

Rifle-Mounted Gunfire Location

by Alan Wignall

Alan Wignall is Technical Director of Ultra Electronics Sonar Systems. In this article he describes how techniques from sonobuoy signal processing have been used to create a gunshot location sensor which is small enough to be rifle-mounted. The sensor could be fitted to a range of other mobile or fixed platforms, or integrated with other sensing or targeting systems. It can operate standalone, or can be used in an 'array of arrays' on vehicles or helicopters, and could be wirelessly networked for real-time plotting or dissemination of live-fire contacts.

Ultra was awarded a contract in November 2007 under the MoD's 'Competition of Ideas' (CoI) initiative, to demonstrate a novel gunfire detection sensor which uses techniques adapted from underwater acoustic signal processing.^{1,2} Development work is continuing, both on the physical sensor and on the signal processing algorithms, to improve the dependability of the unit in difficult acoustic conditions, and to move the Technology Readiness Level³ of the sensor from TRL6 to TRL7 and beyond.

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Technical Description

The technical challenge is to accurately measure the direction of the blast and shock pulses using a small sensor. In the rifle-mounted gunfire locator (RMGL) sensor, direction is obtained by measuring phase shifts between pairs of microphones. The resulting direction vectors (one per frequency cell) are integrated across an appropriate frequency band. This approach is tolerant of pulse shape distortion as the acoustic pulse propagates to each microphone, which enables the use of such a small array.

Acoustic and ballistic plausibility checks are used to associate shock pulses and blast pulses. The plausibility checks, and range estimation accuracy, are optimised for near-miss shots (miss angle ≤ 0.1 radians). Shots at very wide miss angles, and friendly (outbound) fire will be rejected. Orientation compensation is done using micro electro-

mechanical systems (MEMs) gyros, accelerometers, and a digital compass.

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The sensor can be attached to a weapon via a Picatinny rail, or indirectly to a cowling via a bespoke footplate and quick-release mechanism. This enables the sensor to be located almost anywhere convenient on a weapon. Total added mass is less than 400 grams.



Figure 1: First generation prototype RMGL on an SA80. The gunshot detector mounts on the rifle, above or to the side of the optical sight, with a small display giving accurate localisation of the shooter, mechanically aligned with the sight. The sensor gives direct benefit to the soldier, but can also be networked to improve situation awareness at the platoon commander level and above

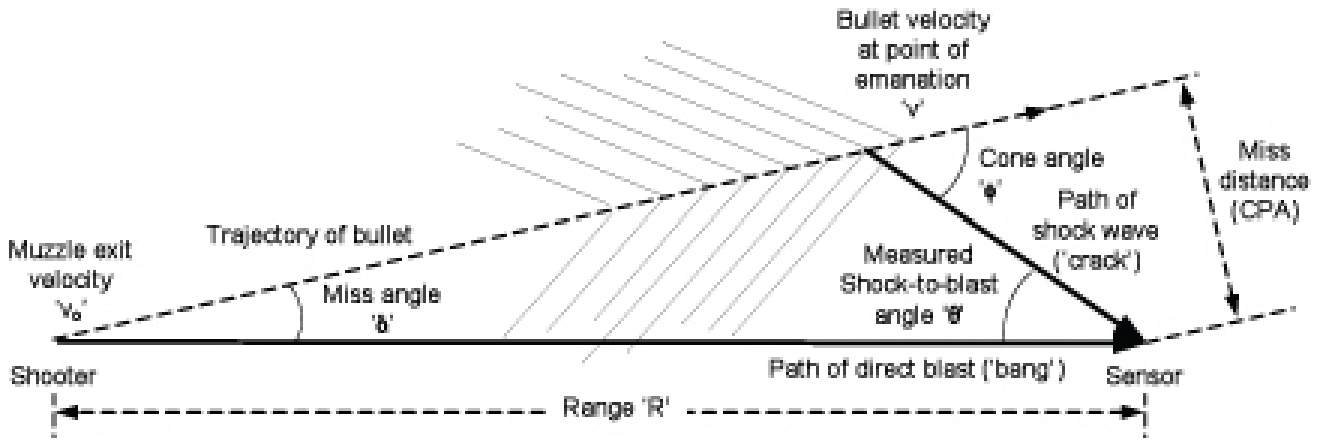


Figure 2: Basic ballistic geometry. The shooter is located by measuring the time of arrival and direction (in three dimensions) of the shock and blast pulses. The crack-bang delay and separation angle validate the blast detection and give range

Unlike the initial prototype (Figure 1), the preferred configuration for further development is to side-mount the unit, with the sensor ball projecting forwards. This minimises obscuration, and allows flexibility over choice of optical sight and precise mounting position. A one-inch cellphone style OLED (Organic LED) display provides full colour capability and is dimmable. However, the preferred display is plain and simple, dimmable-white on black.

