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Opportunities to Develop Smart Farming Technologies to Address Animal Welfare Concerns: Review of the Technology Literature

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1. Initial Findings and Overview

The goal of this research project was to find potential ways that technology could aid in improving animal welfare. Research was done that exemplified how technology that could be applied to different animal settings, whether that be on farms or in veterinary hospitals.

Multiple research questions were fielded throughout the beginning of the research project. Some research questions that were asked were: “How could the introduction of advanced technology and 24/7 autonomous monitoring of farms and veterinary hospitals aid in increasing animal welfare?”, “Does networking farms like smart cities help benefit animal welfare and increase overall farm efficiency?” and “How could implementing smart technology on farms improve animal health and as a result increase animal welfare?”. Because of these research questions, and the resulting research keywords used, the ultimate direction of this research project was focused on “smart” or “precision” farming. Precision farming refers to the idea of constant observation and monitoring of farms and farm animals, focusing on increasing overall efficiency (Berckmans, 2017). Precision farming, as a result, has the potential to also increase animal welfare through 24/7 monitoring.

The above research questions were investigated in two distinct lines of investigation, split among two undergraduate researchers in the Collaborative Systems Laboratory (CSL) at the University of Guelph. The first line of investigation was conducted by undergraduate research assistant (URA) A. Camacho, and focused on the animal sciences, animal welfare literature to identify key animal welfare issues of public and scientific concern and existing technologies being applied to these issues in the farming context, as documented in the technical report CSL2017-01 (Camacho & Scott, 2017). The second line of investigation, summarized in this report (CSL2017-02) was conducted by URA J. Bakelaar (co-author of this report), and focused on the technology literature to determine what technologies exist in the broader literature that may be relevant to an animal farming context.

2. Research Scope and Methodology

This technology investigation particularly focused on gaining a better understanding of developments in the Internet of Things (IoT) systems and their applications to “smart” homes and “smart” cities, where sensors and actuators are deployed in various settings, and connected to the Internet to enable monitoring and control of various data and IoT devices from remotely connected computers, such as smartphones and remote desktops. The aim of this investigation was to better understand the capabilities, and limitations of existing IoT devices and IoT systems deployed in “human inhabited” contexts, and their potential to help address known animal welfare concerns on farms.

The information on the current problems farmers face that is discussed below, and that helped direct the technology literature review, was derived from experiential and academic knowledge of the two URAs on the research team and from review of related farming and animal welfare literature. A. Camacho has an academic background in animal sciences, including animal welfare courses, and J.

Bakelaar's family is engaged in beef (historically) and chicken (currently) farming in rural Ontario. During this project, J. Bakelaar also informally engaged in discussions with his farm connections to better understand the problem space and the needs of farmers related to animal monitoring and welfare.

For the technology investigation summarized in this report, the following main databases were used:

- the ACM Digital Library (http://dl.acm.org),
- the IEEE Xplore Digital Library (http://ieeexplore.ieee.org),
- interruptions.net, and
- Google Scholar (https://scholar.google.ca).

To guide the literature review, the keywords listed in Table 1 were used to find suitable documents and journals related to this research. Additional snowballing from initial documents found through these keywords also contributed to research found for the project.

Table 1. Keywords used in literature search.

Keywords Used
Smart House
Internet of Things (IoT)
Automation
Smart Farm
Applications of IoT
Usability of IoT
Monitoring
Surveillance
Smart City
Shared Autonomy
Universal Sensor
Web of Things (WoT)
Multi Device Ecologies
Smart Environments
Dynamic User Interface
Sensor Network Applications
Farm Management
Continuous Deployment
Environmental Monitoring
Sensors
Sensor Networks

