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A Feasibility-study of a Micro- Communications Sonobuoy Deployable by UAV Robots

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***Abstract*—**This paper describes a feasibility study that is included with the research, development and testing of a micro communications sonobuoy deployable by Maritime Fixed wing Unmanned Aerial Vehicles (M-UAV) and rotor wing Quad Copters which are both currently being developed by the University of Adelaide. The micro communications sonobuoy is developed to act as a seamless communication relay between an Autonomous Underwater Vehicle (AUV) and an above water human operator some distance away. Development of such a device would eliminate the requirement of physical communication tethers attached to submersible vehicles for control and data retrieval.

***Keywords*—**Autonomous Underwater Vehicle, AUV, Maritime, Unmanned Aerial Vehicle, UAV, Micro Sonobuoy, Communication.

I. INTRODUCTION

IN the majority of cases submersible vehicles such as AUV’s still require a physical cable known as tether connecting the underwater vehicle to its human controller aboard the surface deployment- vessel. The lack of current available low cost effective underwater modems is the major case behind this. The micro communications sonobuoy is intended to act as a highly deployable underwater modem coupled to the above water radio Frequency (RF) transmitter, thus forming a seamless communication link between the above and underwater base stations. The underwater communication link must be capable of transferring control commands as well as to maintain a stream of diagnostic data from the AUV’s integrated trouble shooting system ITS [1]. The communication link is packaged in the form of a miniaturised sonobuoy to facilitate deployment via M-UAVs and rotor wing Quad Copters [2 & 3]. In this paper, we present the design of the micro communication sonobuoy with the most critical component, the underwater modem. The underwater modem consists of a transducer, hydrophone and the usage of modulation techniques.

II. CONSTRAINTS

Several constraints were faced during the design of the micro communications sonobuoy. One of the major constraints was cost as the initial funding started with a low budget. The other major constraint was the physical size and weight of the sonobuoy as it must not exceed the maximum payload size and weight that the M-UAVs can carry.

III. ACOUSTIC COMMUNICATIONS

The following sections will present an overview of the design and implementation of the transducers, modulation techniques as well as experimental results.

A. Transducers

Underwater transducers are electro-mechanical devices that convert electric potential energy into a mechanical strain and vice versa. Benson et al [4] showed that it was possible and effective to utilise low cost piezoceramic transducers and then to build the underwater modem around that of the underwater transducers to extract as much performance as possible. Therefore the design substitutes a commercial transducer with a self-manufactured transducer.

As the micro sonobuoy operates in relatively shallow waters, effective acoustic communications can be achieved via 2D Omni-directional beam pattern transducers. Transmission frequency is a trade-off between baud rate and attenuation co-efficient; hence it was decided that a 40 kHz frequency would offer the best compromise. Thus two single radially expanding piezoceramic ring, Steminc model SMR38D127T63 (RING-1) were purchased to achieve an Omni-directional beam pattern at low cost. Several cymbal flex-tensional transducers (DSTO-1) were also provided by our industrial sponsor, Defence Science and Technology Organisation (DSTO) as a possible solution. The transducers were then encapsulated with a two part polyurethane potting compound to prevent contact with any conductive fluids as shown in Figure 1. F-50 Polyurethane Resin was selected due to its similarity in density to that of water thus providing for effective mechanical to acoustic energy coupling. Both solutions where experimentally tested in a test bed to determine their operational frequency range and directionality to ultimately determine the most suitable transducer solution for the micro communications sonobuoy.

