JANUS: Lingua Franca

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Abstract **— JANUS is an emergent underwater communications standard for 'initial contact'. JANUS can serve as an underwater beacon to broadcast information. It is free for public use. The current status of the standard and the areas of its application are presented. The results from multiple governmental programs, recent experiments and early commercial adoptions are provided. Several at-sea data telemetry projects are discussed including between fixed and mobile nodes capable of communicating using multiple physical layer solutions. An overview of the progress and the ongoing efforts for the public and open standard are considered. The utility of JANUS is outlined as an aid for autonomous underwater vehicle navigation by exploiting the infrastructure from cargo ships, wind farms, underwater instrumentation, etc. The relevance of the SUNRISE and Forward-Deployed Energy & Communications Outpost programs are discussed.**

Keywords— JANUS; communications; beacon; autonomous systems; standards; underwater; modem; optical, acoustic, radio frequency; navigation; energy usage

I. Introduction

Standards are essential for machine communications and continue to be the focus of regulating authorities worldwide. Interoperable communications are founded upon well-defined standards. Unfortunately, there is no international regulating authority for underwater communications; a public standard has not yet been universally embraced. Without a codified underwater standard it is impossible for dissimilar assets to communicate amongst themselves. Today the sea is 'awash' with dissimilar underwater unmanned vehicles, gliders, autonomous underwater vehicles (henceforth AUVs), unmanned surface vehicles, moored instrumentation, manned submarines, etc. and all unable to communicate across different manufacturers. The result is that ships and humans must still retrieve AUVs, instrumentation and their data; also submarines are continuing to collide with surface ships. When a common form of communication is available, fewer errors will occur and the energy budgets of AUVs will be reduced.

Work towards JANUS was initiated [1,2] in 2006 at the NATO research centre in La Spezia, Italy. In 2008 and 2009 international workshops solidified the purpose and public nature of JANUS. Over the last ten years scientists, technicians, engineers and their industrial partners have continued to experiment with and produce JANUS-compliant hardware. Multi-national efforts include Norwegian, German, French, Dutch, Spanish, Portuguese, Italian, Turkish, British, Canadian and American researchers. In addition to these national efforts several commercial entities Teledyne-Benthos, Atlas, AppliCon, ELAC Nautik, Evologics and Devolgics have promoted JANUS as an underwater standard. The NATO Centre for Maritime Research and Experimentation (CMRE) and the NATO Industrial Advisory Group (NIAG) are in proceedings to codify [3] JANUS as a NATO Standardization Agreement (STANAG).

II. Opportunity

Today there are four times as many ships at sea than in 1992 with cargo ships accounting from most of the growth [4]. In the future, the Automatic Identification System (AIS) information of a surface ship can re-broadcast to submerged assets encoded as a JANUS transmission. In addition to submarine avoidance, the latitude, longitude, heading, speed, timing, etc. of surface ships will greatly aid subsurface navigation and clock synchronization. Such AIS broadcasts could be made using the existing acoustic transducers including the 12.5 kHz depth sounder transducer and side-scan sonars. No mechanical modifications need to be made only software modifications. Any ship with existing acoustic survey equipment can transmit JANUS. The higher the acoustic frequency (e.g. 100s of kHz side-scan sonar) the higher the accuracy in positioning and clock synchronization while low frequency devices (e.g sub-bottom profilers) can transmit over greater [2] distances (many 10s of kilometers).

Manned submarines, AUVs and fixed instrumentation can decode received messages at distances of over 10 km depending on frequency, power level and environmental conditions. Vehicles could stay submerged for the entire duration of their mission without the need to surface for a GPS fix to correct for their navigation errors. Recent advances in single-beacon one-way-travel-time acoustic navigation for underwater vehicles [5,13] can be exploited. There are thousands of acoustic Doppler current profilers (ADCPs) measuring the currents, temperature and pressure in the world's oceans. Each ADCP, although very narrow beamed by design, could broadcast its data or receive clock synchronizations using JANUS. It is well known [6] that RF, although greatly attenuated, propagates underwater at extremely low frequencies (ELF) – this phenomenon would allow independent underwater clock synchronization on a global scale [15].

III. North American and European Experimental Results

SSC Pacific conducted recent in-water exercises including initial contact between dissimilar nodes. The JANUS modulation scheme was integrated into the Applicon SeaModem in addition to the SUNSET networking protocol [7, 8]. A network of 4 nodes consisting of 3 static nodes and one mobile surface node were utilized. The three static nodes were placed according to the geometry depicted in the Figure 1 and the surface vehicle was navigating inside the orange area.

