Summary report of a 1-day Workshop on Sensors and Sensing Technologies, funded by the NRN-LCEE Research Development Fund.

29th June 2016. Henfaes Research Centre, Abergwyngregyn, Bangor University, Wales, LL33 0LB.

Background:
With a burgeoning population to feed, and dietary changes resulting in even greater demand for livestock products, there is a need to be smarter in terms of resource use efficiency in agricultural production. In addition, the UK has signed up to a number of challenging environmental targets, whilst livestock health and welfare also need to be considered. Sensors and sensing technologies offer tremendous potential to contribute to practical sustainable land and livestock management, and increase profitability and animal welfare. Sensing technologies are also being used in research to improve temporal resolution of sampling the environment, sampling new 'pools' of nutrients, and investigate relationships between e.g. livestock behaviour and environmental outcomes.

Hence, the goals of the Workshop were to: share latest research, development and application of sensing technologies that promote sustainable agricultural production, generate dialogue between the inventors, researchers and users of sensing technologies, and to accelerate their application.

Workshop programme:
>35 participants registered for the Workshop, comprising representatives of academic and industry research, business/industry developers, suppliers and users of sensor technology, Government and NGO's. The Workshop took the format of invited lectures (in three themes), demonstrations of livestock sensors (during the lunch break); and discussions about the barriers to adoption and the potential of sensors and sensing technologies to improve resource use efficiency in land and livestock management.

Presentations:
The detailed programme and pdf's of all the presentations can be found on the NRN-LCEE website at the following link: http://www.nrn-lcee.ac.uk/rdf-sensors.php.en.

Theme 1*. *What is the future of Sensor Development and Use?
- *What things dare we attempt to sense and how do we optimise sensor function?* Speaker: Toby Mottram (eCow)
- *How might we link sensors, systems and networks for best effect?* Speaker: Bruce Grieve (University of Manchester)

Theme 2*. *How can we push the boundaries from 'fixed/managed' sensors across time and space?
- *How much can we sense beneath our feet (Rhizosphere-plot scale)?* Speaker: Rory Shaw (Bangor University)
- *What is the future of whole-farm – smart agriculture sensing (field-farm scale)?* Speaker: Saverio Romeo (Beecham Research)
- *How do we capitalise on real-time data (M2M, IoT approaches)?* Speaker: Gordon Blair (Lancaster University)
- *What can we tell from the air (farm-landscape scale)?* Speaker: Dan Morton (CEH).

Theme 3. How can we best use sensors to interrogate livestock?
- *What sensors work for livestock now and where might we go?* Speaker: Mark Rutter (Harper Adams University)
- *Example of livestock-borne sensor use / virtual fences*. Speaker: Tony Waterhouse (SRUC)

- *How do we maximize tag capacity and deal with big data?* Speaker: Mark Holton (Swansea University)
- *How far can we push our understanding of animal behaviour, 'opinion' and 'state' with sensors?* Speaker: Rory Wilson (Swansea University).

Demonstrations:
Tom Misselbrook (***Photo 1***. Rothamsted Research, North Wyke) show-cased the urine sensor used to collect information on urination volume and frequency by grazing (female) cattle, as well as the total N content of the urine (using an on-board refractive index sensor). Tom Misselbrook has recently published the data generated by these urine sensors fitted to beef cattle in a study with SRUC (Misselbrook et al., 2016).

Rory Wilson and Mark Holton demonstrated accelerometers and visualisation of behavioural 'fingerprints' (***Photo 2***.) that are being used in the new NERC funded *Uplands-N_2O* project to assess the relationship between sheep grazing behaviour with urine composition and subsequent N_2O emissions from upland soils.

Photo 1. **Photo 2.**

Photo 1. Demonstration of a cattle urine sensor by Tom Misselbrook (RRes). ***Photo 2***. Demonstration of accelerometer sensors for assessing livestock movement and behaviour (Mark Holton and Rory Wilson, Swansea University).

Discussion sessions:
Below we summarise the main topics of discussion under the headings 'Challenges' and 'Opportunities'.

Challenges:

- <u>Power:</u> remains a constant limitation to long-term sensor deployment. The main drain on power is use of GPS and transmission of any data, such as uploading to the Cloud. However, novel power harvesting approaches are being trialled, and low power systems (including smart sampling rates) are being developed with attendant low battery consumption. This is being complimented by on-board analysis allowing reduced data upload rates, thus increasing the reliability of networks.
- <u>Site of data processing:</u> there was some agreement that sending minimal data to the Cloud for processing was better although, where possible, it is a good idea to store all data on the

sensor for more in-depth analysis at the end of the deployment. On-node and edge-Cloud computing were seen as better sites for data processing.

