Development and testing of an Internet-of-Things (IoT) based system for remote monitoring of thermal environments in swine barns

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Improving Swine Production through Technology

Swine production has evolved from dirt lots to confined buildings in a short period of time. The evolution of hog building has been a result of technology development. But also, the development of swine confined building brings higher requirements for the thermal environment management. If the swine barn has high temperature, several problems may encountered with pigs, such as the loss of appetite, poor growth performance, which resulted in increased mortality and morbidity of pigs (Ross et al., 2015). Conversely, low temperature also has negative effect to pigs, which result in low growth rate and low feed-to-meat conversion efficiency to pigs (Ames et al., 1980). Therefore, the monitoring of thermal environments is important in a swine barn.

In this case, a system, which can measure the thermal environment and send relevant information to producers in real-time, is very helpful to swine producers.

Typically, an IoT-based monitoring system is composed of four physical layers:

- Sensor nodes. A sensor node performs measurement and transfers data to an IoT gateway.

- IoT gateways. An IoT gateway brings sensor nodes with an access point to the Internet.
- Network servers. A network server directs the data to its right destination (i.e., IP address).
- Web servers. A web server hosts webpages or mobile applications to interact with human users.

LoRa (Long range) is a low-power and wide-area network modulation derived from Chirp Spread Spectrum (CSS) technology. This technology uses a wide band to counter interference and to handle frequency offsets due to low cost crystals. LoRa has several advantages: low-power consumption, high robustness, and long range. (Bor et al., 2016). Therefore, it is a best candidate to construct the IoT network in the swine barn scenario, which can provide long-distance and stable data transfer. LoRaWAN is a Media Access Control (MAC) layer protocol built on top of LoRa modulation. It is a software layer defining how devices use the LoRa hardware, for example the format of transferring messages. Figure 1 presents a typical LoRaWAN monitoring system architecture.

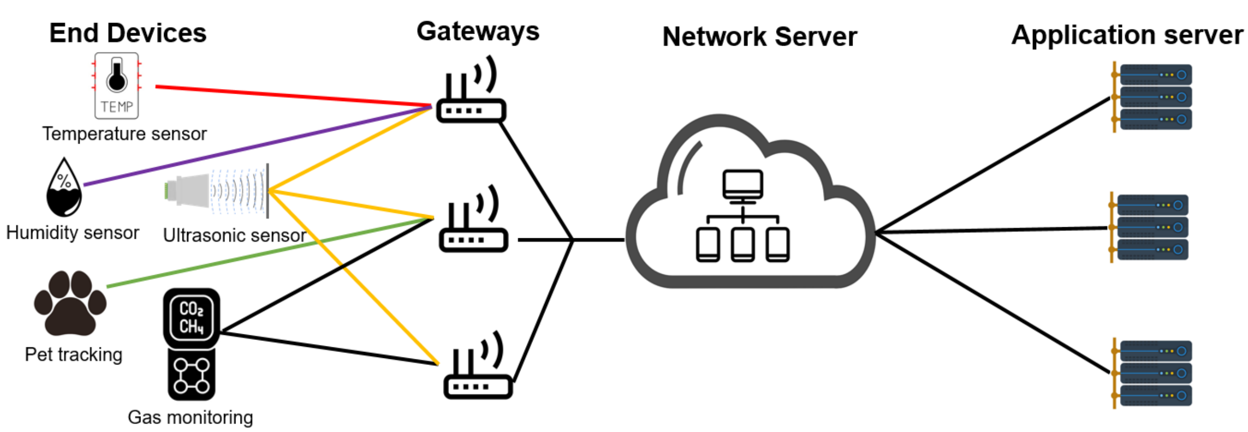

Figure 1. LoRaWAN monitoring system architecture

The objectives of this project are to:

- Develop an understanding of sensor and Internet-of-Things (IoT) technologies and their potential applications in swine production
- Be aware of the basic principles and procedures of scientific research
- Enhance the students' writing and presentation skills
- Gain first-hand experience with extension and outreach critical for the U.S. swine industry

Project Execution

Starting off our project three students met with each other and were introduced to one another. All coming from different backgrounds, they learned to utilize their skills to develop a plan that we could introduce for both Precision Agriculture as well as Animal Science. Zhiseng Cen (Jason) is a graduate research assistant for the Ag Engineering department on SDSU's campus in Brookings, SD. Audree Berreth would be an undergraduate Animal Science student at SDSU's campus as well. The final person in the group would be Hunter Koolstra who is an Agricultural Science major at SDSU. The group decided to use Internet of Things (IoT) while trying to implement the monitors/sensors in an animal environment.

