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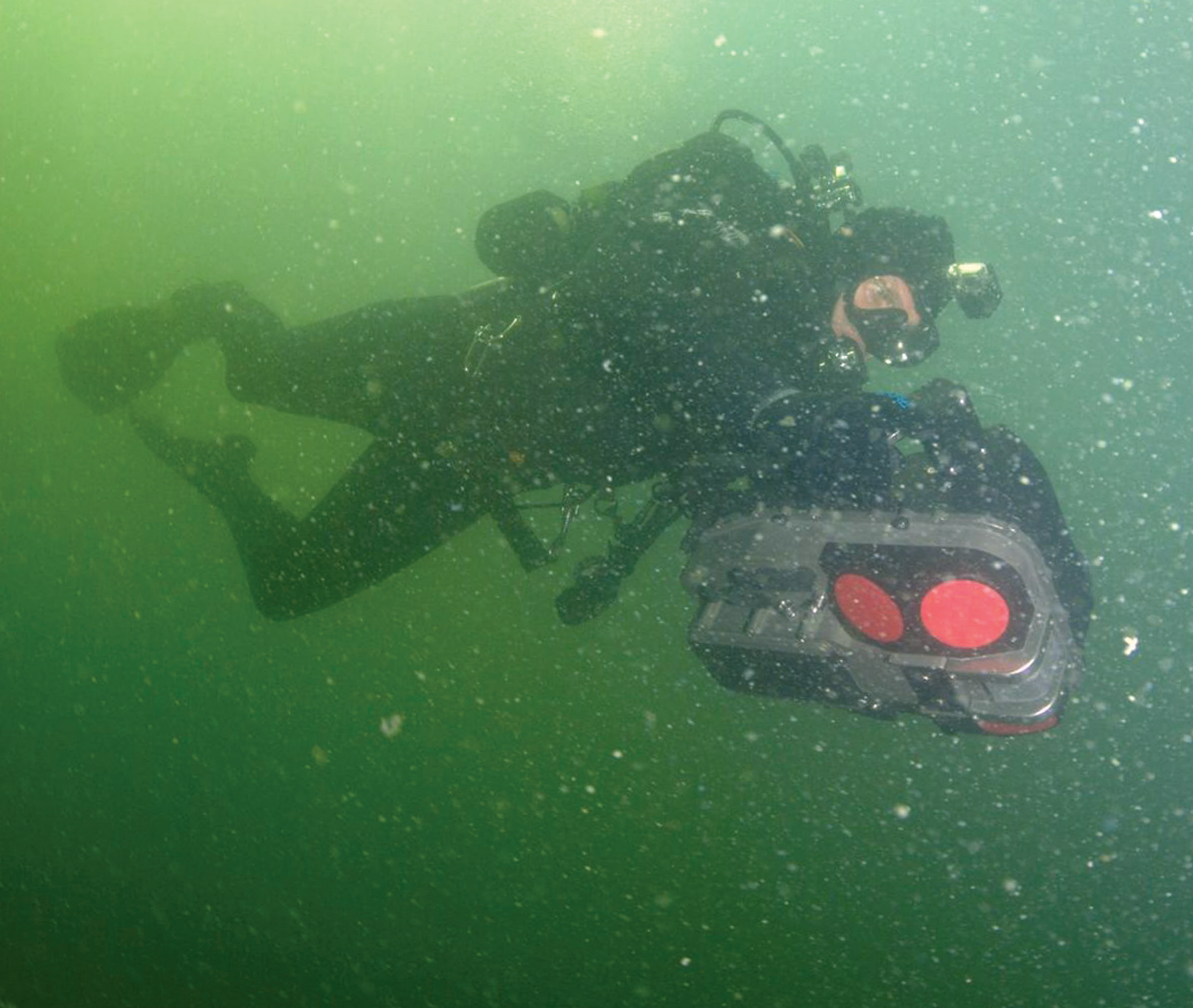
By Ben Kinnaman • Bill Hellman • Jeff Carr



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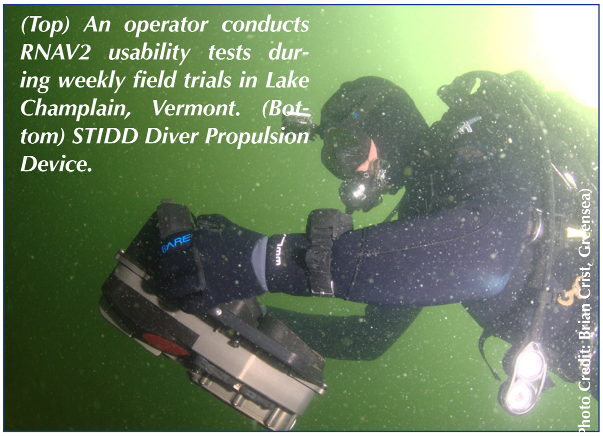
Accurate subsea navigation and integrated mission management tools can significantly enhance the job of the modern combat diver while reducing his work load. However, current systems on the market have found limited adoption because they either do not fully deliver the capabilities required by the operational community, or they are difficult to use in a combat scenario. There exists a significant need and opportunity for a compact diver navigation and mission planning tool that can be used by either a swimmer or a team in a propelled diver transportation system.