Measured Performance

Under the Col programme, ten live fire tests and trials were conducted between November 2007 and July 2009. A variety of ammunition and weapons were used, including 5.56mm (SA80, FAMAS), 7.62mm short (AK47), 7.62mm long (L96, Dragunov SVD, GPMG), 12.7mm (PGM). Data was also collected for RPGs and Mortars, for future development. The tests were conducted at the National Shooting Centre (Bisley), at the Infantry Trials and Development Unit (ITDU) Warminster, and as part of a NATO test at Bourges.

The first eight live fire events gave encouraging results. The last two trials, including one on a rifle being carried by

a soldier, revealed robustness problems in the hardware design and algorithms, which have since been corrected. The performance summary presented here is based on 656 shots from the eight initial tests. These include 630 shots within a miss angle of 0.1 radians, and 26 with miss angles of up to 0.3 radians.

Table I summarises the probability of detection (Pd) and probability of localisation given a detection (PL) results. The criteria used for correct localisation are that the azimuth should be within $\pm 10^\circ$, the elevation should be within $\pm 10^\circ$, and the range should be within $\pm 15\%$. Figures 4 and 5 give the actual accuracies obtained.

Challenges: Concept of Employment

One of the greatest challenges in exploiting any novel technology is the absence of a formal user requirement or Concept of Employment (CONEMP). For the RMGL sensor it is unclear at this stage whether the sensor should be given to every soldier in a platoon, or just to a platoon leader or specialist. Should it actually be on the rifle, or integrated with a separate sighting device? Should it be

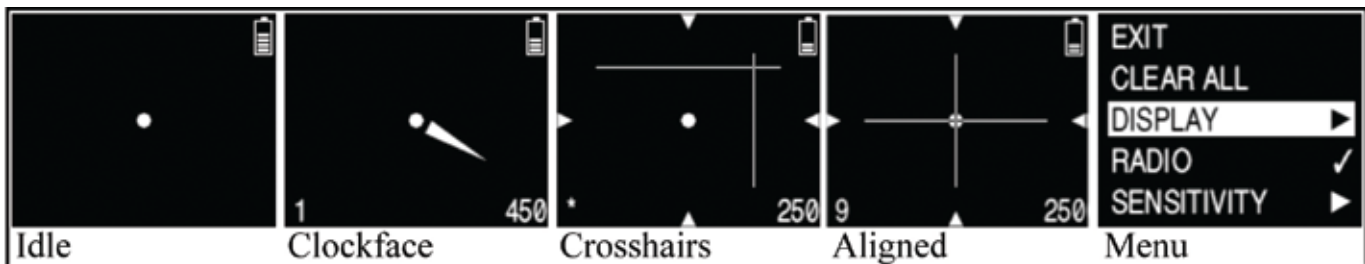


Figure 3. Operator-machine interface. A clockface indicates the bearing and range of the shooter, updating continuously as the weapon rotates. Bearing/elevation cross-hairs appear when the weapon is aligned within 30° of the target. When aligned, the shooter should be within the field of view of the optical sight. The number of detected shots and the range of the current shot are displayed numerically. A simple menu enables adjustment of operating modes and parameters

	Shots	% Pd	% PL	% Pd*PL
30-150m	214	98.6%	91.9%	90.7%
151-350m	293	96.2%	86.9%	83.6%
351-500m	117	95.7%	76.8%	73.5%
500m+	32	93.8%	100.0%	93.8%
L96	287	96.9%	84.2%	81.5%
SA80 & FAMAS	219	97.3%	90.1%	87.7%
AK47	73	91.8%	80.6%	74.0%
Dragunov	64	100.0%	96.9%	96.9%
PGM	13	100.0%	100.0%	100.0%
Overall	656	96.8%	87.4%	84.6%

Table 1: Probability of detection and localisation v. range and v. weapon type. Overall probability of detection (Pd) was 96.8%. Overall probability of detection and localisation (Pd*PL) was 84.6%

networked, and, if so, how would information be used and disseminated? Should it also be fitted to static weapon emplacements, or to vehicles, or to remotely controlled weapons on vehicles?