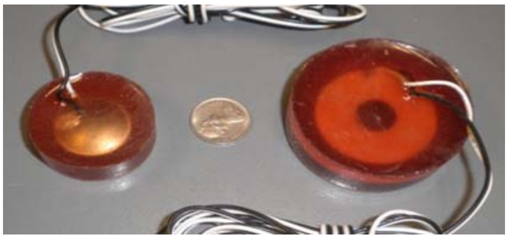

Fig. 1 Potted Transducers, DSTO-1 (see left), RING-1 (see right)

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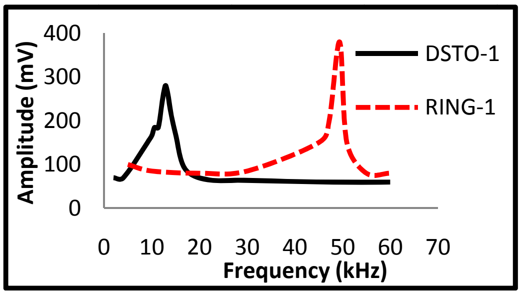

Fig. 2 Experimental results - Transducer resonant frequency comparison

Experimental results are tabulated and shown in Figure 2. Based on results, the resonant frequencies of DSTO-1 and Ring-1 where found to be 13.1 and 49.4 kHz respectively. DSTO-1 was also discovered to not offer a 2D Omni-directional beam pattern, which meant that several transducers had to be arranged in an array in order to provide an effective solution. As such Ring-1 transducers were selected due to their appropriate resonant frequency combined with 2D Omni-directionality.

B. Modulation Technique

Modulation methods dictate the maximum data rate achievable for a given frequency. Furthermore they must contend with Doppler effects, multipath effects and the ambient noise of the underwater channel. Frequency Shift Key (FSK) is a fairly simple modulation technique that has been widely used in underwater communications due to its resistance to time and frequency spreading of the underwater acoustic channel [4, 5]. Other modulation such as Phase Shift Key (PSK) and Quadrature Phase Shift Key (QPSK) are now being considered for higher data rate underwater applications. Kim et al [6] showed that QPSK data modulation transmission in a shallow underwater channel at 3kbps can achieve a Bit Error Rate (BER) of 8.4 x10^{-3} without compensation techniques. QPSK was determined the ideal budget solution for the micro communications sonobuoy.

Instead a hardware modem was designed around the properties of the RING-1 transducer. Two Ring-1 transducers are utilised within the sonobuoy, providing a separated hydrophone and projector thus simplifying the electronic circuitry required. A hardware modem and host Seeduino microcontroller are connected via serial UART at a bus rate of 300 baud. Upon receiving binary data the hardware modem modulates the data into FSK mark and space frequencies of 48 and 52 kHz respectively. Carrier frequency is variable via flash programming of the hardware modem allowing support for alternate current unit size and costs.

C. Underwater Modem

Digital Signal Processors (DSP), utilising software signal analysis were considered initially, however later ruled out due to transducers and environments however carrier frequency is not changeable on the fly. A dual MOSFET amplifier is integrated into the hardware modem as shown in Figure 3. Composing two 40 Volt MOSFET amplifiers operating in opposing polarity, thus creating a voltage difference of 80Volts alternating current.

Applying a substantial reversed polarity voltage across a transducer has the potential to de-polarise the piezoelectric crystal. Due to the large volume of piezo crystal and relatively low operating voltage this effect has been avoided.

