Seafloor Nodules Collection Assisted by Microwave/RF Technologies

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Abstract— **This essay examines the role of microwave technology in collecting nodules from the deep sea, which contain essential material for electric vehicle batteries. The collection of these nodules has the potential to reduce land mining and the associated environmental impact significantly. The essay discusses the importance of environmentally friendly practices in preparation for the emergence of more electric vehicles. It also explores the technology behind the microwave-assisted extraction of nodules and its advantages over traditional methods. The essay concludes by highlighting the potential of deep-sea nodules as a sustainable source of critical minerals for the electric vehicle industry.**

Keywords— **RF, Microwaves, mmWave.**

I. Introduction

A. Background

Humanity faces a significant environmental challenge from global warming caused by greenhouse gas emissions.[1] Burning fossil fuels, such as coal, oil, and gas, is a primary source of these emissions. Conventional vehicles, for example, burn oil, contributing to the problem. To combat this issue, it is crucial to reduce the use of fossil fuels and transition to renewable energy sources like wind and solar power. This transition is essential to achieve net-zero emissions by mid-century, where carbon capture and storage or reforestation offset any remaining emissions. By completing this goal, we can effectively limit global warming and create a sustainable future for all.

As mentioned before, conventional vehicles burning oil is one of the primary sources of greenhouse gases; replacing them with electric vehicles is an unstoppable historical trend. Electric vehicles are powered by electricity stored in batteries and produce zero direct emissions, significantly reducing greenhouse gas emissions and improving air quality. However, there are still many challenges with transitioning from conventional fuel vehicles to electric vehicles.

B. Shortage in Battery of Electric Vehicle

Transition to Electric Vehicles is necessary, but the biggest problem is that there need to be more batteries to support enough electric vehicles. Electric vehicle batteries use lithium-ion technology, which relies on critical raw materials such as lithium, cobalt, and nickel. These materials are essential in producing high-performance batteries that can store enough energy to power a vehicle for extended periods.

Unfortunately, there currently needs to be more critical raw materials. Lithium, for example, is predominantly found in a few countries, such as Chile and Australia. As demand for lithium-ion batteries increases, securing reliable lithium supplies is increasingly challenging. In addition, cobalt and nickel are also in high demand, with the majority of global production coming from a few countries, such as the Democratic Republic of Congo and Russia.

Although there might have sufficient minerals or raw materials on land, significant land-based mining raises many environmental and humanitarian issues. For instance, clearing forests for land-mining activities has led to a loss of biodiversity and habitats for wildlife. The excavation of land for mineral extraction has also caused soil erosion, which has reduced soil fertility, making it difficult for farmers to cultivate crops. Additionally, land-mining activities have resulted in water pollution, which has affected aquatic life and made the water unsafe for human consumption. Moreover, take Congo as an example; the extraction of minerals in Congo is often associated with human rights abuses, including child labor, forced labor, and hazardous working conditions. Children are often used in land-mining activities, exposed to dangerous working conditions, and denied access to education. Land-mining activities have also displaced communities, who are often forced to relocate to make way for mining activities.

To avoid massive land-mining activities, easily collected raw material sources, the seafloor nodules, attract people's attention.

C. Seafloor Nodules

The ocean floor is a vast and largely unexplored region home to various mineral resources. One such resource that has attracted attention recently is seafloor nodules, small, potato-shaped rocks with high concentrations of minerals such as manganese, cobalt, and nickel. These minerals are essential in producing electric vehicle batteries, making seafloor nodules a potentially valuable source of raw materials for the growing electric vehicle industry.

