

MRV SYSTEMS: MARINE ROBOTIC VEHICLES

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ABSTRACT

MRV Systems, LLC was founded in 2010. MRV's overall goal is to provide inexpensive, high-quality vehicles for measurements of the ocean. Its product line is primarily based on technology developed at the Scripps Institution of Oceanography (SIO), and licensed from the University of California San Diego (UCSD). These products include the SOLO-II profiling float, sold as the MRV S2-A, and the Deep SOLO. Several variants of the S2 have been built to meet customer-specific requirements. MRV has developed a smaller profiling float, in collaboration with the Woods Hole Oceanographic Institution (WHOI), named the Air-Launched Autonomous Micro-Observer, or ALAMO. The ALAMO is "A-size" and has been successfully deployed with temperature-pressure and CTD sensors in hurricane studies and in high-latitudes. MRV also has several new products under development, which aim to enhance endurance, communications, station keeping, anchoring, air-deployment systems, sensor accommodation, and user interaction.

1. BACKGROUND

J. Dufour founded MRV Systems, LLC in 2010, with a license from the University of California San Diego (UCSD) to manufacture the SOLO-II profiling float, developed under the leadership of R. Davis at the Scripps Institution of Oceanography (SIO). MRV's initial customers were SOLO-II users at SIO (D. Roemmich, R. Davis) and the Woods Hole Oceanographic Institution (B. Owens, S. Jayne). Collaborations from both groups were critical to the early success of MRV.

MRV Systems was restructured in April, 2014, when a group led by F. Maas bought a controlling stake in the company. Maas became President and Chief Executive Officer; Dufour served as Chief Technology Officer. N. Bogue became a Senior Advisor to MRV later that year. In early 2015, MRV moved its manufacturing operation from San Diego to The RDI Group in Itasca IL. The RDI Group is a nearly 100-year-old company that makes capital equipment for manufacturing companies in a variety of industries, including asphalt roofing, metal coil processing, and laser blanking systems. MRV benefits from this contract manufacturing arrangement by taking advantage of The RDI Group's robust quality control and assurance systems, manufacturing cost tracking, and ability to quickly scale operations to the size of orders. The RDI Group also brought rigor to MRV's configuration, manufacturing engineering, and project management systems.

In 2016, N. Bogue accepted the MRV board's offer to become President and Chief Executive Officer. F. Maas is Executive Chairman. J. Dufour retains the title of Founder and Chief Technology Officer. A. Massa serves as Director of Engineering, and D. Zupancic as Director of Manufacturing.

The mission of MRV Systems remains to build robotic vehicles that provide inexpensive, high-quality oceanographic measurements from air-deployable packages. Low unit cost is a good way to achieve spatial coverage and reliability through redundancy. Air-deployment provides access to many parts of the ocean that are unavailable to or prohibitively expensive by ship-based methods.

2. PRODUCTS

The MRV product line is primarily based on technology developed at the Scripps Institution of Oceanography (SIO), and licensed from the University of California San Diego (UCSD). The SIO Instrument Development Group (IDG), under the leadership of R. Davis, developed the SOLO-II profiling float as a smaller, more efficient version of their previous floats (Davis et al., 1992, and Davis et al., 2001).

MRV refined the SOLO-II float design in collaboration with its initial customers at SIO (D. Roemmich) and WHOI (B. Owens, S. Jayne). The enhanced SOLO-II is marketed and sold as the MRV S2-A. The S2-A is a 19.2 kg device, with 1.6kg available for payload. It carries a Sea-Bird Electronics SBE-41CP CTD, and uses Iridium Short Burst Data (SBD) for bi-directional communication over an MRV designed and built combined

GPS and Iridium antenna. The S2-A has 650cc of displacement change; $dV/V = 3.4\%$. The S2-A with a full load of Lithium primary batteries is capable of 325 profiles to 2000m. The MRV S2-A is shown in Figure 1.



Figure 1. The MRV S2-A profiling float (L), with SBE-41CP CTD and MRV GPS-Iridium antenna. The MRV ALAMO “A-size” profiling float (R), with RBR temperature-pressure sensors and MRV GPS-Iridium antenna.

A stretched version of the S2-A, called the S2-X, is available with alkaline battery packs. The longer pressure hull was required to carry enough alkaline batteries to achieve over 200 profiles to the S2-X’s rated depth of 1200m. The S2-X is a 28kg device, with 650cc of available displacement change. It is available in ship-deployed or air-deployed configurations. The air-deployment system consists of a protective cardboard box with external harness, 24-foot diameter ring-slot parachute, and a water release mechanism. These floats have been deployed successfully off the stern ramp of C-130s.

The S2-A and S2-X run the SIO-developed and maintained SOLO-II code, with slight modifications as necessary to support the hardware and customer-specific mission operations. They both perform the standard Argo mission, and are adaptable to other mission profiles.