The results from the Col technology demonstration programme, and continuing work by Ultra, are helping MoD to develop a CONEMP for RMGL.

Challenges: Acoustic Environment

The acoustic signal processing algorithms, and the detection and localisation algorithms, must be robust to variability in the operating environment, including difficult acoustic conditions, complex operational scenarios and unknown weapon types.

The problem was overcome by using a liquid repellent nano-coating, which involves attaching a nanometer-thick polymer layer over the entire surface of the sensor ball

A complex operational scenario would include urban terrain with strong acoustic multi-path, with multiple shooters, each firing in bursts, and in the presence of friendly outbound fire. The challenge is to correctly associate shocks and blasts from each shooter. The existing algorithm provides some capability in these '3-M' scenarios (Multi-shot, Multi-path, Multi-shooter), but it is planned to improve the detection and localisation algorithms in the next generation of the RMGL sensor, in conjunction with a more powerful signal processor.

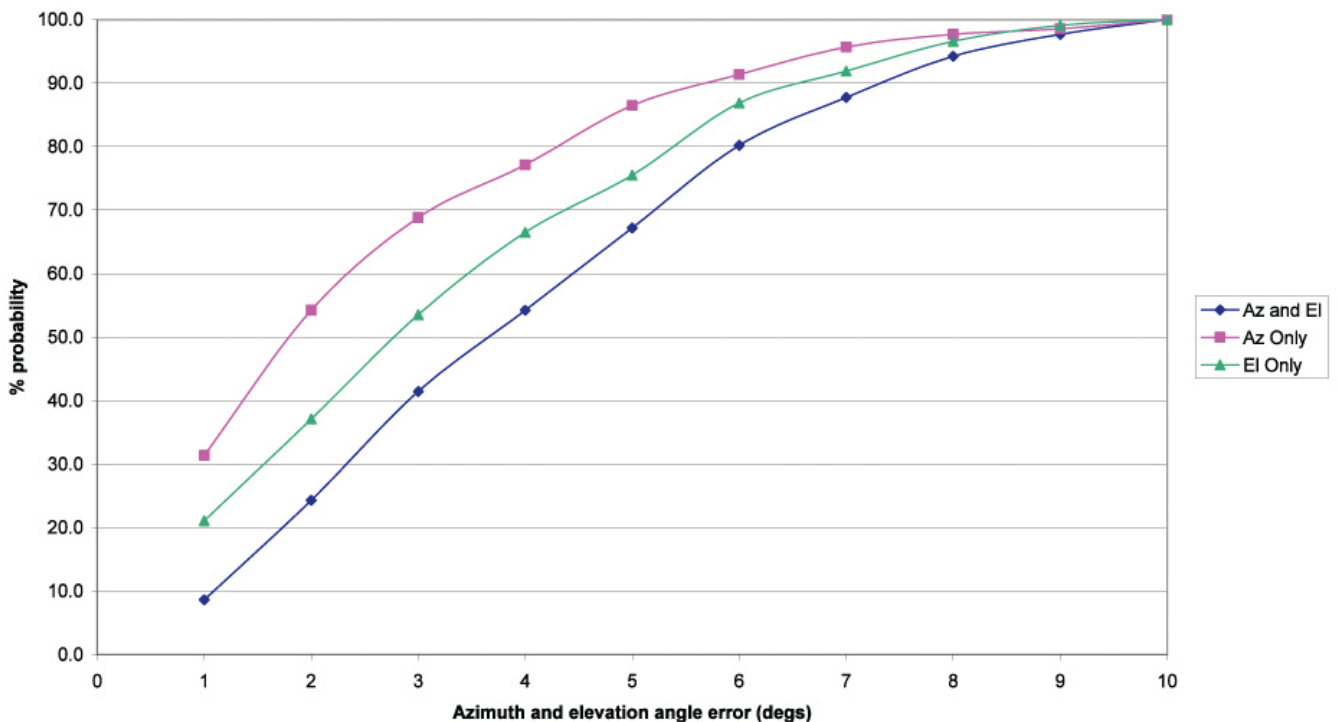


Figure 4: Cumulative probability distribution of angular errors for correctly localised shots. 85% of shots are within $\pm 5^\circ$ in azimuth, 75% are within $\pm 5^\circ$ in elevation, and 67% are within $\pm 5^\circ$ in both azimuth and elevation