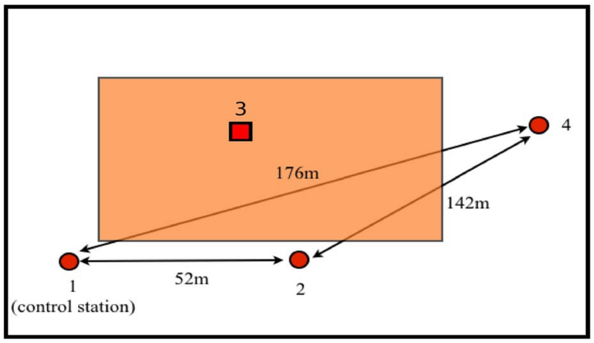

Fig. 1. Nodes 1, 2, and 4 fixed while the mobile node (3) was navigating inside the orange area

Communication Scheme	Distance:100 m	Distance: 200 m
SeaModem	0.04	0.19
JANUS	0	0

Table 1: Packet Error Rate at different distances.

One static node (control station) and the surface vehicle were able to support both JANUS and the proprietary SeaModem modulation scheme, while the other two static nodes were running only the SeaModem modulation scheme. The surface vehicle was using JANUS to announce its presence to the control station when approaching the area and to negotiate the communication parameters. The mobile surface vehicle based node adaptively switched to the non-JANUS proprietary modulation scheme to interact with the other three nodes in the network. This is the most important function of JANUS: to allow dissimilar fixed and mobile underwater assets to make first contact and then optimize communications as needed.

Additionally, when the main channel was disrupted and not reliable, JANUS was used as a robust control channel between the vehicle and the control station to deliver messages at a lower bit rate (about one fourth of the one obtained using the proprietary modulation scheme). The transducers were placed at 1.5m below the sea surface during acoustically noisy periods (rain and wind) – challenging conditions for communications.

Table I shows the packet error rate over the link connecting the surface vehicle and the control station at different distances when using JANUS and the proprietary modulation scheme.

In Germany, the University of Kiel and the Research Department for Underwater Acoustics and Marine Geophysics have been active [1,9] in the promotion of JANUS as a beacon. Ivor Nissen has lead these efforts and has contributed to the development of JANUS since its inception onboard the German research vessel Planet in 2007. JANUS sequences have been successfully transmitted over many nautical miles in harsh conditions and include transmissions using different central frequencies. Radio frequency (RF) transmissions have also been made over short distances underwater. Such RF transmissions demonstrate how JANUS transmissions can be made using acoustic, RF or optical techniques. A promising commercial application for JANUS is for 'obstacle avoidance' of offshore wind farms in the European Seas. Efforts at ELAC Nautik have made progress extending the functionality of the UT 3000 (underwater telephone) to include JANUS functionality.

The European Union funded Project SUNRISE [10] has been active 'Building the Internet of Underwater Things' since 2013. The consortium of institutions has performed several field experiments to facilitate the interoperability of underwater communications. SUNRISE goes beyond the physical layer of JANUS and hopes to provide a complete end-to-end solution for medium access control (i.e. MAC), networking, data, transport, etc. layers.

The United States Office of Naval Research "Forward-Deployed Energy & Communications Outpost" (FDECO) project is an effort to greatly enhance the operational envelope of underwater vehicles. FDECO's goal is to provide additional subsurface energy and communication resources to underwater vehicles. It is envisioned to be an outpost where vehicles can recharge batteries, communicate, identify their needs and share information with other 'assets'. When FDECO is implemented vehicles will be enabled to work for extended periods - even years in remote, sensitive and denied areas – a new type of 'wet cold war'. When enabled with JANUS underwater vehicles will collect their data more accurately, communicate more frequently, navigate more accurately and use energy more efficiently.

IV. Energy Trends in AUVs

Today's AUVs are still mission limited by battery life, poor communication channels (limited data rates, environmental complexity and high latency) and their ability to accurately determine their location underwater. Although microprocessor, sensor, and battery technology continues to improve, the energy costs per bit (Joules/bit) underwater [11] are large and surfaced RF communication channel are beginning to reach their physical limits. JANUS can help reduce AUV energy usage.