While animal welfare issues in farm livestock exist in a variety of contexts, including their primary habitat during birth and during their growth, transportation during their life, and slaughter, this research focused on technologies that could improve an animal's welfare while they were in the growth stage of the farm production cycle. This scoping decision was made since it was felt this is the context in shich most livestock spent the majority of their lives. Also, with a thought to technology adoption, it is a context which represents the largest potential impact for farmer's ongoing costs related to livestock lifecycle. Nonetheless, it is likely that identified technologys may also be applicable to other welfare contexts, such as transportation contexts. This investigation also focused on what specific problems

farmers (farm owners, farm managers) face in their daily duties that could be addressed through "smart" farm technology. These problems specifically focus on data collection and reporting challenges, and internal and external farm communication and reporting, that might be assisted with increased automation on a farm. The overarching premise in identifying such opportunities for technological development, is that multi-faceted. First, freeing up time farmers and farm workers must spend on such tasks provides additional time for them to spend caring for their animals. Second, providing more timely and accurate information about their animals' current health status provides allows more timely and accurate responses to these concerns, including quicker response to acute health concerns, or even potential pro-active response to disease prevention, for instance, should more accurate and timely information be available of disease indicators.

3. Data Collection, Reporting, and Communication Challenges on Modern Farms

The main issues that came up through this research were communication between different levels of users on farms, overall access to information on a daily basis, and the fact that information is mostly only accessible through physically visiting a farm. Addressing these problems could lead to a drastic efficiency increase in farming, leading to more time that farmers would be able to dedicate to taking care of their animals. Ideas began to sprout around the use of smart systems in farms. We found that there are many sensors and other data collection technologies currently being used in farming that track specific levels, such as the overall temperature of a farm or the amount of water that the animals in the farm are drinking. However, we found that there was a potential research direction to follow in the implementation of smart systems that utilize these sensors in a more advanced way, and as a result more advanced sensing and prediction technology in farming.

According to our research, modern farms are already fitted with a vast number of sensors and data collection technologies that could potentially be used in a smart/precision farm system. These sensors include cameras, weight sensors, temperature sensors, various chemical sensors, and more, as outlined in the CSL2017-01 technical report (Camacho & Scott, 2017). We found that using currently implemented technology and melding this technology with smart systems would likely be the most cost effective, and thus best adopted, approach to this research project. Other sensors that could be useful in a system like this that may or may not be implemented in many modern farms already include IR sensors and other more advanced camera sensors.

In terms of the Human Computer Interaction (HCI) opportunities for this research project, an issue presents itself in the form of presenting the data to the user. It is incredibly important for smart systems, which are in their own nature very vast and complicated, to be presented in very simple and elegant ways. Without a focus on smart systems/networks being easy to use and implement, it is unlikely that they will be openly adopted into farms. Additionally, it was thought that there may be better ways to use devices displaying data for just this purpose. As a result, we looked into possible automation and prediction based research already being done to see if there was a possibility that this technology could be implemented into our research. Automation and predictions in these types of systems would require less input from the farm manager in order to display useful information. As a result, the overall welfare of farm animals in the growth stage of their production cycle may improve through valuable information being readily available for farm managers. Actions such as automatically filling out spreadsheets, saving farm managers time that can be dedicated to the animals on the farm, with information for other users of the system to look at, or being able to see updated information wherever a farmer may be, could drastically improve the overall welfare of animals on farms. Access to this information would result in the

ability for farmers to check on their animals wherever they may be, leading to a better understanding of the animal's current state on the farm. Simple tasks such as opening and closing doors, or turning down the overall temperature of the farm, based on information that the system provides a farmer, could help improve animal welfare in a drastic way.

The result of having information readily available wherever a farmer may be, however, leads to an issue in the amount of information that is provided to the farmer. Notifications being sent to the primary user of the system, the farm manager, could be overwhelming if sent all at once. The sheer amount of data that could be processed by sensors and sent to the farmer could result in an information overload for the farmer that is too large to easily sort and comprehend. This results in a potential research direction of solving the mass notification issue that would result from this information overload, and how that would look in a smart farm system.

The advantage to sending all of this information to the primary user of the smart farm system would be for the farmer to be able to make more accurate decisions that benefit the animals the farmer is taking care of. These decisions would be based on more accurate and timely information, as the farmer would not need to take trips to the farm to gather information about the animals. This leads to increased animal welfare as the farmer is able to make quicker and better decisions for the animals based on information that is constantly being updated and sent to the farmer.

