Institution: University of Bath

Unit of Assessment: B9 Physics

Title of case study: No place to hide: law enforcement and protection of critical infrastructure through detection of GPS jamming

Period when the underpinning research was undertaken: 2003-2020

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:
Robert Watson	Senior Lecturer, previously Lecturer	September 1998 to present

Period when the claimed impact occurred: 1/8/2013 – 31/12/2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Research conducted at the University of Bath has increased the resilience of Position, Navigation and Timing (PNT) systems to the criminal operation of devices that can jam Global Navigation Satellite System (GNSS) signals and specifically Global Positioning System (GPS) signals. Deliberate jamming can now be detected and located in real time, allowing rapid and efficient law-enforcement response, and protecting critical infrastructure. Chronos Technology markets two handheld detectors, CTL3510 and CTL3520, developed by the University of Bath and the CTL3530 GPS JammerCam developed in a collaborative project. These are now in use by many police forces in the UK and overseas, and have resulted in the detection and arrest of organized crime activity related to high value asset theft (30 cars [text removed for publication]). [text removed for publication].

2. Underpinning research

The timing signals from GPS satellites are very weak when they arrive at a receiver on Earth. The signal to noise ratio is much less than one, and a GPS receiver must extract the time and position information by comparing the received signal with templates of the known transmissions of the different satellites at different times when observed from different locations on Earth. When a match is found, that gives the current time and location.

Watson undertook research at the University of Bath using the propagation of GPS signals through the atmosphere to map the density of free electrons in the ionosphere by recording the dephasing (or scintillation) of the signals received by a fixed ground station in a known location [1]. This analysis relied on Watson's deep understanding of the propagation of electromagnetic waves, both in the bulk of the troposphere and also in the final few 100 metres to the receiver, where local multiple path interference from buildings or traffic can disturb the signal [2]. The result of this research was an understanding of how GPS signals can be used to observe the effects on the ionosphere of events like coronal mass ejections from the sun, and conversely how these space weather events can affect GPS navigation and timing on Earth. It also gave Watson a detailed knowledge of the delicate effects of many different natural noise sources on the GPS signals.

[text removed for publication]With his understanding of the usual variability of noise in the GPS frequency range, and also knowledge of the magnitude of intermittent events associated with space weather, Watson was immediately able to see that the disruption did not fit any of these existing patterns. It quickly became apparent that the events seen by Chronos were man-made in origin, and Watson set about to devise an instrument able to distinguish automatically between natural and man-made interference in GPS signals. This

interference may also be very weak; the GPS signal is already below the natural noise levels and so can be swamped by something that itself is barely above that background. This makes deliberate GPS jamming devices cheap to buy, but also very difficult to detect. To make a detection system particularly useful it would need to be hand-held, and would also need to detect the direction of the man-made noise in order to locate it [3,4,5,6]. Watson designed a detection and analysis system to identify different types of additional man-made noise, which became the product CTL3510 (late 2013). He further developed an interferometric detector to give direction information, which became the product CTL3520 (2013/14). A particular challenge here was to devise an interferometer that is smaller than the 20 cm wavelength of the GPS signals, in order for the complete system to be hand-held.

Technology transfer to Chronos Technology Ltd was accelerated by three joint Innovate UK projects, GAARDIAN (TS/G002592/1, 2008-11), SENTINEL (TS/I00257X/1, 2011-13) and AJR (UKRI 131602, 2014-15). Continuing engagement between Watson and Chronos Technology has led to the development of the JammerCam (CTL3530), which combines jammer-triggered camera technology with automatic number plate recognition.

3. References to the research

[1] Smith, AM, Mitchell, CN, Watson, RJ, Meggs, RW, Kintner, PM, Kauristie, K & Honary, F 2008, 'GPS scintillation in the high arctic associated with an auroral arc', *Space Weather*, vol. 6, no. 3, S03D01, pp. 1-7. https://doi.org/10.1029/2007sw000349

[2] Davies, OT, Mitchell, CN, Spencer, PSJ, Nash, JD, Watson, RJ & Watson, PA 2004, 'Application of GPS phase delay measurements in radio science and atmospheric studies', *IEE Proceedings - Microwaves Antennas and Propagation*, vol. 151, no. 1, pp. 1-6. https://doi.org/10.1049/ip-map:20040126

[3] Portugués, IE, Moore, PJ, Glover, IA & Watson, RJ 2008, 'A portable wideband impulsive noise location system', *IEEE Transactions on Instrumentation and Measurement*, vol. 57, no. 9, pp. 2059-2066. https://doi.org/10.1109/TIM.2008.917258

[4] Lloyd, EM & Watson, RJ 2018, 'An array antenna for low power localisation of GPS interference' in *Proceedings of 12th European Conference on Antennas and Propagation EuCAP 2018,* IET, pp. 1-5, 12th European Conference on Antennas and Propagation, EuCAP 2018, London, UK United Kingdom, 9/04/18. https://doi.org/10.1049/cp.2018.0585

[5] Lloyd, EM & Watson, RJ 2019, 'Using a bio-inspired algorithm for efficient Angle-of-Arrival estimation of GNSS jammers' in *13th European Conference on Antennas and Propagation, EuCAP 2019*, 8739781, IEEE, 13th European Conference on Antennas and Propagation, EuCAP 2019, Krakow, Poland, 31/03/19.