SSC PAC recently acquired three Riptide Autonomous Solutions Micro AUVs. The micro-UUV features open hardware and software interfaces to provide users a reliable and robust platform to advance technology development. A SeaModem with a Chip Scale Atomic Clock (CSAC) and JANUS compatibility [5,12] and a MEMS IMU will be added to the Micro AUVs for the development of Distributed Localization and Cooperative Control and underwater networking algorithms. Endurance of these compact (7 kgs) AUVs is projected to be over two weeks with aluminum seawater battery. At 3 knots they can travel up to 1200 nautical miles. The low cost (~ $10,000 USD) AUVs will augment current ocean sampling. JANUS messages will be used to synchronize clocks and provide a one-way navigation message containing the timing and GPS information from the sender. The Micro AUVs will only receive the acoustic messages; it will not transmit, thus reducing the amount of energy required.

V. Acoustic ranging estimation and Time synchronization

Traditional LBL long baseline, ultra-short baseline (USBL) and more recent single underwater transponder positioning (UTP) acoustic positioning navigation systems require at least two if not three acoustic messages to be exchanged. The difference between the two methods is that the two-way (or three-way) approaches do not scale [13] as well as one-way methods, thus existing acoustic navigation systems lack scalability for simultaneously navigating multiple vehicles.

The two-way method is the simpler but it introduces higher delays due to the need to exchange several messages. The one-way method is the quickest way to estimate the distance between pairs or larger groups of vehicles. Moreover, the vehicles could be made aware of their positions passively, without emitting any acoustic signal in response to the one-way ping message. One-way ranging however requires that the vehicles' clocks be synchronized at the beginning of operations and that the synchronization remains stable for the whole duration of the mission.

Synchronization needs are dictated by position accuracy requirements and the speed of sound in water. Assuming that the speed of sound in water is approximately 1500 m/s, synchronizing to within 1 ms corresponds a position estimate accurate to 1.5 m. For short duration missions, a lack of synchronization may not be an issue. However, for longer duration missions, over a month, a CSAC will only drift approximately 350 microseconds. Other system requirements (e.g. propulsion) preclude missions long than a month.

In addition to using GPS and the detection of ambient fields, clock synchronization can be also performed acoustically to avoid the surfacing of the underwater vehicles while performing a long-term mission for GPS clock fixing.

In particular, a reference node, such a cargo ship, can be equipped with a stable GPS clock and can serve as a moving beacon that broadcasts one-way messages to acoustically synchronize the clocks of the AUVs. At the same time, the AUVs are able to estimate their distances to the reference node measuring the one-way travel time with a very high accuracy. In order to perform acoustic synchronization and one-way ranging estimation, we have integrated the CSAC with the SeaModem acoustic modem [5]. The modem firmware has been improved to provide transmission scheduling and transmission and reception timing information to the upper layers of the protocol stack. The SUNSET framework [12] has been used to provide networking capabilities. In particular, new protocols have been designed and developed to acoustically synchronize the clocks of multiple node to that of a reference node and at the same time to estimate their distance through one-way messages. These new solutions can be used with any commercial acoustic modems that implement firmware features described above.

We performed several at-sea trials [12, 14] that implemented acoustic synchronization and one-way ranging estimations. These methods have high accuracy, low communication overhead and low energy consumption. These techniques are fast, scalable and suitable for supporting cooperation of multiple AUVs where high accuracy and simplified overheads are required.

VI. Conclusions

Beacons have been efficient methods of communicating information for mellenia. In the 1800s lighthouses (transmitters) and maritime navigation (receivers) were revolutionized by the invention of the Fresnel lens. Fresnel's invention efficiently redirected light energy horizontally – the fires that burned in the lighthouses needed less fuel, the lenses weighed less and the light could be seen further. Maritime charts subsequently disseminated the lighting patern of each lighthouse aiding more efficient ship navigation and cargo delivery. Today's beacon requirements have not changed – information needs to be transmitted robustly with as little energy as possibile sometimes over great distances. The significance of each transmission needs to be public and receiver needs to decode each signal efficiently. The amount of energy required to decode an underwater message must be substancially less energy than than the energy a AUV would need to surface and receive a GPS fix. JANUS has been demonstrated as a robust method to transmit information underwater. Its adoption will increase navigational efficiency, reduce energy usage and augment collision avoidance methods. The cost of creating a JANUS transmission is low - a 'smart phone' application could easily perform both encoding and decoding processes. JANUS is designed to be robust, easily decoded and used freely.

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