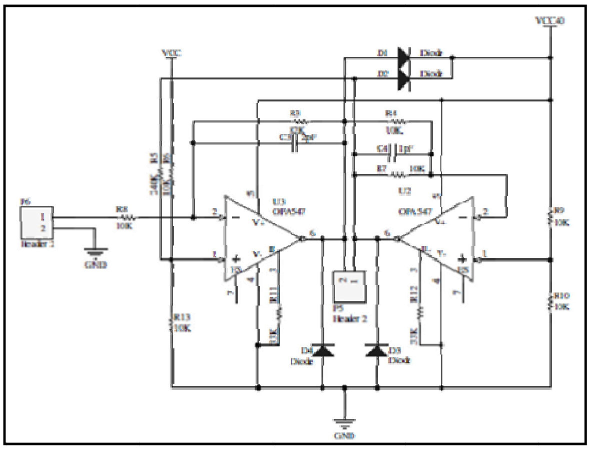

Fig. 3 Hardware modem MOSFET amplifier

IV. DEPLOYMENT PHASE

The deployment procedure of the micro communications sonobuoy involves three main phases. In Phase I, the micro-sonobuoy sits on board the UAVs at a maximum altitude of 50 meters waiting for deployment. Phase II involves the deployment of the micro sonobuoy from the UAV and the activation of its retardation system. Phase III then commences as soon as the micro communications sonobuoy enters the maritime environment where the floats and transducers are activated and deployed immediately. Figure 4 gives an illustration of the deployment phases of the micro communications sonobuoy.

Fig. 4 Micro Communications Sonobuoy Deployment Phases

V. FLOATATION SYSTEM

In order to establish constant communications uplink with the above water base stations, the micro communication sonobuoy has to stay afloat on the surface of the maritime environment. Instead of using traditional floatation designs currently found in commercial sonobuoys, three high strength latex balloons are used. Initially, carbon dioxide (CO2) canisters and reactive chemicals were to be used to inflate the floats. However, reactive chemicals are pollutants to the maritime environment and the micro communications sonobuoys' casing and electronics components were not able to withstand the air pressure in the CO2 canister. As such, the design was replaced with pressurising the main compartment of the micro communications sonobuoy casing with an internal air pressure of 40 psig. Due to space constraints in the casing, miniature pneumatic fittings had to be sourced from various manufacturers in order and assembled to fit into the limited space in the top bulkhead section. Check valves are also incorporated in the system as a fail-safe device to prevent any back flow of air in situations of a puncture in the floats. A common Schrader valve is implemented to facilitate pressurisation from common air compressors and bike pumps for field testing. An image of the floatation system can be seen in Figure 5.

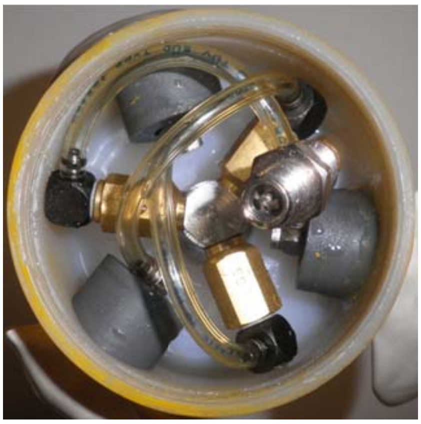

Fig. 5 Floatation system

Modular testing of the inflation system revealed it to be effective; the micro communications sonobuoy was dropped from a height of three meters into a body of water. Figure 6 displays a freeze frame from the underwater camera utilised during the experiment.

The experiment revealed that the inflation system was adequate to prevent the sonobuoy from sinking and also suspend the sonobuoy at a suitable waterline to prevent water damage or interference to the above water radio frequency antenna.

VI. CASING DESIGN

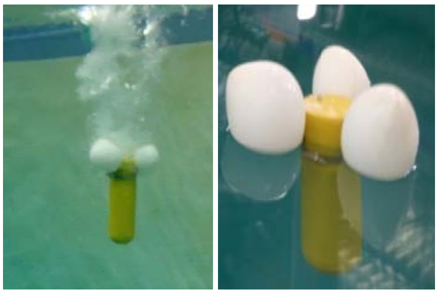

Fig. 6 Modular float tests

The micro communications sonobuoy is to be deployed at a maximum altitude of fifty meters from the M-UAVs. As such, the casing has to be tough in order to withstand the impact force. The design of the casing was made to be sealed (water-tight) completely to prevent any water leakage which would cause damage to the electronics system. Several commonly available materials such as High Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low Density Polyethylene (LDPE), and Aluminum Alloy 2024-T3 were taken into consideration. Using the maximum elongation and stress formulas as shown below, a graph of the impact stress versus the release height for various materials is plotted and shown in Figure 7.

