accounted for 309.69 billion RMB, with an average

compound annual growth rate of 12.26% from 2019 to 2022. Although the growth rate of China's sensor market is relatively stable, global leaders like Emerson, Siemens, Bosch, STMicroelectronics, and Honeywell occupy about 60% of the Chinese sensor market share. Approximately 80% of sensors in China are imported, particularly in the high-end sensor market. It is important to note that aside from the trillion-level market of sensors alone, studies indicate that the upstream and downstream industries driven by sensors generate a value approximately six times higher than that of the sensor industry itself.

Sensors: The "Decisive Factor" in National Strategic Projects

The performance and quality of sensors directly determine the performance and quality of major equipment and strategic products. For example, high-speed rail relies heavily on sensors, now a symbol of China's technological prowess. High-end sensors play a critical role in six key areas of high-speed rail: train monitoring and maintenance, track health monitoring, train safety protection, passenger information interaction, energy management, and comprehensive environmental monitoring. Take the Harmony CRH380AL high-speed train as an example: each train is equipped with over 1,000 sensors, averaging one sensor for every 40 components. These sensors are responsible for status monitoring, fault alarms, and onboard equipment control and are regarded as essential technologies for ensuring operational safety and driving the continuous upgrade of rail transport. Looking ahead, sensors will increasingly integrate with emerging technologies like artificial intelligence, making China's high-speed rail even smarter and safer.

In healthcare, sensors are like the "diamond drill bits", cutting through the most complex problems with ease and precision. Modern medical care relies heavily on various diagnostic tools, which, through different sensors, gather critical patient-related data for doctors. Examples include sensors for measuring physiological parameters like vessel diameter, blood flow, blood pressure, intracardiac pressure, body temperature, displacement, velocity, vibration (acceleration), force, flow, pressure, and temperature sensors. Chemical sensors measure ion concentrations (K^+ , Na^+ , and Ca^{2+}) and blood gases (such as O_2 and CO_2). Biosensors such as enzyme, microbial, immunological, tissue, and DNA sensors detect biochemical substances through selective recognition. Bioelectric sensors like electrocardiogram (EKG), electroencephalogram (EEG), and electromyogram (EMG) sensors monitor physiological conditions by measuring weak electrical signals from cells or tissues, playing a critical role in diagnosing heart diseases and assessing muscle function. In healthcare, sensors are

indispensable technologies for disease prevention, diagnosis, and treatment.

In national defence, sensors are the "combat capability". In many ways, Modern warfare is a battle of sensors. During the recent Ukraine crisis, statistics revealed that 80% of the destructive effects were caused by precision-guided munitions, such as missiles and guided bombs, which made up only 20% of the total ammunition used. These precise guidance systems, relying on technologies like inertial, radio, laser, electro-optical, infrared, and satellite sensors, were driven by critical high-end sensors such as inertial measurement units (IMUs), laser sensors, infrared sensors, millimetre-wave sensors, electro-optical sensors, and radar. Additionally, advanced weapon systems like stealth fighters, aircraft carrier fleets, and satellite constellations require sensor networks to provide data for situational awareness, target engagement, and coordinated operations. Unmanned systems equipped with high-end sensors have already made their mark on modern battlefields, and in the future, drones, unmanned vehicles, and robotic systems will become even more common. These "machine warriors" rely entirely on high-end sensors for their surveillance and communication abilities. As sensor technology continues to advance, new-concept weaponry will also emerge, further cementing the crucial role of sensors in national defence.

How Far Is China from Becoming a Sensor Powerhouse?

Sensors play a crucial role and have a vast market. Therefore, China must prioritize the development of high-end sensors. However, the current state of China's high-end sensor industry is far from promising. Many MEMS used in mid-to-high-end sensors are still heavily reliant on imports, creating a significant "chokepoint". Apart from this dependency, China's high-end sensor industry also lacks in areas such as innovation ecosystem, design

tools, research and development (R&D) platforms, advanced materials and core components, high-end chips and manufacturing equipment, as well as in system integration and application conversion.

China needs to sustain efforts in several areas to establish itself as a global leader in sensor technology. First, there needs to be a strong connection between talent development and industrial growth, known as "industry-education integration". As mentioned, sensors are a multidisciplinary, technology-intensive field closely tied to practical applications. The importance of high-level talent and technological innovation cannot be overstated. Integrating talent cultivation with original technological development must become a priority to build a robust sensor industry. Second, collaborative innovation must be strengthened. The sensor industry is capital-intensive, with broad product applications but the market is fragmented. Therefore, it is essential for various stakeholders—governments, businesses, universities, research institutions, users, and financial institutions—to plan strategically, innovate collaboratively, and align resources. Building public R&D platforms and developing shared technologies will enhance the overall efficiency of the industry, promoting sustainable and rapid growth. Third, it is essential to intensify demonstration applications. This can be achieved by focusing innovation efforts on major national projects, urgently needed strategic equipment, and representative socioeconomic demands. By leveraging the advantages of the new nationwide system and empowering industries with sensors, new productive forces will emerge, driving industrial clustering and fostering the formation of a complete sensor industry ecosystem.

Conflicts of Interest:

The authoauthor declare no competing interests.

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