The environment would be in a commercial wean-to-finish swine barn of approximately 800 hogs located just outside the Nunda exit on I29. The swine barn is owned by SDSU and is operated by students and faculty that attend the university and uses mechanical tunnel ventilation and deep pit manure management. The sensors being used in the project would be 2 separate LHT65 Temperature and Humidity Sensors as well as a LoRaWAN Distance Detection Sensor (LDDS75). The advantage of LoRa compared to a typical WIFI wireless connection would be the extended communication distance achieved by LoRa (up to tens of kilometers). In a commercial farm setting, it would be impractical for WIFI (with connectivity coverage < 30 m) to accomplish long range data transmission tasks that are often required.

During the first in-person meeting of the group, we decided to elect roles of Supervisor, President, Vice President, and Secretary/Treasurer. During this Hunter would be elected President, Jason Vice President, Dr. Yang Supervisor, and Audree the Secretary/Treasurer. During this meeting we also selected and prepared a budget for the sensors that we would be needing and ordered them that Thursday to be received the following Monday. The group decided the LHT65 and LoRaWAN sensors would be best fitting for the barn and to get results in a prompt manner. Audree was in charge of ordering the equipment and making sure the group's order was everything that was needed. Once Audree ordered the equipment she made sure to track the package and to pick it up from the Ag Engineering building. The package contained everything that was needed for this project and arrived in swift fashion.

In the third meeting, the group also was planning on how to set up TTN (The Things Network) as well as finishing up a MyDevices account through Cayenne for a The Things Network that helped the devices connect to the router to determine a more appropriate data response. As President, Hunter took charge in setting up the main parts of the sensors database. Once the device was set up, its data results would then be dispersed through the Cayenne network. Jason, Hunter, and Audree made an account for The Things Network as well as a MyDevices Cayenne that would be accessible for everybody. Making the account was similar to making an account for anything else and was easy to do. The convenience of logging in and checking your data while sitting at home, office, or etc. can save producer's time as well as limit time in a building. Not only is convenience a factor, but biosafety is also a factor. The biohazards that are present when dealing with swine are high because of their feces and odor. Swine must be kept clean and must have a clean environment when there are such an abundance of them in one area. By using IoT, we are able to view the data from our devices instead of having to physically go into the barn. Thus reducing the opportunity for biomatter contamination.

Setting up the devices in the Cayenne network went well between the group. Dr. Yang, the supervisor of everybody, helped us code the devices in a manner of allowing all of us to do it at once as well as ensuring accuracy between our devices. The steps given to the group helped everyone use critical thinking and make sure the data entered into the devices was correct. Trial and error occurred but the devices were set up to 100% precision for complete efficiency.

After completing the coding for the devices the group had to decide an appropriate location inside of the hog barn as well as keeping the LoRaWAN Distance Detection Sensor inside of a safe capsule that the pigs would not get access to. Jason and Hunter came up with a plan that would work but would have to be modified. The two individuals entered the Ag Engineering shop in hopes of a 6 inch wide PVC pipe that would have to be the length of the sensor with caps on both ends preventing the device from falling out as well as debris/ pigs entering the capsule and disarranging the device. They found the perfect prototype and attempted to develop it. The PVC pipe was a perfect prototype but would need a restoration.