- Data quality: when are high quality, low output data better than cheap and cheerful high output, lower quality data acceptable? If 'direction of travel' is more important than fully quantitative data, then greater spatial representivity can be achieved using multiple cheap sensors. But there potential issues of interoperability, with a lack of standards at all stages (data capture, processing and storage).
- Skill-base: with the huge amounts of data generated, the future will see a critical need for data scientists / bio-informaticians. Developing the sensor *per se* is often the easier part of the process. It is how the data are used to generate smart information that is now a key challenge.
- Cost: There was agreement that the sensor developers could make virtually any sensor asked of them. The challenge would be that the cost of the unit may be unacceptable to the market. Most livestock sensors are used in the dairy industry, and precision fertiliser and herbicide spreading sensing technologies are used in the arable and dairy sectors. Beef and lamb margins would not currently afford the use of (m)any sensors, unless supported by other mechanisms, i.e. environmental stewardship or assurance schemes.
- Public perception: there is potential for using sensors to control movement of livestock in fields e.g. through the use of collars and virtual fences. Public perception of such collars would be more acceptable if audio-based sensors were used. Public opinion is an important part of the equation for use of livestock-borne systems and support is much more likely to be gleaned if the sensors are presented as enhancing animal wellbeing.

Opportunities:

- Visualisation: humans are visual beings. We can make sense of data when presented in a visual form. Hence there is great opportunity to explore visualisation approaches.
- Image analysis: linked to the bullet point above, computer-based image analysis offers great opportunity to determine e.g. individual animal performance, readiness for market, health and welfare (via gait analysis).
- Data processing and computer-based learning: Sensors can measure at up to 800Hz (e.g. micro-accelerometers). With such high temporal resolution sampling – huge amounts of data can be captured, requiring specialist data processing tools. In addition, computer-based learning can be used to detect patterns to enable us to learn about new relationships and formulate new hypotheses.
- Bio-acoustics: whilst there was no demonstration of bioacoustics sensor technologies, within house sensors (especially pig and poultry systems) would be able to assess state of being, e.g. positive affective state or aggression, so that interventions could be implemented if needed. Sensors on access gateposts in fields could determine cattle and sheep presence etc. From a research perspective, bioacoustics technology could infer grazing preference (as well as information on bites, chew, bite mass = intake) and differentiate between urination and defecation events, especially if coupled with other sensors such as accelerometers, and so be able to improve grazing management.

- Biodegradeable sensors: many sensors are deployed in the environment, e.g. in soil, water, the rumen – and retrieval post-use can be a challenge. So, constructing sensors out of biodegradable materials seems like a useful strategy.
- Smartphone technologies: Smart-phones can be used to receive recommendations from the Cloud following data processing from sensor networks. But smartphones can also be used / adapted e.g. through cheap attachments, for e.g. hyperspectral imaging for crop disease. This type of technology can help ground-truth remote sensing observations.
- Cross-over technologies: We are now using medical scientific approaches, e.g. micro-dialysis, in soil science. What were once measurements that could only be made in a GP's practice or hospitals, or developed by the military or space agencies, are now routinely encompassed in, and accessible by, smart watches and phones (e.g. GPS, heart rate, etc). There is still great potential for using cross-over technologies, and deploying them in different ways in a range of environments.
- Livestock sensor applications: in extensive systems, where locating livestock is challenging, then livestock-based sensors offer a solution, e.g. as a virtual shepherd to assess livestock health and welfare. But these types of farming systems are not always profitable, so costs may outweigh the benefits. The challenge is to determine if some of these additional sensor costs can be supported via other sources, e.g. via environmental stewardship schemes. The use of sensors would need to be linked to the delivery of additional ecosystem services.
- Livestock as sensor carriers: Livestock roam the fields, and hill and upland landscapes. Can we fit unobtrusive sensors to them, so they can gather useful information for the farmer about the soil, pasture, etc. e.g. measure places of soil compaction, determine standing sward height.

Future funding opportunities:

Participants at the Workshop mentioned the following specific funding opportunities:

- The Science and Technologies Facilities Council - http://www.stfc.ac.uk/funding/

References:

Misselbrook, T., Flemming, H., Camp, V., Umstatter, C., Duthie, C.-A., Nicoll, L., Waterhouse, T. (2016). Automated monitoring of urination events from grazing cattle. *Agriculture, Ecosystems and Environment* **230**, 191-198.