Seafloor nodules are a valuable source of these minerals because they are often found in high concentrations. For example, The main constituents of interest in addition to manganese (28%) are nickel (1.3%), copper (1.1%), cobalt (0.2%), molybdenum (0.059%), and rare earth metals (0.081%).[3][4] Nodules also contain traces of other commercially relevant elements, including platinum and tellurium, essential constituents of technological products such as photovoltaic cells and catalytic technology.[3][5][6] This

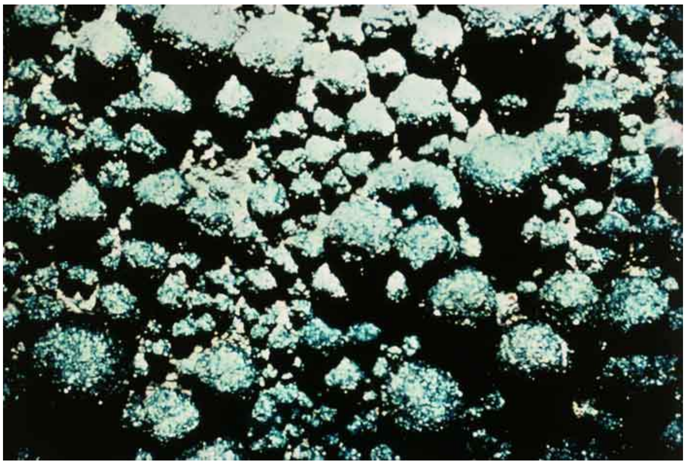

Fig. 1. Manganese nodules on the bed of the Pacific Ocean[2]

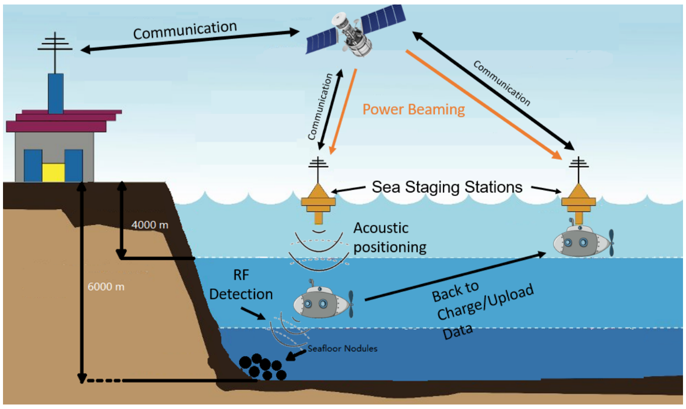

Fig. 2. Proposed communication and supporting system for Seafloor Nodules Collection Robots

means seafloor nodules could provide a more efficient and cost-effective source of these critical battery components.

II. Challenges in Collecting Seafloor Nodules

The collection of seafloor nodules poses significant challenges due to their location at depths ranging from 4,000 to 6,000 meters, much more profound than most current mining operations. The immense pressure and hostile environment at these depths make it difficult for humans and machinery to operate. Communication with the surface is also problematic, complicating the use of remotely operated vehicles and other equipment.

Another challenge is the logistics of collecting seafloor nodules. Because they are located in remote areas of the ocean, far from any landmass, it is expensive and difficult to transport equipment and personnel to the collection sites. This makes seafloor mining a high-cost, high-risk venture that requires significant investment and expertise.

In addition to the technological and economic challenges, there are also significant environmental concerns associated with seafloor mining. Seafloor ecosystems are poorly understood, and there is a risk that mining activities could disrupt these fragile ecosystems. For example, the equipment used in mining could damage or destroy deep-sea corals, sponges, and other organisms that provide critical habitats for many species of marine life.

III. Microwave/RF Technologies in Supporting Seafloor Nodules Collection

To tackle the challenges mentioned in Section II, this section first proposes a communication and supporting system for seafloor nodule collection robots and discusses the detailed composition of the system. Based on the discussion, specific RF/Microwaves technologies are identified for use in this scenario.

A. Communication and Supporting system for Seafloor Nodules Collection Robots

One of the primary challenges of seafloor nodule collection is the vast and remote nature of the ocean. The harsh and unpredictable nature of the ocean environment presents significant risks to human divers and equipment, making it necessary to find alternative collection methods.

Robots solve these challenges, allowing for safe and efficient seafloor nodules exploration and extraction in remote ocean areas. These robots can operate at depths that would be dangerous for human divers and can withstand harsh ocean conditions, ensuring that exploration and extraction can be carried out reliably and safely.

Additionally, using robots for seafloor nodule collection is cost-effective, reducing the time and cost required compared to traditional ship-based dredging methods.