After developing the prototype Jason, Hunter, and Dr. Yang went to the offsite SDSU swine unit. The three decided to go to the unit to develop a plan on an appropriate place for the devices for complete accuracy as well as how the devices would be safe from the pigs and out of the way of the workers inside of the barn. Entering the barn Jason and Hunter came up with scenarios and ideas of possible locations for the sensors. After looking into different spots the two decided that the LHT65 would be safe at eye level, screwed into the wall on opposite sides of the fan. The fan could change the data and could provide the sensors with faulty data that would not be accurate to the project. The next thing the group had to decide on was where the LoraWAN Distance Detection Sensor would have to be located inside of the barn. Since the device would have a transducer facing towards the pit to emit accurate data of pit manure level, they would have to have the device and capsule over top of the gap in the slats.

The offsite barn includes many features and one of the features would be a scale to weigh pigs. In between where the scale is as well as where a pen of pigs would be was a gap between the steel gates. The gap had everything the group was looking for, enough room for the capsule but also allowed for the transducer to reach just in between the cracks decreasing the chance of the unit swinging around. Keeping the capsule in between the two gates also decreases the chance of contact with pigs.

Following the attempt of the prototype as well as determining the final location of the sensors, Jason and Hunter met up and developed the supplies needed to make the finished capsule. The two individuals planned to go to Runnings in Brookings and get a 6 inch wide PVC pipe in a roll of 10 feet just in case of error in developing the product. With the roll of PVC Jason and Hunter got two 6 inch PVC caps that they would put on both ends. The group figured it was not worth glue because it still held a seal. After finding the roll, the two had to come up with an idea of how they were going to keep the capsule held up straight. Knowing that the capsule and sensor would have to come out they decided to buy two 14 inch hose clamps that they could fasten the capsule to the gates. After obtaining the supplies Jason and Hunter headed back to the Ag Engineering Building to cut the capsule to size and make any necessary adjustments. The capsule was cut to a foot long in length. After smoothing off the edges to make sure the lids fit on tightly, Hunter drilled an inch and half hole in the bottom cap to give room for the transducer to fit and work properly.

The following Friday Hunter, Audree, and Jason all met at the offsite barn to install all of the sensors. Since the router was pre-installed the group just had to make sure every sensor was reset and turned on and were installed properly. Since the offsite
barn is strictly bio secure every member of the group was required to shower in and shower out while following biosecurity protocols with outside objects entering the barn. After cleaning all of the tools and equipment the group then put on boots provided by the unit and started approaching where they were going to set the equipment up.

The group found a pen full of pigs that was in the middle of the barn that would allow for an average temperature of the barn as well as humidity. Like previously stated, the sensors were set in a way that the fan was not directly facing them as well. To get the LHT65 into the wall the group used one size #12 screws to get the device attached to the wall. Ensuring the screw wouldn't fall out Jason and Hunter made sure they found the stud in the wall. Once the stud was found the installation happened, screwing through the wall at about eye level for Hunter. The LHT65 temperature probe was pointed out towards the barn so that the data would be most accurate to the barn's environment.

The next sensor installed for the group was the LoRaWAN Distance Detection. Since the capsule and sensor were already set up the group just had to make sure it was firm to the gate and wasn't allowing for any slack. The capsule was lowered and held into place and a hose clamp was used to fasten the capsule to the gate. The capsule was on the gate closest to the pigs pen. Then finally for the last installation step was installing the final LHT65 sensor to the wall on the other side of the barn. Having the experience of putting one sensor into the wall the second was made for an easy process. All the sensors installed allowed the group to go back to the unit's office and double check that everything was running through The Things Network.

A week went by and the LoRaWAN Distance Detection gave a faulty reading in The Things Network. The group believed that either the sensor was malfunctioning or the capsule was tipped over. So Hunter, Audree, and Jason go back to the unit to either reset the sensor in whole or to find a plan to make sure it doesn't tip over. When the three got to the building they found the capsule was tipped over. The pigs got access to the hose clamps and made the capsule loose and ended up tipping it over resulting in fault data displayed to The Things Network.

The group decided to put the capsule on the gate towards the scale where no pigs could access it like the ones in the pen could. It also helped that pigs wouldn't be in contact with the capsule allowing the risk of a tip over to slim to almost nothing. Since the group only had one hose clamp the first time they decided to use two this time and tighten it even more to make sure the sensor was safe and sturdy. After checking the sensor and capsule and realizing that the capsule falling was the only problem it allowed the group to be able to check the LHT65's on the wall and double check that they were safe and running properly. The group once again met in the office after installing the LoRaWAN sensor for the second time and the products and database was giving accurate results to The Things Network.

