# Interview with Junku Yuh, Principal Investigator of the SAUVIM Project

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The following is an interview conducted for *IEEE Robotics and Automation Magazine* (*RAM*) with Dr. Junku Yuh, director of the Robotics and Media Institute at the Korea Institute of Science and Technology, Seoul. Dr. Yuh was the principal investigator of the Semi-autonomous Underwater Vehicle for Intervention Missions (SAUVIM) project, which achieved an important milestone in underwater robotics' history: the first demonstration of autonomous underwater floating manipulation.

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***RAM*: What do you consider to be the main founding goals of the SAUVIM project? What are the possible markets and applications where the technology developed within SAUVIM could be exploited?**

**Junku Yuh:** The main goal of the SAUVIM project, funded by the U.S. Office of Naval Research, was to develop a semiautonomous underwater vehicle for intervention missions. Three organizations worked together to achieve this goal: the Autonomous Systems Laboratory of the University of Hawaii, Marine Autonomous System Engineering, Inc., and Naval Undersea Warfare Center, Newport.

The SAUVIM is equipped with autonomous underwater manipulation capability that can support diverse ocean-related activities—aquaculture, commercial fishing, ocean research, seafood marketing, ocean recreation, marine mining, marine biotechnology, and ocean energy. Living and nonliving resources of the ocean are abundant. For example, it is estimated that there are about 2,000 billion tons of manganese nodules at the bottom of the Pacific Ocean. The ocean also plays a critical role in global environmental issues such as pollution and carbon cycles, with the ocean retaining more heat than the atmosphere. Therefore, it is not difficult to predict that the ocean will have a great effect on the future existence of all human beings, and underwater systems like SAUVIM would be a necessity in fully exploring the ocean.

This goal was established because many underwater intervention tasks are today performed using manned submersibles or remotely operated vehicles in teleoperation mode. Autonomous underwater vehicles (AUVs) are mostly employed in survey applications. In fact, the low bandwidth and significant time delay inherent in acoustic subsea communications represent a considerable obstacle for remotely operating a manipulation system, making it impossible for remote controllers to react to problems in a timely manner. Nevertheless, vehicles with no physical link and with no human occupants permit intervention in dangerous areas, such as in deep ocean, under ice, in missions to retrieve hazardous objects, or in classified areas. The key element in underwater intervention performed with autonomous vehicles is autonomous manipulation, which refers to the capability of a robot system that performs intervention tasks requiring physical contacts in unstructured environments without continuous human supervision.

Only a few AUVs are equipped with manipulators. SAUVIM, at its current state of the art, is one of the very first underwater vehicles designed to perform autonomous manipulation tasks.

***RAM*: What are some of the major scientific and technological challenges you encountered in the SAUVIM project—specifically, in relation to floating manipulation?**

**Yuh:** The autonomous manipulation system on SAUVIM, unlike teleoperated manipulation systems controlled by human operators with the aid of visual and other sensory feedback, must be capable of assessing a situation, including self-calibration based on sensory information, and executing or revising a course of manipulating action without continuous human intervention.

Instead of directly operating the manipulator, the SAUVIM user may provide higher-level commands during a particular mission, such as "unplug the connector." In this approach, the function of the operator is to decide, after analysis of the data, which particular task the

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vehicle is ready to execute and successively to send the decision command. The lower-level control commands are provided by a preprogrammed onboard subsystem, and the virtual reality model in the local zone uses only the symbolic information received through the low-bandwidth channel to reproduce the actual behavior of the system.

It is worthwhile to note that the coordinated motion control of the vehicle and its manipulator must be considered for efficient manipulation since the base of the manipulator is the vehicle's main body and floats. Various hydrodynamic effects on the motion are also present, and most underwater manipulators are oil-filled for pressure compensation.

***RAM*:** Have you noticed a technological shift, either in terms of computational power and/or available hardware? How would that change your design approach?

**Yuh:** Yes, we have noticed a technological shift and advancement in various sectors such as computational power, actuators, sensors, and data networks along with new materials. This allows one to now build systems with designs that are much more compact and robust. This is important because underwater vehicle systems require buoyancy materials that perform at a range of depths with low power consumption while providing maximum lift. In general, the heavier the underwater vehicle system, the more buoyancy materials are needed, which, in turn, increases the overall weight.

***RAM*:** In your opinion, what are the main challenges current researchers are addressing? What would you consider as a state-of-the-art autonomous manipulation scenario?

**Yuh:** As mentioned earlier, there are various challenging issues for underwater manipulation due to the harsh environment. Another challenge is working with operating limitations in the field. Most underwater manipulators are remotely operated by human operators. The operators must complete a lengthy training course, and yet the actual operation in the field is very difficult, leading to operator fatigue. Therefore, continued research toward developing fully autonomous mobile manipulation is desirable.

A common scenario for a generic autonomous manipulation intervention in water is a situation where the vehicle is stationary while the arm performs the required task. In this configuration, the vehicle's position and orientation are maintained with the aid of several different sensors, which may have considerable measurement noise as well as different accuracy measurements. For example, a long baseline system (or similar sensors) is often used to measure the position in $x$, $y$, and $z$ (or altitude) in Earth-fixed coordinates, and its output has an accuracy of about 1 m. However, $z$-position can also be measured by a depth sensor that gives a much more accurate output. Orientation in $x$, $y$, and $z$ (vehicle coordinates) are measured by an attitude and heading reference sensor. Since all sensors experience a certain level of random noise in their measurements, the absolute position and orientation measurements of the vehicle, especially in $x$ and $y$, have an insufficient accuracy for a precision manipulation task. However, as long as the error in the measurement of the vehicle position/orientation is confined within the magnitude of the arm workspace, the manipulator can compensate for this inaccuracy using the precise measurement given by the target position sensor.

***RAM*:** Many international research projects are focusing more and more on floating manipulation. When will those results be transferred to the industry?

**Yuh:** We have seen advances in industrial manipulators in terms of hardware, software, and design along with innovative concepts such as cobots, modular design, and cloud robotics. However, offshore industry, where underwater manipulators are used most, is very conservative, accepting only proven technologies or systems with strong track records since even minor errors or failure could result in disastrous situations due to the nature of the industry. This is one of the reasons why one single company manufacturing underwater manipulators is dominating the market. Most commercial underwater manipulators are remotely operated and not equipped with advanced features like visual servoing, which can be found with many industrial manipulators. On the other hand, researchers in the area of underwater robotics have achieved substantial progress in developing advanced underwater vehicles and manipulator systems, and some of them are used for scientific applications. Some exemplary research programs in advanced underwater manipulators include the SAUVIM project in the United States, the TRIDENT project in Europe, and the UCRC project in Korea.

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