A specific communication and supporting system must be proposed to enable the proper operation of the robots. The proposed whole operating system is shown in Fig. 2.

According to Fig. 2, seafloor nodule collection robots' communication and supporting system consists of four parts: Ground Control Systems, Sea Staging Stations, Satellites, and Robots. Ground Control Systems are the primary communication link between the operators and the Sea Staging Stations. These systems use satellite communications to send signals to the Sea Staging Stations to control their position, send commands to the seafloor nodules collection robots, or receive data from them.

The satellites play a crucial role in this communication and supporting system by providing communication between the Ground Control Systems and the Sea Staging Stations. They also use power beaming to supply power to the Sea Staging Stations, which in turn supply power to the robots when connected to the Sea Staging Stations. This ensures that the robots have a reliable power source and can operate for extended periods without interruption.

The Sea Staging Stations are strategically located on the sea surface and serve as a base station for the robots. They provide a stable and secure platform for the robots to dock and recharge batteries or empty containers. The Sea Staging Stations also serve as relay stations between the robots and the Ground Control Systems. When the robots are connected to the Sea Staging Stations, they transfer data and seafloor nodules collected during their operations. The Sea Staging Stations also use acoustic signals to guide the robots back to the station if they lose their way, as acoustic signals can penetrate through the water column and travel long distances, making them an ideal method for underwater communication for a long range.

However, microwave/RF signals can have advantages over acoustic signals in short-range communication in the deep sea. The first advantage of microwave/RF signals over acoustic signals is they can transmit higher data rates, allowing for high-speed data transfer of large files. The second advantage of microwave/RF signals is their ability to penetrate through certain types of materials. Unlike acoustic signals, microwave/RF signals can penetrate through certain materials, such as plastics and composites. This property makes microwave/RF signals ideal for interacting differently with different materials. Also, according to [7], the attenuation constant is low at depths ranging from 4,000 to 6,000 meters, making microwave/RF applicable in short-range undersea communication.

The robots are the heart of the seafloor nodules collection system. They operate autonomously and are equipped with advanced sensors and navigational systems to locate and collect seafloor nodules. The reason for autonomous robots is that complete control of the robots requires a constant monitor and connection to the system, which usually means the underwater robot will be wired to the surface controller like those Deep-submergence vehicles. The wire-controlled solution is not feasible considering the vast area and how deep those Seafloor Nodules are. Once the containers of the robots are full, or the robots' batteries are almost drained out, they will return to the Sea Staging Stations to charge up or empty their container. Based on the above characteristic, the robots must be brilliant, energy efficient, and multi-functional, requiring multiple Microwave/RF technologies.

The following parts identify and discuss the potential usage of multiple Microwave/RF technologies in the proposed system.

B. Quantum sensor

If robots need to find and collect seafloor nodules on their own accurately, they need a better navigation system to enable this task; that is when the quantum sensor comes into play.

Quantum sensors, shown in Fig. 3, use quantum mechanics to measure magnetic fields, gravity, and acceleration. These sensors are susceptible but also affected by external factors such as temperature and magnetic fields. These factors can cause errors in measurement, making it challenging to use quantum sensors in navigation applications. Microwave technologies can help address these challenges by providing a means of controlling and stabilizing quantum sensors. One approach uses microwave fields to manipulate the spin of the electrons in the quantum sensor, allowing for precise magnetic field measurement. This approach has been used in several navigation applications, including developing magnetic compasses for underwater navigation.

Another way microwave technologies can enable quantum sensors in navigation is by stabilizing the sensors. Microwave fields can control the temperature and magnetic fields around the quantum sensor, ensuring that the sensor remains stable and accurate even in challenging environments. This approach has been used in developing gravity sensors for deep-sea navigation, enabling precise measurement of gravitational forces in the underwater environment.