Doing it again, using two or more hose clamps will definitely help rather than hurt. Getting inaccurate detections from the device could lead to problems for producer's so allowing one to ensure the sensor is safe will make data more accurate. The only problem with the LHT65 sensor is when it is mounted to the wall the plastic can crack because it is a harder plastic and is also a smaller hole to fit certain screws or pins.

Every week following the group would meet and have a meeting to discuss the sensors and observe any problems notified. Since the first problem of the LoRaWAN falling over the group never seemed to have any problems since. Audree or Hunter would enter the unit on their own time throughout each week and just make sure all of the sensors and units were safe and also making sure that the project wasn’t in the way of the staff that works at the offsite swine unit. The LHT65 and LoRaWAN Distance Detection sensors are rather small devices so it makes it convenient for them to be out of the way but for any pig barn, things happen and the group would rather have been safe than sorry in that respect.

During this project, we concluded that with proper placement and management, these IoT devices work great for reducing the amount of foot traffic in the Swine Barn. The data portrayed on the website was always accurate and updated very rapidly and frequently to ensure proper data collection and monitoring. Aside from this general conclusion, Audree and Hunter, being Undergraduates in this research project, learned a lot about how the process of researching goes at SDSU. They learned how to properly present data collected and information learned. They also obtained experience in a multitude of different processes. Handling power tools, using Microsoft Word for meeting notes, working as a collaborative team during a global pandemic, swine management, on your feet thinking for fast solutions to sudden problems, and mainly, new knowledge of IoT systems.

One of the issues we worried about running into during the experiment was not being in the way of those who work at the SDSU Offsite Swine Barn. We wanted to ensure that the times that we went in to check on the monitors did not interfere with their feeding or cleaning schedule. They were all very kind and respectful to us and our project. When it came time for them to clean the swine barn, the workers removed the sensors, marked where they were, and kindly labeled them for us so we knew what pen the sensors came from so we could reset and replace them easily. This was certainly a step that they did not have to do, but that small amount of time they gave to making our project easier to accomplish did not go unnoticed and we are very grateful for their support and cooperation with this project.

One of the best things that we were hoping to achieve from this project was making swine management easier and safer by monitoring the data needed using technology that could relay accurate and frequently updated information to devices outside of the swine barn. The Internet of Things technology has proven to do just that and more. This method of data collection is a small initial cost, and with the money that you could save on labor, these devices will pay for themselves in a relatively short amount of time. Figure 1.1 is the spreadsheet used to determine total cost of the probes, $224. We also spent about $20 on PVC pipe to create a protective barrier for the manure sensor probe since it had to be on the floor. Finally, it took about two hours to build the barrier for the manure level sensor, and place the sensors in the barn for three student workers, a cost of roughly $78 Therefore, the total cost for applying these IoT sensors and technology is about $322. This total does not count the cost of labor spent monitoring the project, as this is not a step that would be needed when using it in a commercial swine barn. IoT systems like the one we used and studied here, are not new by any means. One webpage, *The Channel Company* wrote a great article about the multiple uses of IoT technology just in swine. An excerpt from the article gives some information on the endless realm of possibilities for IoT in swine.

Farmers monitor pig growth through the Asimetrix dashboard, which provides real-time displays of the average daily weight of the pigs and any environmental information being tracked. Alerts can be sent via phone or email if specific thresholds are met. The dashboard also allows farmers to predict when finishers will be ready for market and operational changes that can improve efficiency on the farm. “We can detect anomalies in growth. We can detect when a pen is growing too fast or too slow," Sanin says. Those anomalies could indicate health issues or illness within a pen or potential feeding issues—not enough or too much feed for certain pens. A similar system, called Piggy Check, comes from Meier-Brakenberg. The Piggy Check application uses a 3D camera and AI-based software to determine the weight of pigs while they move about their enclosures. The software runs on a smartphone or tablet and combines the digital images or videos of pigs to create "depth images" that are used to estimate weight. The weight is displayed on the phone right after the photos are taken, and the data collected is stored in the cloud for later analysis. When finishers are taken to market, the actual body data is compared to the Piggy Check data, so farmers can use precise statistics to make adjustments based on genetics and feeding regimes. Knowing when finishers are ready for market can improve efficiency on the farm. For example, if the finishers are removed in a more timely fashion, the farm can operate more economically. They save money on feed because the largest pigs eat the most and they do not overfeed pigs beyond their ideal weight.

