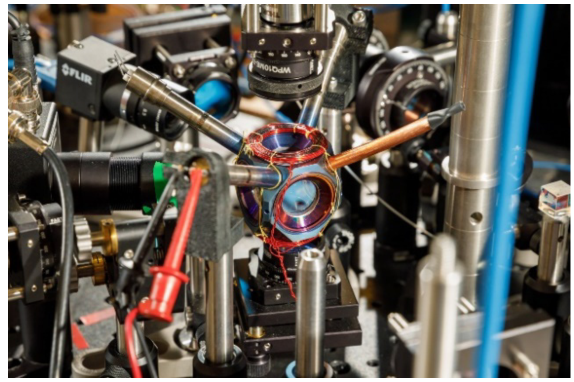
Science, Technology Assessment, and Analytics

SCIENCE & TECH SPOTLIGHT:

QUANTUM SENSORS

GAO-25-107876, January 2025



WHY THIS MATTERS

Precise measurements can support major improvements in medicine, defense, and research. Quantum sensors have the potential to make a wide variety of measurements with unprecedented precision.

KEY TAKEAWAYS

» Quantum sensors are the most mature form of quantum technology, but some sensors require further improvements in reliability and cost-effectiveness.

» The field faces several challenges, including technology transfer obstacles, a small workforce, and a low supply of key components.

» Policymakers could consider how to support the technology and address concerns, such as adversaries potentially using the sensors to detect stealth technology.

THE TECHNOLOGY

What is it? Quantum sensors make exceedingly precise and versatile measurements. They can measure time, temperature, distance, gravity, electromagnetic fields, and more. They have numerous applications in government, industry, health care, and science. For example, quantum sensors could expand navigation without GPS.

How does it work? Like other forms of quantum technology, quantum sensors rely on the properties of quantum physics. One such property is a connection between two or more particles called "entanglement," in which characteristics are linked between particles, and measuring one particle reveals information about the others. Another property is "superposition," which allows a particle, while unobserved, to be in all possible observable states simultaneously. This enables measurements that cannot be obtained using classical physics.

How mature is it? Quantum sensors are the most developed type of quantum technology. Since the mid-20th century, commercialized quantum sensors include magnetic resonance imaging (MRI) and atomic clocks, which are used in GPS.

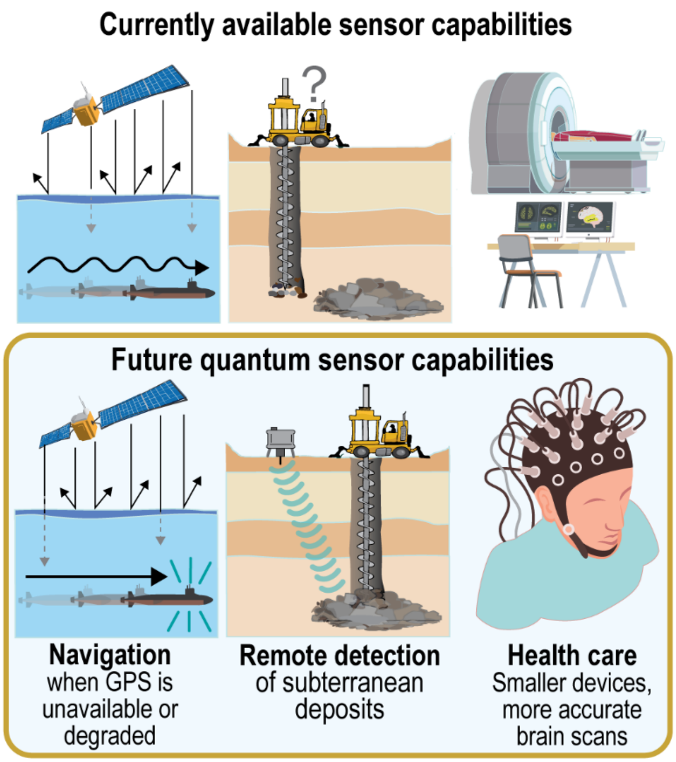
Further breakthroughs could have wide-ranging implications as soon as the next decade. For example, atomic interferometers, which can measure gravity, could be used to map mineral deposits and volcanic activity. Other sensors could be used to detect dark matter, a component of the cosmos that remains unidentified, or to monitor the behavior of quantum computers.

Federal agencies are investing in quantum sensor research. For example, the Department of Energy and the National Science Foundation are supporting research to enhance monitoring of critical infrastructure and look at the inner functions of living cells, respectively. The National Quantum Initiative Act, enacted in 2018, requires the federal government to accelerate development and implementation of quantum technology, including quantum sensors.

OPPORTUNITIES

- **Defense and navigation.** Quantum sensors improve measurements of time and position, enabling navigation when GPS is unavailable or degraded and helping vehicles navigate adverse weather and terrain. In national security, they could help the military overcome jamming and detect stealth technology.
- **Remote Detection.** Quantum sensors could improve the accuracy and scope of measurements that can be collected in research and field settings. For example, sensors could be placed on or above the ground to detect subterranean mineral deposits, oil, or groundwater before drilling, which could reduce costs and environmental impacts of extracting these resources.
- **Health care.** Further advances in quantum sensors could lead to more precise measurements of the human body, such as new ways of imaging brain activity or determining

protein structures. Such advances could help diagnose and monitor diseases such as Alzheimer's.



Source: GAO analysis (data); GAO illustration (submarine); staskrasowski/stock.adobe.com (satellite), theblackrhino/stock.adobe.com (mining), iconicbestiary/stock.adobe.com (MRI), Macrovector/stock.adobe.com (helmet). | GAO-25-107876

Figure 1. Potential Improvements with Quantum Sensors

CHALLENGES

Addressing challenges for quantum sensors would help advance national security and economic competitiveness.

- **Technology transfer.** Efforts to translate research and development of quantum sensors into products are spread across industries. Maturing quantum sensors from prototypes into commercially viable devices could benefit from further coordination between researchers and companies across public, academic, and private sectors.
- **Workforce.** Quantum sensor research and applications will require an interdisciplinary workforce. This will include quantum scientists and engineers with expertise in sectors such as biology, computer science, and defense.
- **Availability of components.** Some quantum sensors need compact lasers or other components whose availability may be limited by manufacturing capability or access to specialized materials. For example, a "quantum grade" diamond can help produce uniquely detailed maps of magnetic fields, but the U.S. lacks a reliable source.

POLICY CONTEXT AND QUESTIONS

- Congress is considering reauthorizing the National Quantum Initiative Act and continuing to support quantum research and applications, including for quantum sensors.
- What actions could help ensure the workforce and manufacturing sector can sufficiently support U.S. competitiveness in quantum sensors?
- What are the implications for national security of applications like anti-stealth technology?

SELECTED GAO WORK

Quantum Computing and Communications: Status and Prospects, GAO-22-104422.

Science & Tech Spotlight: Quantum Technologies, GAO-20-527SP.

SELECTED REFERENCES

National Science & Technology Council. *Bringing Quantum Sensors to Fruition*. Washington, D.C.: 2022.

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