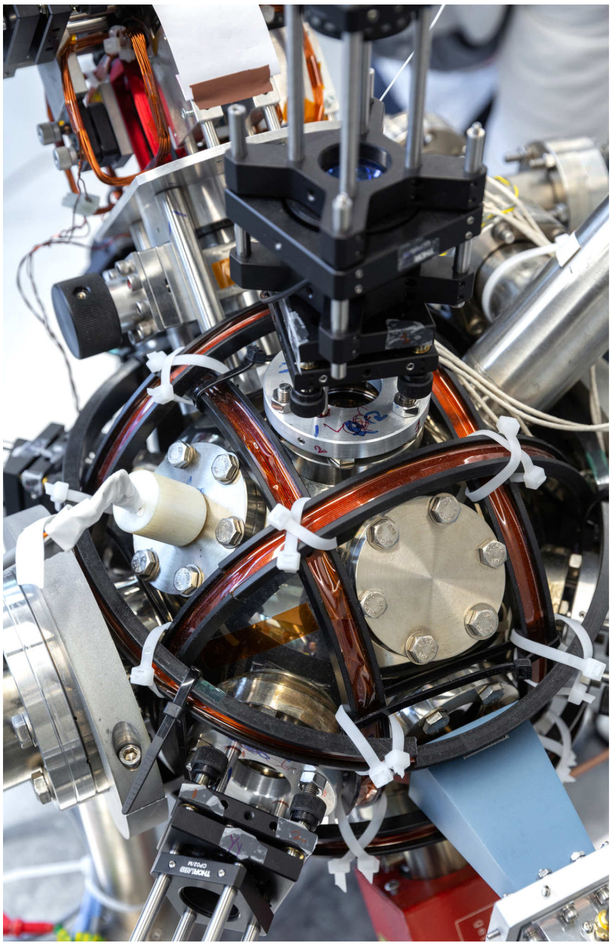

Fig. 3. A quantum sensor from Imperial College London and Glasgow-based M Squared can help ships navigate even when GPS is unavailable[8][9]

C. Power-Beaming System

Power-beaming from space, shown in Fig. 4, is a technology that involves transmitting energy wirelessly from a satellite in space to a receiver on Earth. This technology has the potential to revolutionize the way we power remote control robots on the sea, making it possible to charge these devices without the need for traditional batteries or cables.

Remote control robots are typically powered by batteries, which can limit their range and endurance. Additionally, the harsh and unpredictable nature of the ocean environment can make it challenging to replace or recharge batteries, particularly in remote ocean areas. Power-beaming from space solves these challenges, allowing remote control robots to be charged wirelessly and continuously.

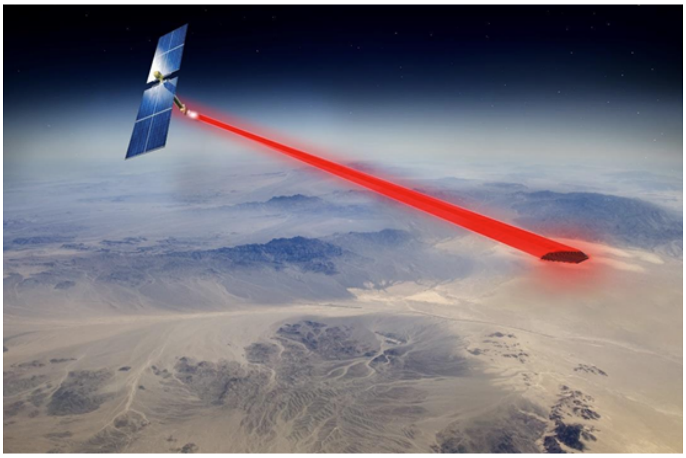

Fig. 4. Power-Beaming from Space[10]

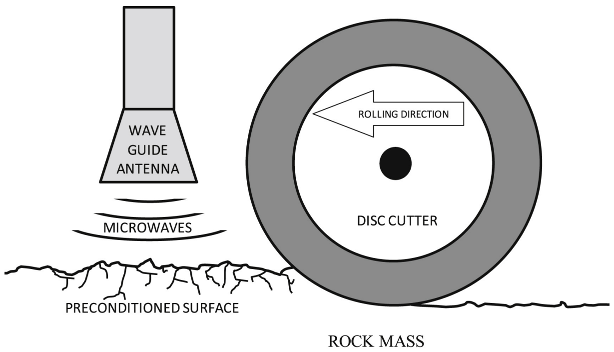

Fig. 5. Schematic of a Microwave-Assisted Disc Cutter Concept of a Continuous Tunnel Boring Machine.[11]

D. *Microwave-assisted Mineral Liberation*

Microwave-assisted Mineral Liberation is a process that involves the use of microwave energy to break down seafloor nodules into smaller particles, as shown in Fig. 5. The process involves heating the nodules using microwave energy, which causes thermal stress and breaks the nodules into smaller particles. These smaller particles are then processed to extract valuable metals.