The conclusion of the project that we worked on proved the good in our hypothesis correct, and removed doubts of difficulty from us as the sensors withstood the trial of being with the hogs, held up during the wash, and proved easy and accurate data collection. IoT technology like the ones tested in this project are a great tool for swine barns to reduce biohazards, risk of injury to the swine, and lessen the amount of manpower needed; in turn saving the farmers money. IoT will help the future of the swine industry "bring home the bacon."

Project Outcome

On May 18, 2021, Audree and Hunter gave a final presentation before the SDSU swine group that consisted of 8 faculty and students, including two swine extension specialists (Drs.

Robert Thaler and Ryan Samuels who also co-PI'ed this project). The group raised many questions and discussed the future applications of IoT technologies in precision swine farming. For example, one professor proposed the use of a similar system to remotely monitor the feed level in feed bins – by doing so, caretakers will not have to shower in and check the load cell readings.

The final system uses all commercial products or parts (Table 1), with minimal installation or maintenance needed. All the sensors are waterproof and dustproof. However, to play safe, the LHT65 temperature/humidity sensors were covered with plastic bags during power washing. The SDSU offsite swine farm has only two rooms. To measure the thermal environment and manure level at this site, only two LHT65 temperature/humidity sensors and one LDDS75 ultrasonic distance sensor were needed. The total purchase costs for the sensors were $122 as of May 2021. It is noteworthy that each LHT65 sensor has two temperature probes: one inside the sensor enclosure and one on an extension cord. Thus, it can offer two temperature readings. To better monitor the spatial variability of air temperature, additional sensors can be purchase at the unit price of $32, including a lithium-ion battery. Both LHT65 and LDDS75 sensors were running on batteries. According to the supplier, the sensors can run for over five years without battery replacement, which minimizes the maintenance for producers. The installation of the sensors was simple and straightforward (Figure 1). For the LDDS75 ultrasonic distance sensor, a PVC shield or alike was necessary as aforementioned; however, this will not add significant material or labor costs to the system. For the LHT65 temperature/humidity sensors, they were mounted on walls in this project. Because they are of light weight and battery powered, they can also be hung to feed, water or power lines with zip ties. A RAK7258 LoRaWAN gateway was pre-installed in the office of the offsite swine farm. It collects the data signals from the sensors and transmits them to the Internet through WIFI connectivity. The gateway costs $200. However, the gateway can support over 100 sensors, which means the IoT system can be readily expanded without incurring significant additional costs. The SDSU offsite swine farm has Internet and WIFI connectivity. For farms with no such capacity, a LoRaWAN gateway can be installed at the producer’s home or office where Internet connectivity is available. LoRaWAN is a great technology for farm IoT projects as it enables long-range data communication (up to tens of miles) between sensors and gateways. Another solution is to have a LoRaWAN gateway with cellular modules (e.g. 3G or 4G). However, this will result in additional expenses.

Table 1. System components and their purchase costs.

Item	Quantity	Cost	Purpose
LHT65 temperature/humidity sensor	2	$64.00	For thermal environmental measurement
LDDS75 ultrasonic distance sensor	1	$58.00	For manure level measurement
RAK7258 LoRaWAN gateway*	1	$200.00	Serving as an Internet access point
PVC capsule	1	$20.00	For protecting the distance sensor
Total		$342.00	

* A single gateway can support >100 sensors that are concurrently working.

Figure 1. (Left) Installation of the LHT65 temperature/humidity sensor. One can see a heavy-duty temperature probe on an extension cable; (Middle) Installation of the LDDS75 ultrasonic distance sensor with a PVC shield; (Right) The LDDS75 sensor being tipped over by pigs.