To address this need, STIDD Systems Inc. and Greensea Systems Inc. partnered to develop a new concept for combat swimmer navigation and mission management, RNAV2. It builds on proven systems from both companies and leverages a combined 25 years of product development and testing in this domain. Using Greensea's powerful OPENSEA software operating platform, the RNAV2 provides advanced capabilities for STIDD's Diver Propulsion Device (DPD).



(Top) An operator conducts RNAV2 usability tests during weekly field trials in Lake Champlain, Vermont. (Bottom) STIDD Diver Propulsion Device.

STIDD fielded the DPD in 2001 and has delivered more than 500 units to the international special forces community. The newest DPD model can transport two divers with full payloads to distances over 10 km, at speeds up to 4 kt.

RNAV2 provides an inertial navigation solution, mission planning tools and automation to make the DPD and its pilots more effective, powerful and accurate. RNAV2 can also be used as a stand-alone swimming system without the DPD. To utilize the system effectively, the greatest challenge was making it easy to use and intuitive. If we succeeded, the RNAV2 would mark a paradigm shift in combat diving operations.

Problem

Fully integrated navigation and control software packages such as SmartFlight, found on the popular Teledyne SeaBotix vLBV, have become the standard among explosive ordnance disposal and mine countermeasure groups utilizing inspection-class ROVs. These systems provide inertial navigation, sensor fusion, automation, sonar integration, task automation and mission planning in a single-operator interface to simplify the operation of the vehicle and increase the effectiveness of the operator. The operator is closer to the task at hand by removing the nuances of vehicle operation from the problem. Combat divers can also benefit from this technology, but several operational issues need to be addressed.

For the STIDD-Greensea team, the barrier to usefulness was not the technology itself so much as the access and utilization of the technology. The real engineering task was to make this technology user-friendly in a combat diver application.

This is a familiar theme in robotics, automation and even personal computers that extends back to the advent of modern computer science. Technology has enabled more powerful sensors with new capabilities in smaller sizes. However, we cannot simply focus on making a smarter machine. We have to consider our relationship with it and how we as operators will be affected. How will we use it? How will we communicate with it? How will it serve us? This was the critical issue in adding intelligence to the DPD.

The conversations within our development team, comprising robotics engineers and diver-operators, often mirrored a famous conversation between artificial intelligence forefather Marvin Minsky and Doug Engelbart, the creator of the computer mouse, in the 1950s at MIT as cited by Kevin Kelly in his 1994 book, "Out of Control".

Minsky: "We're going to make machines intelligent. We are going to make them conscious!"

Engelbart: "You're going to do all that for the machines? What are you going to do for the people?"

Approach

To develop a user-friendly interface for RNAV2, our engineering team used three primary tactics: create a simple interface, increase operator bandwidth and test regularly. This approach was supported with meaningful training and education for the operator.

Provide a Simple and Task-Specific Interface. Greensea's user interface, commonly used in ROV applications, needed to be reconceived for the diver application. While the task-specific architecture combining navigation, vehicle control, mission planning, payload management and imaging sensors remained intact, the new implementation recognized that a typical ROV operator sits on a ship in a warm, dry control room, often with support staff—a dramatically different environment than a diver piloting the DPD in zero visibility at 4 kt. underwater.

To provide a similar tool set underwater, we reimagined the user experience. We focused on compartmentalizing the operator's tasks and understanding the diver's workflow through a wide variety of mission profiles, from swimming to driving the DPD. Once we had a software architecture that matched the operator's in-water workflow, we designed a fast and simple input methodology that absolutely minimized the diver's physical movements.

We employed a software architecture featuring two sets of stacked screens that match the diver's operation profile—the machine is either working for the operator (operations), or the operator is working on the machine (diagnostics). The operations stack consists of primary operating screens and provides task-specific screens for pre-dive checks, fully aided subsurface navigation on a chart-plotting screen, limited-aid subsurface navigation in a familiar "Tac-Board" format, and a sonar-only screen. These screens allow the operator to "swipe left and right" through the stack as his mission progresses, simply keeping only the most task-relevant information on the display. The diagnostic stack of screens is accessed through a workflow outside the normal operating stack and provides detailed information on the health and status of RNAV2, calibration tools and an alarm history.

(Top) RNAV2 provides a complete fly-by-wire and automation package to increase operator bandwidth. (Middle) RNAV2 functionality is easily accessed by a three-axis joystick under the diver's thumb and a rocker trigger under their fingers. (Bottom) RNAV2 allows users to import maps and easily zoom in or out to focus on a desired location.

RNAV2 provides two ergonomic handles to keep the unit correctly positioned for swimming or DPD operations. The goal was to keep the operator's hands comfortably on the RNAV2 handles and literally place all functions under a thumb. The exception to this was the desire to have several mechanical buttons accessing specific task screens and a panic button that could be mapped to muscle memory. RNAV2 provides a three-axis joystick under each thumb and a rocker trigger under the diver's fingers on each hand. The controls on the right hand are the mouse functions and the controls on the left hand are function controls that change with the displayed screen. The diver accesses each task screen through a familiar "swipe-left" or "swipe-right" motion of the left thumb and navigates a simple pop-up menu structure with the left trigger buttons, up to select and down to display task options.

