Institution: Newcastle University		
Unit of Assessment: 12		
Title of case study: Low cost and low power underwater acoustic communication and positioning		
Period when the underpinning research was undertaken: 2000-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Jeffrey Neasham	Senior Lecturer	2000-present
Period when the claimed impact occurred: 2013-2020		
Is this case study continued from a case study submitted in 2014? Y		

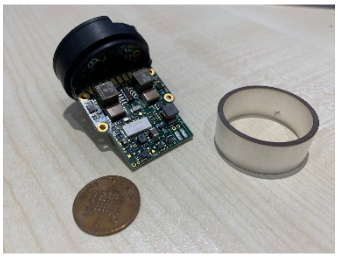
1. Summary of the impact (indicative maximum 100 words)

Building on Newcastle University's pioneering research in underwater acoustic communication (UAC), a new generation of communication and positioning devices have been commercialised via licensing to 3 industrial partners. Newcastle's waveforms, algorithms and circuit designs have enabled vast reduction in cost, energy consumption, sound emission and size, enabling the "Internet of Underwater Things" - large scale, bio-friendly subsea networks deployed worldwide in diver safety, underwater navigation, marine monitoring and aquaculture. The most mature product, Seatrac, has generated >£3M sales for Blueprint Subsea since 2016. Newcastle's waveforms and algorithms are now incorporated in an emerging standard for interoperable UAC defined by UK DSTL/MoD.

2. Underpinning research (indicative maximum 500 words)

Due to the absorption of radio waves in water, the wealth of long range, high bandwidth wireless communication we rely on above water is completely unusable below. Hence the subsea sector relies on acoustic signals (sound waves) for underwater wireless communication and navigation. Underwater acoustic propagation leads to severe signal distortion making this one of the most difficult channels encountered in wireless communication. Newcastle University were among the pioneers in developing modulation and receiver structures able to tolerate severe time varying multipath and Doppler effects encountered in this channel [P1, P2, P3], leading to ground-breaking products e.g. Tritech's MicronNav covered by a REF2014 impact case study.

EU FP7 project Cognitive Autonomous Dive Buddy (JN, 01/14–12/16, £272,712.14) demonstrated advanced diver-robot interaction enabled by subsea communication and positioning (http://caddy-fp7.eu/). Newcastle developed UAC devices for divers and autonomous underwater/surface vehicles to exchange commands/data and track relative positions. These devices needed to be small/light, for use on divers and small vehicles, using low acoustic source level and ultrasonic frequencies for diver safety. This led to the development of novel spread spectrum modulation schemes for the 24-32 kHz frequency band, one for low rate command/control/positioning and one for medium rate data transfer. These were implemented on a miniature hardware platform, based on a system-on-chip ARM Cortex M4 processor, known as "SeaTrac" [P4]. This device incorporates a tiny receiver array for ultra-short-baseline (USBL) positioning so range and direction between units can be measured with a resolution of 5cm and 1 degree respectively. EPSRC DTA PhD project "Spread-Spectrum Techniques For Environmentally-Friendly Underwater Acoustic Communications" (JN/CT/BS, 04/13-08/17) built on ideas developed by JN for spread spectrum modulation schemes operating at very low signal to noise ratio i.e. with received signals well below background noise level. This allows transmission of data with source power below limits recommended by marine biologists and noise-like signals to minimise potential impact on marine mammals. Despite very high spreading ratio up to 1000, useful data rates are maintained using novel M-ary orthogonal code keying modulation (M-OCK). This has achieved reliable 100 bits/s communication over 10km with <1W of acoustic power and with received SNR as low as -15 dB [P5].