A user interface (dashboard) created using MyDevices Cayenne is shown in Figure 2. The interface allows a producer or caretaker to monitor the real-time thermal environment conditions inside a hog barn and the manure level in a deep pit. The system has been running for over 4 weeks. Both LHT65 temperature/humidity sensors worked properly for most of the time. Wrong temperature readings (over 100ºC) were occasionally seen. However, they could be easily identified. By clicking the icon, one can access the historical record of sensor readings (Figure 3). An automated alarm can be activated when the temperature and humidity exceed certain thresholds. Apparently, this greatly benefits the management of heat stress and other thermal environmental abnormalities, particularly for farms with no smart controllers or farm information systems in place. The LDDS75 ultrasonic distance sensor did not work properly as expected. This is likely caused by an orientation issue with the ultrasonic sensor. Ultrasonic sensors emit a cone-like sonic wave for distance sensing. When improperly oriented, the sound reflection by concrete slats and other objects will create noises and wrong readings. The sensor will be inspected and adjusted in the coming weeks.

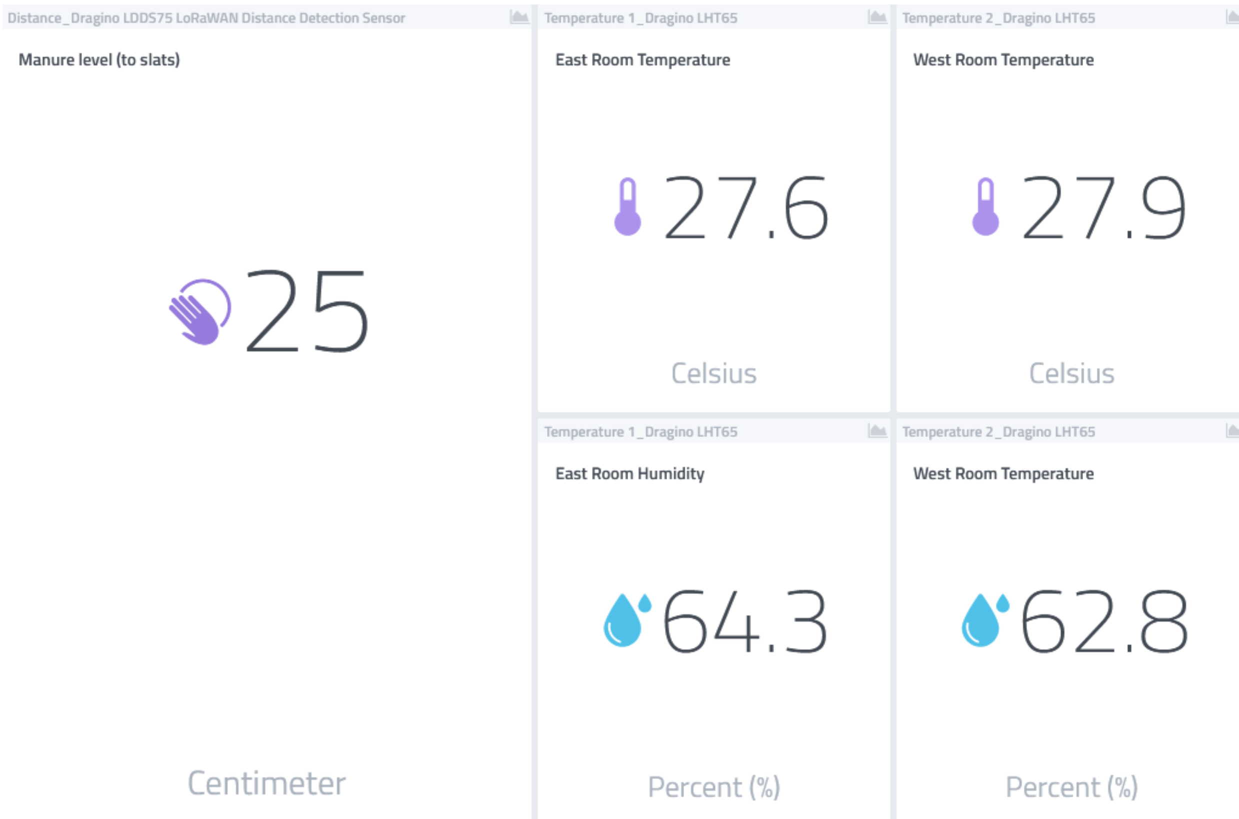

Figure 2. A dashboard created by using myDevices Cayenne. A public sharing link is: https://cayenne.mydevices.com/shared/60416fe0ae410d4d50908ce6/project/8a669c15-aa13-44ed-bc7b-069f2fd6a738.