This constant flow of information being sent to the primary user, as well as potentially other types of users of the system, would likely also lead to improved communication between the different types of users in the system. Communication is another issue that is openly discussed by farmers as something that should be addressed and improved on. The potential to use technology, such as that of a smart system on a farm, would lead to increased animal welfare through information being more accessible to the different types of users on the farm. For example, information such as different illnesses being spread in specific farms could be sent almost automatically by the smart farm system to different types of users on the farm. More timely action could be made to help prevent the spread of these illnesses, while also providing more time to attempt to cure the illness in the animals for tertiary users such as veterinarians.

4. Smart Farms/Systems

During the beginning of the research project, the question was asked if there was an opportunity for research into farms that acted like smart houses. These systems would perform similar functions to smart homes, predicting functions that would need to be operated on the farm depending on data provided to the system (Kadouche & Abdulrazak, 2011). These smart farms would utilize a various amount of different sensors, both already being used on farms as well as sensors that would be required to be installed, to make their predictions for functions. Examples of sensors include cameras (Kulkarni, Ganesan, Shenoy, & Lu, 2005), IR sensors, heat sensors and chemical sensors could be used to make predictions and analyze different information throughout the farm (Eldib et al., 2014). For example, cameras could be used to analyze animal behaviour on a farm which could lead to better decision making regarding the animal's overall stress levels (Gualdi et al., 2008; Kuznetsov, Odom, Pierce, & Paulos, 2011). Other sensors could be used to make predictions about an animal's health and overall welfare level as a result (Bagaveyev & Cook, 2014). The differences and challenges, however, with researching this information and comparing smart homes to smart farms is the sheer potential size of smart farms and the amount of data they could produce (Bouchard & Giroux, 2015). The fact that there could be many different farms connected to each other through the same network presents a problem that relates more closely to smart

cities as opposed to individual smart houses. There is a potential research direction in how to adapt different ideas and research from smart homes and smart cities and adapt them to the smart farm.

The overall idea would be for a series of farms to be connected in a network, with each individual farm operating as a sort of node. Each node would have its own individual functions. All of these data would then be fed to an individual terminal where it could be collected and analyzed by the farmers. The major benefit of this approach would be that information could already be collected, and potentially formatted, in a useful way (spreadsheets, etc.) without the farm manager having to do it manually. Additionally, research into smart farming could lead to more automated farming systems that would leave less margins of error compared to traditional farming where humans make most of the decisions. With the help of automation guiding farmers' decisions throughout the farming process, animal welfare may be positively impacted.

Developed smart farm systems could also provide different types of users, beyond the farmer/farm manager, with access to information automatically, without having to wait for farm managers to provide the information to the farm owner by manually completing information sheets. While fielding possible research approaches, we found this to be a major benefit as it would shave off a number of hours of a farm manager's work week by not having to manually fill in information for upper level users to see. The system would automatically do this for the different types of users and provide this information as soon as the system is given the required information to format.

5. Human-Computer Interaction (HCI) and Notifications

Several important human-computer interaction (HCI) implications of smart farm systems include appropriately handling the massive number of potential notifications and other data outputs that the systems may generate for farmers and other potential users, interpreting collected system data, and providing available system data to potential users in a valuable way. Moreover, ensuring the usability of the system for a variety of different types of user. Not all farmers and farm managers are willing to adopt new technology, so making the system easy to use and incredibly helpful may help aid in adoption among existing farms.

When handling notifications, the most important issue is determining what notifications are useful to different types of users (Pignotti, Beran, & Edwards, 2014). While the manager may require notifications based on whether certain alarms are being triggered on the farm, whether certain animals are consuming their required amount of food or water, etc. other types of potential users (e.g. farm regulation boards, veterinarians, etc.) may not require this level of detailed information. As a result, it is incredibly important in a system like this to balance what is and isn't required information for users to see in notifications, or to be presented in reports and other system outputs.

This also presents the issue of trying to limit the sheer number of potential notifications that could potentially be provided to different types of users. For example, a farm manager may not need to see specific notifications about low food stock, temperature changes on the farm, etc. unless they are incredibly urgent. Notifications can act as a fairly large factor in overall employee stress, and interruptions can take 15 seconds or more to recover from (Altmann & Trafton, 2007). As a result, a system may need to be implemented to deal with the number of potentially useless notifications that could be sent to the farmer. There are many potential ways to limit these notifications, such as setting thresholds for the number of notifications being sent during a set time based on importance and using software that would determine if a notification is valuable enough to send to a user, based on the user's overall busyness or other various factors (Keralapura, Cormode, & Ramamirtham, 2006; Ruge, Cassens,

Kindsmüller, & Herczeg, 2010). These solutions may limit the number of notifications being sent to different types of users, resulting in less notification overload for the farmer.