EPSRC project USMART (JN/CT/BS, 05/17-09/20, £1,284,429) exploited the above innovations to enable large-scale, subsea wireless sensor networks that are cost effective, long life and environment friendly (https://research.ncl.ac.uk/usmart/). A critical element of this is very low receive energy consumption to allow long deployment from small batteries. Novel sparse signal processing techniques were developed to reduce the computational load of the receiver and enable implementation on a very low power ARM Cortex M0 processor consuming only 12mW. Combined with highly cost-engineered transmit/receive circuits, a small piezoceramic transducer and low cost encapsulation, this forms the "Nanomodem" [P6]. The latest generation of this device (V3) is a tiny 40mm by 60 mm package which can be manufactured for <£50 in volume but achieves 500 bits/s communication and accurate ranging over distances >3km whilst emitting only 0.5W. This is a step change in performance vs cost, power and size and networks of these devices have been deployed in the North Sea to wirelessly gather underwater sensor data over periods exceeding 6 months.

3. References to the research (indicative maximum of six references)

P1. Hinton OR, Neasham J, Sharif BS, Adams AE, *A Computationally Efficient Doppler Compensation System for Underwater Acoustic Communications*, IEEE Journal of Oceanic Engineering, 25, No 1, 52-61, 2000. DOI:10.1109/48.820736 (**432 citations**) – This publication showed how synchronisation could be maintained in the presence of severe Doppler effects, multipath and noise.

P2. Sharif BS, Neasham JA, Hinton OR, Adams AE, Davies J, *Adaptive Doppler Compensation for Coherent Acoustic Communications*, IEE Proceedings on Radar, Sonar and Navigation 2000, 147(5) DOI:10.1049/ip-rsn:20000665 (**53 citations**). – This paper showed how receivers could tolerate time varying Doppler effects and defined a technique used today in the commercial products.

P3. C. P. Shah, C. C. Tsimenidis, B. S. Sharif and J. A. Neasham, "Low-Complexity Iterative Receiver Structure for Time-Varying Frequency-Selective Shallow Underwater Acoustic Channels Using BICM-ID: Design and Experimental Results," in IEEE Journal of Oceanic Engineering, vol. 36, no. 3, pp. 406-421, July 2011. DOI:10.1109/JOE.2011.2144670 (**25 citations**) This paper showed how iterative, soft decision decoding techniques could enhance the performance of adaptive UAC receivers.

P4. J. A. Neasham, G. Goodfellow and R. Sharphouse, "Development of the "Seatrac" miniature acoustic modem and USBL positioning units for subsea robotics and diver applications," OCEANS 2015 - Genova, Genoa, 2015, pp. 1-8. DOI: 10.1109/OCEANS-Genova.2015.7271578 (**23 citations**) – This describes the design of hardware and software algorithms used in the successfully commercialised Seatrac communication and positioning products.

P5. B. Sherlock, J. A. Neasham and C. C. Tsimenidis, "Spread-Spectrum Techniques for Bio-Friendly Underwater Acoustic Communications," in IEEE Access, vol. 6, pp. 4506-4520, 2018. DOI: 10.1109/ACCESS.2018.2790478 (**16 citations**) – This paper describes the development of M-OCK techniques used for very low power transmission with low probability of detection, applied in the latest products and a NATO standard.

P6. N. Morozs, J.A. Neasham et al, Robust TDA-MAC for practical underwater sensor network deployment: lessons from USMART sea trials. In Proceedings of the Thirteenth ACM International Conference on Underwater Networks & Systems (WUWNet '18). Association for Computing Machinery, New York, NY, USA, Article 11, 1–8. DOI: 10.1145/3291940.3291970 (**14 citations**