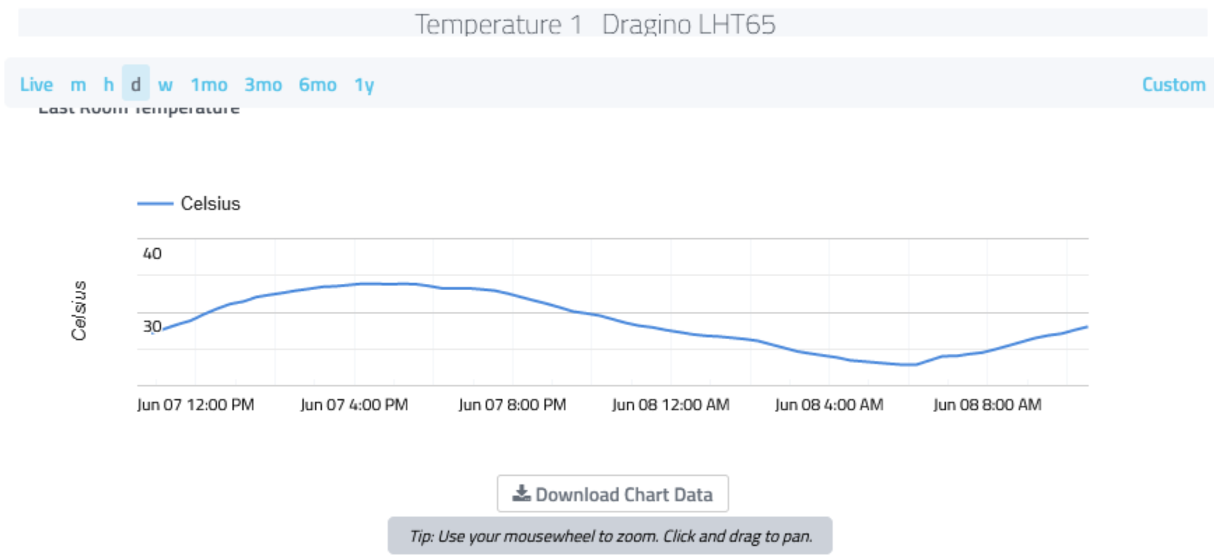

Figure 3. Diurnal temperature readings in the east room of the onsite swine farm. The data was retrieved from the Cayenne user interface (dashboard). Note the "Download Chart Data" button that allows one to save historical records as an Excel file.

Regardless of the challenges and limitations, we find LoRaWAN IoT a promising technology for future smart swine farming practices. It is affordable, requires minimal maintenance and installation, and demands no advanced knowledge or skills. Average producers should be able to handle the system set up and operation with the assistance from companies and university extension specialists.

References

Ames, D. (1980). Thermal environment affects production efficiency of livestock. *BioScience*, 30(7), 457-460.

Bor, M., Vidler, J. E., Roedig, U. (2016). LoRa for the Internet of Things. *EWSN '16 Proceedings of the 2016 International Conference on Embedded Wireless Systems and Networks*.

"Farmers Go Whole Hog for Intelligent IoT Ag Solution." *IoT Integrator*, 9 Sept. 2020, www.theiotintegrator.com/agriculture/farmers-go-whole-hog-for-intelligent-iot-ag-solution.

Ross, J. W., Hale, B. J., Gabler, N. K., Rhoads, R. P., Keating, A. F., Baumgard, L. H. (2015). Physiological consequences of heat stress in pigs. *Animal Production Science*, 55(12), 1381-1390.