The next potential useful implication of a smart system like this would be the automation of data collection and distribution. Previously, farm managers relied on filling out forms and spreadsheets manually. With a precision farm system that automatically collects data from sensor networks, as well as collecting data manually input into the system such as culls (the number of animal deaths per day) and other various data points, the system could fill out information in spreadsheets that would be incredibly useful for sharing data for all groups of users of the system to see. This could potentially eliminate or reduce the many hours of work that is currently needed for completing spreadsheets and forms. Automating such data collection could also help reduce data input errors. This may help lead to better overall animal welfare as the information displayed to the farm managers would likely be more accurate and thus decisions that benefit the animals could be made based on more accurate and timely information.

Finally, precision farming could help organize how farms are scheduled in a drastic way. For example, possible methods of presenting schedule based data for primary and secondary level users to observe is through calendar based user interfaces. A smart farm system could technically make use of a calendar scheduling system that could sync important dates for operations on the farm, as well as deadlines and meetings, to user's smart phones. By doing this, every user that requires this scheduling information would automatically have it in their phone to observe and make plans around without having to ask other users whether or not certain functions on the farm are taking place on certain days. This could drastically improve communications on farms, leading to higher efficiency of farming and less uncertainty. As a result, the general welfare of the animals on the farm would improve.

6. Security

Security in large connected systems similar to the envisioned smart farming systems has been a topic of concern within the smart homes context. While most of the information relating to research on security in smart homes is transferable to research on security on smart farms, it is important to emphasize just how much more vital security is to a system like this. Many high production farms are relied upon to feed hundreds of thousands of people. If just one farm were to be breached and its animals were deemed unusable as a result, this could affect the entire market landscape of the specific animal type on this farm. Additionally, security breaches affecting the animals on a farm would lead to huge losses for the farm owner. Thus, while security on smart homes is important to individual people who want to ensure their possessions are not tampered with, security on a large smart farm is even more important as without security measures thousands of animal lives, as well as entire markets, could be influenced through a security breach.

In terms of security for smart farms, it is important to look at network security research being done as a whole. This is because precision farming would likely rely on networks of farms being connected to share information and improve animal welfare. As of now, it is incredibly easy to breach into insecure smart home systems even with technology as easily obtainable as a smart phone (Sivaraman, Chan, Earl, & Boreli, 2016). Further research needs to be done in terms of network security for smart farms, however an area of research to look at that is already being done is security in smart cities. This research looks at how security could be improved in massive networks of interconnected "things". The reliance on technology in smart cities leads to the massive potential for reduced security and breaches that could affect many people (Ferraz & Ferraz, 2014). The same can be applied to smart farms. If a precision farm were to be breached, as mentioned above, the potential losses could be huge. As a result, it is

incredibly important to look into further researching security in smart cities, and how this research could be applied to smart farms as a whole.

7. Internet of Things (IOT)

For the potential of smart farming systems to be realized, more research is also needed on how to safely implement Internet of Things (IoT) network of connected sensors and actuators in a farming context. By integrating IoT into a smart farm system, operations such as checking on specific information on the farm can be done from anywhere that the farmer is. This ensures that, if something were to go wrong on the farm, someone somewhere would be able to tell.

Additionally, the potential of implementing IoT functionalities into systems like this could dramatically change the landscape of how large-scale farms operate. Communication is a major issue on farms, as deadlines and important dates, as well as important information, are not always shared in a timely manner to employees who may need to know this information. With smart systems, if one user changes a date in the system, or an important set of information is uploaded to the system, every relevant user could be informed of the change almost automatically. This could drastically improve communication between users on a farm in a very positive way. Times for meetings are proven to reduce productivity times and impact decision making in workplaces, and information sharing in general is a mostly inefficient task (Armstrong, 2007). Lowering the need for meetings and manual communication would drastically reduce the amount of time farm managers and different users spend communicating to each other, leading to more efficient workflow and improved animal welfare as a result.