Traditional mining methods involve using heavy machinery such as excavators, bulldozers, and trucks to extract ore from the ground. The ore is then transported to a processing plant, where it is crushed and processed to extract valuable minerals. The process of traditional mining methods is time-consuming and has significant environmental impacts. The use of heavy machinery can cause soil erosion, deforestation, and pollution. Harmful chemicals such as cyanide and mercury in the processing plant can also adversely affect the environment.

IV. Conclusion

In conclusion, microwave technology has the potential to revolutionize the collection of nodules from the deep sea, offering a sustainable source of critical minerals for electric vehicle batteries. As the demand for electric vehicles continues to grow, it is essential to find environmentally friendly practices that reduce the impact of mining. The advantages of microwave-assisted extraction over traditional methods provide a compelling case for exploring this technology further. However, conducting a thorough environmental impact study is crucial before the deep-sea nodule collection commences. Ensuring the collection process does not adversely affect the marine environment is essential. As the world seeks sustainable alternatives to traditional mining practices, deep-sea nodules could be a significant step towards a greener future.

References

[1] Ipcc, "Global warming of 1.5 °c," 2022.

[2] D. Shukman. (2018) The secret on the ocean floor. [Online]. Available: https://www.bbc.co.uk/news/resources/idt-sh/deep-sea-mining

[3] K. A. Miller, K. F. Thompson, P. A. Johnston, and D. G. Santillo, "An overview of seabed mining including the current state of development, environmental impacts, and knowledge gaps," *Frontiers in Marine Science*, vol. 4, 2018.

[4] J. R. Hein, K. Mizell, A. Koschinsky, and T. A. Conrad, "Deep-ocean mineral deposits as a source of critical metals for high- and green-technology applications: Comparison with land-based resources," *Ore Geology Reviews*, vol. 51, pp. 1–14, 2013. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S016913681200234X

[5] A. A. Ojo and I. M. Dharmadasa, "Analysis of electrodeposited cdte thin films grown using cadmium chloride precursor for applications in solar cells," *Journal of Materials Science: Materials in Electronics*, vol. 28, pp. 14 110–14 120, 2017.

[6] M. Antoni, F. Muench, U. Kunz, J. Brötz, W. Donner, and W. Ensinger, "Electrocatalytic applications of platinum-decorated tio2 nanotubes prepared by a fully wet-chemical synthesis," *Journal of Materials Science*, vol. 52, pp. 7754–7767, 2017.

[7] M. Tahir, P. Yan, and L. Shuo, "Channel characterization of em waves propagation at mhz frequency through seawater," *International Journal of Communication Systems*, vol. 31, 2018.

[8] M. S. Hayley Dunning, Thomas Angus [Photographer]. (2018) Quantum 'compass' could allow navigation without relying on satellites. [Online]. Available: https://www.imperial.ac.uk/news/188973/quantum-compass-could-allow-navigation-without/

[9] C. Q. Choi, P. Fairley, T. S. Perry, and P. Patel, "Sensors: A guide to the quantum-sensor boom: Atomic scale bolsters sensing revolutions in medicine, tech, and engineering," *IEEE Spectrum*, vol. 59, pp. 5–13, 2022.

[10] D. Gao, J. Cai, C. Foh, C.-T. Lau, and K. Ngan, "Improving wlan voip capacity through service differentiation," *Vehicular Technology, IEEE Transactions on*, vol. 57, pp. 465 – 474, 02 2008.

[11] F. Hassani, P. M. Nekoovaght, and N. Gharib, "The influence of microwave irradiation on rocks for microwave-assisted underground excavation," *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 8, no. 1, pp. 1–15, 2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1674775515001341