Increase Operator Bandwidth through Automation, Autopilots. Once we started testing RNAV2 in open water with the DPD, we realized we had made the machine more intelligent, but were mindful of Engelbart's motivating question to Minsky: "What are you going to do for the people?" Thus, we implemented a complete fly-by-wire and automation package to increase the operator's bandwidth by removing the task of manually flying the DPD.

The DPD, like most diver propulsion devices and manned submersibles, uses a very simple directly actuated control surface system for maneuvering. The diver simply turns the steering wheel to adjust heading and pushes and pulls the yolk to adjust his pitch angle. We maintained this mode of operation, as well as the simplicity and robustness, but added parallel electronic control to the actuators. We implemented a fly-by-wire autopilot mode and a full automation mode for guidance. The fly-by-wire mode allows the diver to maneuver the DPD with only his right thumb joystick by controlling the heading and pitch/depth autopilots. This allows the diver to "set and forget" the heading and depth controls while freeing him to focus on other tasks. Further, it gives him the ability to fly the DPD without ever removing his hands from the RNAV controls.

We also added the complete mission automation capability used in Greensea's ROV and AUV software packages, so divers can preplan missions fully establishing mission parameters: waypoints, tasks, transit depths, navigational markers and exclusion zones. Once in the water, the diver enables the autopilot with a single button, and RNAV2 executes the preplanned mission, completely automating the steering and depth control while the DPD transits through the selected route. We also added functions to modify routes, create new routes and go to specific waypoints, plus functions to mouse-click on the chart, which provides complete control of the DPD through RNAV2.

Test Early, Test Often, Listen Carefully. At the onset of this project, we felt the only way to develop an effective user interface was to intimately link the software development process to the open-water operation of RNAV2. All the software developers at Greensea involved in this project were divers with regular diving responsibilities during the year of testing and developing RNAV2. Our team tested almost weekly in 2016. Our initial testing was in the warm, clear waters of Marathon, Florida, at STIDD's facility, and then moved to the more operationally realistic dark, cold waters of Lake Champlain at Greensea's facility in Vermont. The focus was on functional verification of the software through module and system testing and on the usability of the software. Functionality testing verified the software's adherence to requirements, while usability testing verified the user experience of operating the software and focused on four main data points: performance, witness data, survey data and path-to-aptitude.

Understandably, a user interface that is hard to use will adversely impact overall system performance; just think of today's text messages versus those of the flip-phone era. To test operator and RNAV2 performance, we assigned divers complex, multilayered, real-world tasks and evaluated their performance. Examples included finding an object with a sonar while swimming in mid-water, creating new routes while flying a current route, and adjusting payloads or changing positions on the DPD while in transit.

Witness data, video of the operator using RNAV2 during a dive and survey data provided critical feedback on how the operators were using and experiencing the interface. During much of our testing, we used a GoPro camera mounted to the diver's head and another mounted to the DPD to record the diver's use of the software through specific tasks. We also asked each diver to regularly complete a survey implementing a System Usability Scale questionnaire that helped us quantify the usability of the interface. Lastly, the path-to-aptitude was an important piece of test data to determine the usability of the interface. Path-to-aptitude shows how quickly a new operator can become functionally proficient with the software, or software intuitiveness. A user interface that has a short path-to-aptitude is easy to learn and intuitive. Ensuring RNAV2 had a short path-to-aptitude would not only make RNAV2 easy to use but also aid a diver in successfully resolving an emergency or stressful situation.

Conclusion

The task-based architecture of RNAV2 provides a focused and compartmentalized display of data specific to the diver's operational mode. Testers find operating the RNAV2 with dual hand controls intuitive and powerful. Test video at the end of the development period showed divers successfully conducting 3- and 4-km submerged complex missions without ever having to remove their hands from RNAV2's hand grips and having the bandwidth to attend to mission and payload tasks. Survey data from divers show the workspace is easy to use and well integrated into the mission workflow. Quantitative test data show the use of autopilots and route automation in RNAV2 leads to better performance and decreased training requirements.

The successful progression of man and machine's relationship relies on attention to both the man and the machine. We cannot just make smarter machines without addressing the man and his relationship with the machine. If we provide operators the communication tools needed to work with their smart machine partners, the work they do together will be more effective, efficient and productive. Addressing the man-machine relationship is also critical to advancing technology. Developing RNAV2 with this relationship in mind has yielded a successful and powerful system to assist the next generation of combat divers. **ST**

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Bill Hellman is the director of diving operations at STIDD Systems Inc. in Greenport, New York. He is a retired U.S. Navy Seal with 39 years of operational experience in wet submersibles and underwater navigation. He continues to work with the military operational communities worldwide to steer STIDD's DPD and RNAV2 products (www.stiddmil.com).

Jeff Carr is the diver training and operations manager for STIDD Systems Inc. He lives in Marathon, Florida, and heads STIDD's field office there.