$$\delta_{max} = \frac{WL}{EA} + [\left(\frac{WL}{EA}\right)^2 + 2h\left(\frac{WL}{EA}\right)^{\frac{1}{2}} \qquad (1)$$

$$\sigma_{max} = \frac{W}{A} + \left[\left(\frac{W}{A}\right)^2 + \frac{2WhE}{AL}\right]^{\frac{1}{2}} \qquad (2)$$

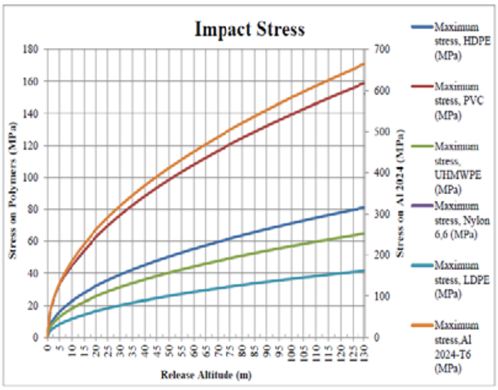

Fig. 7 Impact Stress of the Various Materials

Based on Figure 7, it can be seen that the impact stress increases with the altitude at which the sonobuoy is released. Considerations such as the availability of the material, cost of the material; which is a very important constraint in the design and ease of working are also crucial in the selection of a material to fabricate the micro-sonobuoy's casing. Comparisons have been made between materials and HDPE seems to be the ideal material to be used.

The casing design has been simplified into three main sections for ease of assembly. The top bulkhead section houses the floatation system assembly while the main compartment houses all of the electronic components of the micro communications sonobuoy. The end nose cap is designed to have a dome shape so as to distribute the main impact force faced in Phase III of deployment. In order to waterproof the micro communications sonobuoy, ACME threads are incorporated at all the joints to provide a better grip strength between each section.

VII. CONCLUSION

In summary a prototype micro-sonobuoy has been developed as shown in Figure 8 with effective underwater acoustic communication, RF communication and deployment systems.

Fig. 8 Prototype micro communications sonobuoy

Experimental testing showed that RING-1 transducers where most suitable to the design of a custom hardware modem, tuned to mark and space frequencies of 48kHz and 5kHz respectively. Underwater communication tests revealed that an effective underwater communication of 300 baud was achieved over a range of 10m utilising an improvised power supply. Repair of the power regulation PCB, would allow for full range tests within the vicinity of 50m.

The micro sonobuoy weighs 993 grams. Furthermore, modular tests revealed the sonobuoy custom designed floatation and parachute systems to be effective. In this research and development modular tests were conducted to evaluate the effectiveness of the micro-sonobuoy.

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REFERENCES

[1] Manjit , SG, Ritchie, DS, Taranjit , S 2011, Design, Build and Implementation of Intelligent Troubleshooting Systems for Maritime Underwater Robots' Operations, University of Adelaide, Australia.
[2] Zhao, XN 2011, Design, Build and Implementation of a new version of VTOL Maritime UAV Robot System, University of Adelaide, Australia.
[3] Dong, YL, Lu, EW, Zhu, XW 2011, Design and Development of a new-version of Automated Systems Operations of Catapult-Launched Maritime UAV Robot, University of Adelaide, Australia.
[4] Freitag, L, Grand, M, Singh, S, Parton, J, Koshi, P 2005, The WHOI Micro-Modem: An acoustic communications and navigation system for multiple platforms", IEEE Oceans Europe.
[5] Kilfoyle, DB, Baggeroer, AB 2000, The State of the Art in Underwater Acoustic Telemetry, IEEE Journal of Oceanic Engineering, Vol. 25.
[6] Kim, SY, Han, JW, Kim, KM, Baek, SH, Kim, HC, Kim, CH 2010, Experimental Results of a Single Carrier Digital Modulation for Underwater Sensor Networks, IEEE Journal of Oceanic Engineering, pp. 326-330.