MRV has also developed a smaller profiling float that conforms to the U.S. Navy’s “A-size” sonobuoy specification: 4-7/8” diameter, less than 36” in length, and less than 40lbs in weight. This float is called the Air-Launched Autonomous Micro-Observer, or ALAMO, and is also shown in Figure 1. The idea of an A-size float has been around for many years. This particular design built on previous efforts at SIO, funded by T. Paluszkiwicz at ONR Code 32, but has unique hydraulic systems and control hardware and software. The basic ALAMO is a 8.4kg device, with 1.2kg of available payload. The ALAMO has 400cc of displacement change available, for a dV/V of 3.7%. Its depth rating is 1200m. The ALAMO also uses Iridium Short Burst Data (SBD) for bi-directional communication over an MRV designed and built combined GPS and Iridium antenna. The antenna can be ice-strengthened, and protected with a Delrin hoop above the antenna element.

The ALAMO design and software work at MRV was done in partnership with B. Owens and S. Jayne at WHOI, who supported the work as part of their hurricane studies program. The original ALAMOs were designed to measure temperature and pressure in the upper 300m of the ocean as rapidly as possible. They were to be deployed from C-130 “Hurricane Hunter” aircraft in the path of hurricanes, to measure the heat content of the upper ocean. ALAMOs with RBR T-P sensors have been successfully deployed in front of hurricanes in the Atlantic Ocean, Pacific Ocean, and the Caribbean Sea since the hurricane season of 2014. More detailed information on ALAMO and its deployments can be found in S. Jayne’s APLS-II white paper.

The ALAMO has also been adapted to carry the RBR inductive CTD, the SBE-41CP, the Rockland Scientific turbulence velocity shear probes, and a Li-Cor PAR sensor.

The internals of the ALAMO float (hydraulics, controller, etc.) have been adapted for the S2-A pressure hull. The result is the MRV S2-H (Hybrid). This float is identical to the S2-A on the outside, but because of the smaller ALAMO internals, has room for more batteries or payload. The first S2-H was deployed by WHOI on 18AUG2016 south of Bermuda, and to 11FEB2017 has done 41 profiles, as shown in Figure 2. The S2-H has the potential to carry enough additional batteries to significantly extend the endurance of the standard Argo float. Preliminary calculations indicate that endurance on typical Argo missions should be about 14 years.

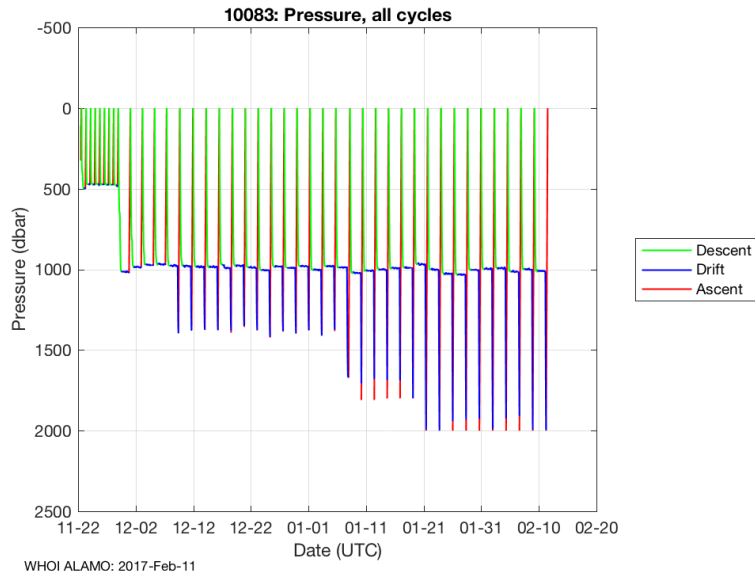


Figure 2: Cycles of MRV S2-H Hybrid float south of Bermuda, from WHOI website argo.who.edu/alamo, courtesy of P. Robbins, WHOI.

Figure 3 shows the Temperature-Salinity plot for the 41 S2-H profiles to date, from the SBE-41CP. MRV currently has over 30 S2-H on order. We anticipate that the additional endurance and payload will make the S2-H an attractive option for scientific users.

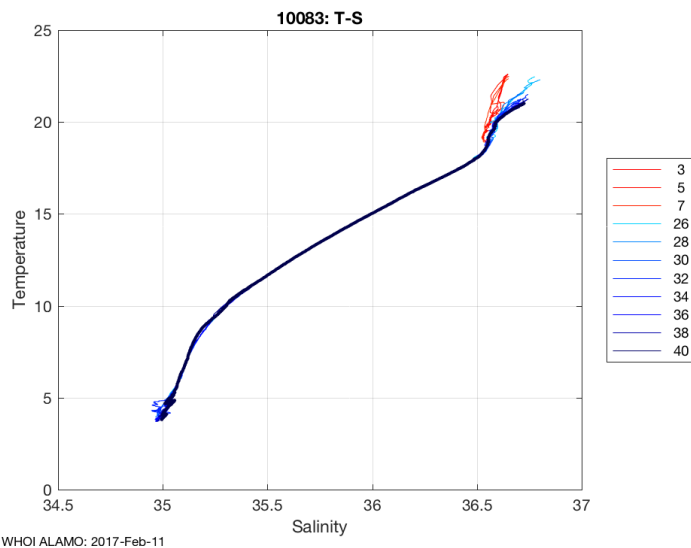


Figure 3: Temperature-Salinity plot from MRV S2-H (Hybrid) float south of Bermuda, from website argo.who.edu/Alamo, courtesy of P. Robbins, WHOI.