Furthermore, implementing systems like this on farms could drastically improve how information is shared. Automated systems collecting data could prevent certain information from potentially being hidden from other user types as the information would be sent to the system automatically. Data that is shared automatically would be basic information about the animals on the farm that would need to be shared through communication instead. Specific user groups would then be able to access this information more efficiently without having to ask the supplier of the information to provide it. This would utilize research already done on smart cities, as many animal and farm owners also own multiple different farms. Information would be supplied through running farms on the same network, much in the same way that smart cities have been proposed through networking different parts of cities (Bhunia, Roy, & Mukherjee, 2015; Yonezawa, Ito, Nakazawa, & Tokuda, 2016). This would lead to an improvement in animal welfare as exact information could be shared across all relevant user groups without the potential for important information to be censored or input incorrectly by users.

IoT provides an incentive for owners to implement systems like these. Through IoT, menial tasks such as creating spreadsheets and setting calendar dates could be handled through smart farm systems. This would provide more information for different user types to see, and the information would be available almost immediately. Communication would increase among the different user types as well, leading to better workflow efficiency. Additionally, because of the constant access to information that farm managers would have, it would be possible for farmers to act remotely on behalf of their animals to ensure that welfare is always a top priority. IoT in precision farming provides a chance at drastically improving animal welfare while simultaneously providing incentive for owners to implement these systems through increased work efficiency.

8. Future Research Directions

Many potential future directions of research were discussed throughout this literature review. It is important to look into the future for this type of research project, as much of the research has yet to be done that directly relates to smart farming/precision farming. It is still a relatively new topic of discussion, however there is massive potential to both improve the overall welfare of animals through the use of precision farming and technology on farms, while also helping to solve many problems that farmers face on a daily basis.

In terms of general smart farming, future research directions could involve looking further into how automation affects farming as a whole. There is huge potential to streamline the farming process through automation introduced through precision farming. Automation as a whole could lead to a massive reduction in human error, with human interaction in some automated processes such as information sharing and general communication of data being incredibly minimal (relied upon to simply double check the information to ensure its general accuracy). Future research may also involve looking into how Artificial Intelligence systems could impact precision farming and its potential to completely revolutionize farming as a whole through cost reduction and improved animal welfare on all sizes of farms.

A large issue that was outlined in this literature review was the potential of massive numbers of notifications that could transpire through precision farming. With the number of sensors and the amount of information that could potentially be applied to a precision farm, notifications and notification overload are a huge area of research that would need to be discussed and looked at. Notification overload could lead to heavy amounts of stress for farm operators, which could lead to reduced levels of efficiency on the farm. Notifications are a distraction that take away from the current task, and reducing the number of general notifications being sent through precision farming is a fairly big issue that needs to be address and researched.

Additionally, the necessity for an easy to use and intuitive interface for precision farming is also a big area of research that needs to be looked into more. Precision farming can only make farming more efficient if farm operators and managers are using the system as little as possible. Precision farming should work in the background, providing farmers with important information and processes while not being intrusive to the work being done by the farmer. If the interface of the system is not well designed and easy to use and implement, there is potential for work efficiency and animal welfare in general to drop. Because of this, research must be done into making the best interface that reduces the amount of times a farm manager must use the interface while still making precision farming helpful in general.

It is also important to research further into how security plays a role on smart farms. Smart homes are notorious for being easy to breach (reference). It is important that when applying research being done on smart homes to precision farming, security of these systems is taken into account. While smart home security is important for individuals, the potential losses resulting from a security breach on a smart farm is a lot more impactful. As mentioned in the literature review, entire markets could be affected by farms being breached and information being made readily available to the public. Additionally, if a third party were to gain access to some farm operations through a security breach, the animals on the farm could be put at risk as well, lowering their general welfare.

The main draw for farm owners to implement precision farm systems may be through the economic gains that systems like these could produce. Improved communication, more efficient work, and more advanced automation with a focus on introducing Artificial Intelligence systems to precision farming could drastically improve the cost effectiveness of these systems. While animal welfare is

important to owners, it is these economic gains that would likely sell owners on implementing these systems. As a result, further research must be done on how smart farms could help "pay for themselves" to ensure that owners implement them into their current farms.

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