4. Details of the impact (indicative maximum 750 words)

The Tritech MicronNav product, described in a REF2014 ICS, continued to sell, with 878 units sold between 2014 and 2020 with an approximate sales value of £2M [E9]. However the underpinning research above has created a new generation of UAC technology with superior specifications in data rate, range, positioning accuracy, power requirements and dimensions, at reduced cost. This has superseded the Tritech product in all markets. Throughout the EU CADDY project the Newcastle team worked closely with **Blueprint Subsea**, a UK manufacturer of subsea instruments, to produce near market prototypes. This led to them funding a technology transfer project and then signing a licence agreement in Nov 2014 to manufacture and sell the SeaTrac range of USBL acoustic positioning units, transponders and data modems (pictured) based on Newcastle's circuit designs and software algorithms. Since then, these products have been widely taken up for underwater vehicle navigation, diver tracking/telemetry and AUV telemetry for oil/gas and scientific surveys. They have gained a large worldwide market share for in these applications selling 1329 units for a total sales value of >£3M between product launch in 2016 and the end of 2020, returning royalties of £207,000 to Newcastle University [E1,E8]. The SeaTrac devices are also a key component of Blueprint Subsea's Artemis Pro and Artemis Elite diver navigation consoles (pictured) where they enable teams of divers to share information and their positions over distances up to 2km. These are in use by police search and rescue divers and Naval divers of several NATO nations e.g. 30 systems are in use by special forces of the UK Royal Navy [E7].

More recently, commercialisation of the Nanomodem (NM) technology has opened up applications that were previously too cost sensitive for underwater acoustic communications to be feasible. WSENSE are an Italian company who licenced the circuit designs and firmware for NM v3 in May 2019 and have incorporated the technology in Internet of Underwater Things (IoUT) solutions used in aquaculture, defence, energy and environment applications. [*redacted text*] WSENSE sold 136 NM v3 equipped devices during 2020 and are ramping up for high volume production to meet demand from this industry [E3,E10].

Succorfish Ltd are a manufacturer of asset and personnel tracking systems who took a strong interest in the NM technology from the beginning of development and licenced early designs in Feb 2017. The latest NM design is now used in the SC4X underwater messaging system (pictured) for naval/professional divers and a low cost safety product for recreational divers providing remote tank pressure monitoring, emergency messaging and depth/location [E2].

Due to their low cost, size and power, NM devices were found by Ecosub Robotics to be the only viable technology for integration in their miniature AUV products (pictured). Through an Innovate UK project, Newcastle and licensees supplied NM to provide communication and cooperative navigation to a swarm of vehicles spanning several km, enabling large areas to be systems and greatly strengthening Ecosub's product offering [E6].

150 devices were supplied to the University of Zagreb, Croatia for use in the H2020 Subcultron project enabling a large network of underwater robots to monitor water quality in Venice Lagoon [E4, E5]. Another 30 were supplied to the University of Washington, US to enable 3D current mapping using small, inexpensive "microfloats" for tidal energy projects near Seattle. The technology is also contributing to positive impacts on the marine environment through a major project with marine scientists, net manufacturers and the fishing industry. The EU NetTag project has demonstrated how NM devices can be used to provide cost effective tagging

of fishing gear (nets and traps) to enable lost gear to be located and recovered, reducing one of the largest and most damaging forms of marine plastic pollution.

Newcastle's world leading research in UAC and its successful use by naval divers led to their participation in a working group on UAC run by UK DSTL/MoD. Newcastle were then selected to lead a team with Sonardyne to develop and validate a UK led UAC standard for NATO forces known as Phorcys [E7]. To meet a very demanding specification, an advanced spread spectrum waveform has been developed and tested by the team, drawing upon much of the underpinning research described above, to achieve reliable and secure communications in the most hostile channels in excess of 20km range. The standard was delivered in 2020 and Phorcys compliance will be promoted to equipment manufacturers supplying NATO nations.

5. Sources to corroborate the impact (indicative maximum of 10 references)

Factual statements from:

- E1. Robin Sharphouse, Blueprint Subsea (licensee)
- E2. Richard Hooper, Succorfish Ltd (licensee)
- E3. Chiara Petrioli, WSENSE (licensee)
- E4. Nikola Miskovic, University of Zagreb (end user)
- E5. Vladimir Djapic, H20 Robotics (end user)
- E6. Terry Sloane Ecosub Robotics, (end user)
- E7. Alex Hamilton, DSTL (end user and NATO standard lead)

Licence statements (confidential) from:

- E8. Blueprint Subsea
- E9. Tritech
- E10. WENSE