[6] Lloyd, EM & Watson, RJ 2020, 'Comparison of adaptive null-steering algorithms for low power GNSS phased arrays' in *14th European Conference on Antennas and Propagation, EuCAP 2020*, 9136029, 14th European Conference on Antennas and Propagation, EuCAP 2020, IEEE, U. S. A., 14th European Conference on Antennas and Propagation, EuCAP 2020, Copenhagen, Denmark, 15/03/20. https://doi.org/10.23919/EuCAP48036.2020.9136029

4. Details of the impact

Research at Bath has translated into economic impact through the development of a new product range and service from Chronos Technology since late 2013, and societal impact through removing threats to critical systems and uncovering criminal activity, resulting in enhanced security for businesses and people.

There are many reasons for individuals to use deliberate GPS jammers. Fleet operators often install location systems in their vehicles and individuals may want to defeat that system, for example to conceal personal use of vehicles, to sleep at home rather than a lorry park, or to manipulate working hours. These jammers are small and just plug into the cigarette lighter socket of the vehicle, but the jamming can affect others in the area, including infrastructure. Jammers are also used by criminals, particularly to defeat in-car GPS tracking systems. High value vehicles often have concealed tracking devices to relay their location if they are stolen. Organised crime gangs targeting vehicle theft use GPS jammers to remove vehicles without them being tracked. [text removed for publication]. Criminals may also fear that law enforcement have fitted trackers to their vehicles and so use GPS jammers. Using GPS jamming is itself an offence in the UK, but it is also associated with higher-level crime.

GPS jamming may also be unintentional, for example from faulty installation of GPS equipment causing leakage of the amplified signal that it is using. This may be in vehicles or in fixed installations and will disrupt local systems.

Economic impact

Chronos Technology Ltd is a UK SME specialising in bespoke products for time and frequency synchronisation. In 2016 it had 45 full time staff and a turnover of GBP5,500,000 [A]. The collaboration with Bath researchers has led to commercialisation of a new range of products during the REF period: the CTL3510, CTL3520 and CTL3530 GPS jamming detectors [B]. ***The key features of these products are that they are hand-held and that they generate alarm signals in real time when jamming is detected.*** From August 2013 up until end of December 2020, more than [text removed for publication] devices have been sold to the civilian, defence and security markets in the UK and [text removed for publication] other countries, [text removed for publication]:

[text removed for publication]

Protection of critical infrastructure

Many critical systems rely on GNSS-derived timing and navigation, including aviation, shipping, transportation of high-value or hazardous goods, banking transactions, mobile phone networks and emergency service communications. The protection of these systems is vital to the daily operation of a nation's infrastructure [D].

Port systems rely heavily on GPS for container handling and operations can be seriously disrupted by jammers. Chronos have test installations at port entries ([text removed for publication]) and motorway services in collaboration with UK police [E]. These regularly detect and image vehicles carrying jammers [text removed for publication]. As an example of the effective protection of port systems using Chronos products, [text removed for publication].

Not all jamming is intentional. Chronos detectors are also used to quickly identify jamming signals coming from faulty cables and antennas, enabling rapid restoration of timing information in critical commercial operations [F].

Chronos CTL3510 jamming detector fitted to a police motorcycle.

Detection of criminal activity

- [text removed for publication].

For example, in a case where jamming detection was used[text removed for publication]:

[text removed for publication]

Chronos Technology continue to work with Bath to develop new products. The latest Chronos product to emerge is the "JammerCam" [H] and is the first GPS jamming detector in the world to be able to identify and photograph a moving vehicle which is carrying a GPS jammer. This product is currently in trials with various local police forces, with the apprehension of jammer users, seizure of jammers [text removed for publication].

Summary of impact

- Multiple police forces in the UK and across law-enforcement agencies internationally (including Europe, USA[text removed for publication]) are now aware of the problem of GNSS jamming and have access to new detection techniques.
- The use of the Bath-Chronos products for jamming detection has had a major impact on law-enforcement activities in multiple countries including the discovery and retrieval of high-value assets (30 cars [text removed for publication]) [text removed for publication][C,E,G].
- Critical infrastructure has been protected [E,F].
- Bath-Chronos jamming detectors are in regular use with [text removed for publication] [C].
- Development of a new product range and service has had [text removed for publication]impact on Chronos Technology Ltd's continued business success, [text removed for publication] [C].

5. Sources to corroborate the impact

[A] Chronos company description https://navisp.esa.int/actors-involved/details/35/show (accessed 14/01/2021).

[B] Details of the products can be found on the Chronos website: https://www.gps-world.biz/products/gnss-interference-detection products CTL3510, CTL3520 and JAMMERCAM. (accessed 14/01/2021).

[C] Letter from [text removed for publication] of Chronos Technology, 15 October 2020.

[D] London Economics technical report, "Economic impact to the UK of a disruption to GNSS", April 2017. Commissioned by Innovate UK, the UK Space Agency and the Royal Institute of Navigation.

[E] [text removed for publication] Newsletter [text removed for publication], Feb/March 2020.

[F] Chronos case study: Detecting Rogue GPS Antennas, 2020. https://www.chronos.co.uk/files/pdfs/cs-an/chronos_detecting-rogue_gps_antenna.pdf

[G] Email from [text removed for publication] Police, 18 November 2018.

[H] Chronos website, Jammercam product information https://www.chronos.co.uk/files/pdfs/ctl/chronos_jammercam_ctl3530.pdf (accessed 14/01/2021).