The final product in the current MRV line is the Deep SOLO, developed by the SIO IDG, and licensed by MRV from UCSD. The Deep SOLO float is designed, and has been demonstrated, to profile from 6000m depths to near the ocean surface, with an SBE-61 CTD. The Deep SOLO is constructed in a 13" glass sphere, and carries the SBE-61 CTD mounted horizontally, as shown in Figure 4.



Figure 4. Deep SOLO in IDG lab at SIO.

MRV has personnel trained at SIO in the production of the Deep SOLO, and is in the final phases of negotiation with the launch customer. We anticipate establishing full production of the Deep SOLO during 2017.

3. APPLICATIONS

The Argo program (Roemmich, et al., 2009) continues to be the core business of MRV. The MRV S2-A has provided about half of the U. S. Argo program's recent annual contribution to the International Argo program array, including fully assembled units and parts kits. The U. S. Naval Oceanographic Office (NAVOCEANO) is the major customer for the S2-X. NAVOCEANO uses the float in diverse locations and in interesting ways, rarely sticking to the standard Argo mission profile.

S. Jayne and his colleagues at WHOI have used the ALAMO float extensively in their hurricane studies programs, and have purchased CTD-equipped ALAMO floats for the NASCar and SODA programs. CAPT E. Sanabia, USN of the U. S. Naval Academy also uses ALAMO floats in her research.

ALAMO deployments have been made by air in marginal ice zones of the Beaufort and Chukchi Seas (K. Wood et al., NOAA PMEL), and the Ross Sea (L. Padman et al., LDEO). Work continues on improving the reliability of the ALAMO air-deployment system, to ensure successful tube launches from smaller aircraft flying lower, and faster than are typical for C-130 aircraft.

Details of the ALAMO deployments are found in S. Jayne's ALPS-II white paper.

4. DEVELOPMENTS

MRV has several development projects underway, mainly collaborations with S. Jayne, B. Owens, L. St. Laurent and their colleagues at WHOI.

The ALAMO float is the basis for most of the development projects. We have started preliminary design work on the next version of the ALAMO, internally called ALAMO 2.0. This version will have a smaller pressure case to more easily accommodate an enhanced, sonobuoy-like air deployment system and still fit easily into the variety of standard A-size tubes encountered on all types of aircraft. There are other hardware and software improvements in the queue for this version.

A focus for the current version of ALAMO is anchoring systems. We are designing an adaptation kit for the ALAMO for its use as an air-launched expendable tide gauge for NAVOCEANO's use in airborne nautical charting programs. This version of ALAMO needs to remain motionless on the bottom in currents up to 5kts, while accurately measuring pressure time series. The initial versions will not be A-size, but that is the eventual goal (using ALAMO 2.0 as a base). ALAMO will also get a one-time anchoring and passive release system so that large numbers of ALAMO floats can be deployed at one time, where they will rest on the bottom until scheduled release occurs to initiate profiling.

MRV also has an ONR-funded STTR in collaboration with WHOI to adapt ALAMO with individually controlled external longitudinal fins. This will allow ALAMO to act as a glider for enhanced station keeping,

and to decrease the turn-around time for more rapid profiling. The focus is initially on turbulence measurements in the upper ocean.

The other ALAMO development projects involve diversity of communications, enhancement of the user interface and status messaging, and integration of passive acoustics.

5. FUTURE

MRV sees the future of autonomous Lagrangian platforms as directly linked to the development of low-cost oceanographic sensors. Many of our customers do not require the levels of accuracy and stability demanded by the Argo program. They would be satisfied with an order-of-magnitude less accuracy, and stability over weeks or months, not years. The success of the Argo program has been partially driven by the sensors, but a lot of users, particularly U. S. Navy users, do not have the same requirements.

MRV wants to move to more environmentally-friendly materials, deployment systems, and end-of-float-life procedures. We are limited in this area by our efforts to keep costs reasonable while maintaining performance, but the regulatory environment in the ocean will only get more rigorous. This needs to be addressed.

Everyone would like better battery systems, especially with respect to safety and certification. Higher power density and better efficiency is wonderful, but it all has to be safely embarked or flown on a variety of ships and aircraft. If the battery technology is not sufficiently protected by safeties, it will be hard to field these instruments.

Finally, the various certification issues with all types of ships, submarines, and aircraft need to be resolved. A great diversity of launch platforms will be a boon to deployment of instrumentation.

These needs are simply stated, but not easily achieved. They are necessary, however, to fulfil the promise of large numbers of easily deployed inexpensive high-quality measurement systems in the ocean.

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