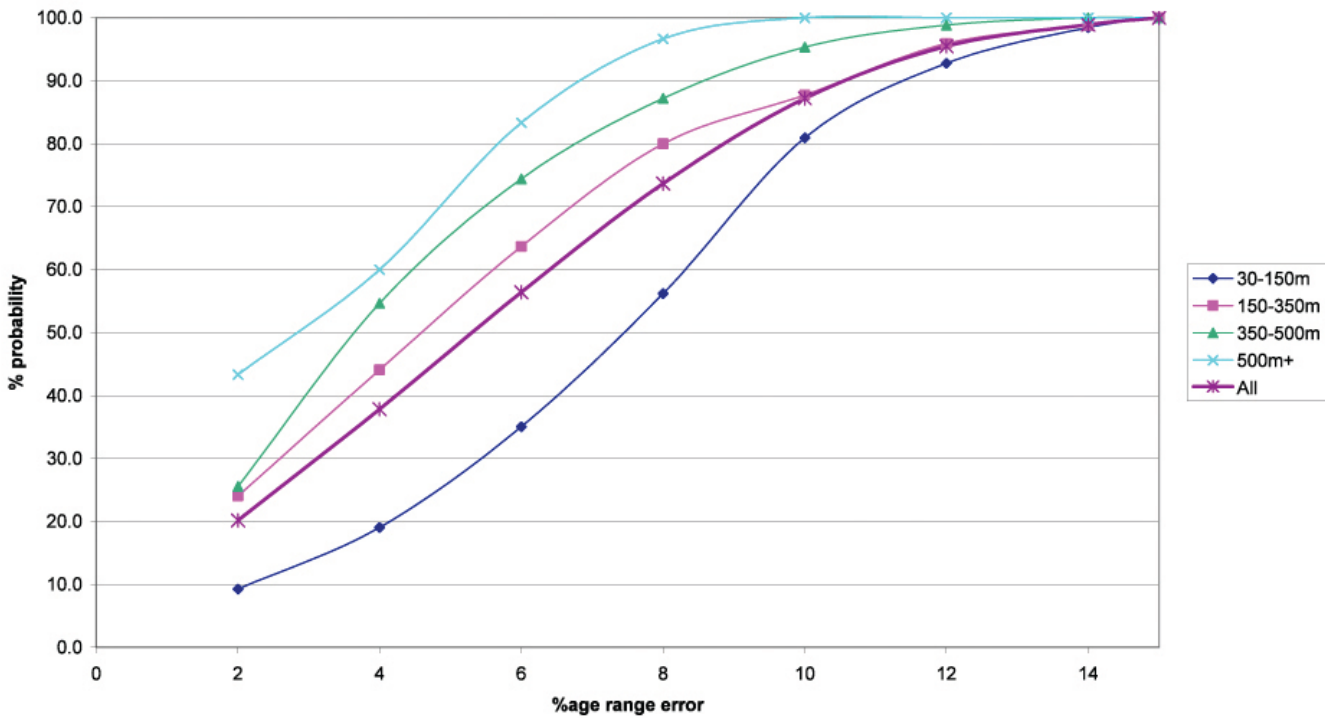


Figure 5. Cumulative probability distribution of range errors for correctly localised shots. Over 80% of shots are localised within +/-10% in range

Challenges: Rain And Dust

The original sensor allowed a thin film of water to form over the acoustic window when used in the rain, which caused attenuation and phase distortion, thereby degrading detection and localisation performance.

Power minimisation and management – to achieve a battery life of at least 24 hours (ideally 36 hours) – is a key design aim for next-generation hardware

The problem was overcome by using a liquid repellent nano-coating, which involves attaching a nanometer-thick polymer layer over the entire surface of the sensor ball.⁴ This is effective in stopping a film of water from forming, ensuring that the acoustic window of each microphone is always sufficiently open to avoid phase distortion. Similar hydrophobic behaviour can be obtained using a Gore-Tex Acoustic Vent or Protective Cover,⁵ which is currently favoured as a longer term solution because it can protect microphones from both water and dust. Development work is continuing on the mechanical and materials design for RMGL.

Challenges: Battery Life

The system architecture enables management of power consumption to extend battery life, by means of display standby, processor standby, and gyro power-down when at rest. The first generation prototype, which used COTS electronics, and only implemented the display standby feature, gives a battery life of only 5-6 hours (using 2 lithium AA cells).

Power minimisation and management – to achieve a battery life of at least 24 hours (ideally 36 hours) – is a key design aim for next-generation hardware.

Applications

Immediate development plans are focused on algorithm and electronics improvements of RMGL as a standalone sensor. However, it is envisaged that the RMGL will evolve to become integrated with modern all-digital and digital/optical sights, thereby reducing weight and clutter on the weapon and providing an operationally simpler package.

The sensor is also suited to a variety of other applications and platforms, used singly, networked, or integrated as an acoustic ‘array of arrays’. The sensor could also augment other sensors or targeting equipment, such as cueing a camera, or an automatic external gun on a land vehicle.

Helicopter hostile fire indication (HHFI) is an important and promising application area. It is a particularly challenging acoustic problem because of wind noise and helicopter



Figure 6: Droplet of water on hydrophobic-coated window. The coating prevents formation of a water film, which keeps the acoustic window sufficiently clear to avoid distortion

self-noise, but a live-fire flight trial using a GPMG with two RMGL sensors fitted to a Lynx helicopter has shown that gunfire can be detected and localised using shock-only detections. Furthermore, the sensors can be used to adaptively cancel spatially and temporally correlated helicopter self-noise. A typical installation would involve fitting an array of three or four RMGL sensors (depending on the size of the helicopter), with digital data outputs sent to the existing mission system or defensive aids system for processing and display.

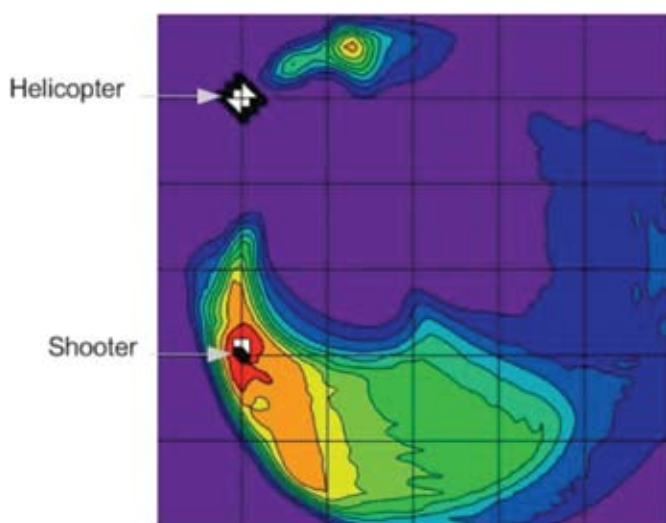


Figure 7: Probability-map localisation method for a simulated HHFI scenario. The aircraft flies west to east, at an altitude of 200 metres, and speed of 40 m/s. The shooter is at a range of 600 metres to the south (indicated as a black dot on the map), and starts firing when the aircraft is due north of his position. The assumed aim point is 20 metres ahead of the aircraft and 20 metres below the aircraft. A burst of 2 shots is fired, at 0.2 second intervals. The estimated shooter location is shown as a white square

The HHFI signal processing involves generating a probability map by reconciling hypothetical shooter positions (on the ground) with measured direction and time differences, over a number of possible weapon classes, accumulated over a number of shots, and as the helicopter moves.

The challenge of being able to tolerate rain and dust is particularly severe for HHFI, and to address this Ultra is developing a waterproof solid-state version of the RMGL sensor, using sonobuoy hydrophone technology.

However, poor performance in some environments, especially rain, resulted in a number of physical and software modifications

Conclusions

Since the award to Ultra in November 2007 of a 'Competition of Ideas' contract by DTIC, the Rifle Mounted Gunfire Locator has been developed from a concept, with the help of the British Army ITDU, to prototype units that are small and robust enough to be mounted on a weapon and trialled by soldiers in live-fire scenarios.

Performance was consistently good across most of the trials conducted during the CoI programme (96% of all single shots in an open environment were correctly detected and 87% of those were accurately localised). However, poor performance in some environments, especially rain, resulted in a number of physical and software modifications, which are being verified using further live-fire trials.

Significant interest in RMGL and related applications has been shown by the UK and by other armed forces worldwide, which it is hoped will lead to exploitation of the technology. ■

NOTES

- ¹ UK patent GB 2446941B 'Acoustic Pulse Analysis', October 2008
- ² US patent 7502279 'Improvements Relating To Target Direction Indication And Acoustic Pulse Analysis', March 2009
- ³ TRL Definitions www.aof.mod.uk/aofcontent/tactical/techman/downloads/trl_definitions.pdf
- ⁴ Liquid repellent nano-coating technology. <http://www.p2ilabs.com/>
- ⁵ Gore-tex acoustic vents http://www.gore.com/en_xx/products/venting/protective/products/acoustic_holder.html