Opportunities for ACI in PLF: Applying Animal- and User-Centred Design to Precision Livestock Farming

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ABSTRACT
The fields of animal-computer interaction (ACI) and precision livestock farming (PFL) have emerged in parallel, distinct communities, but have many overlapping goals and concerns. PLF is concerned with the development of new technologies to improve livestock farming operations and outcomes, including improving the health and welfare of farm animals. However, unlike ACI, which has roots in the human-computer interaction field and thus incorporates many user-centred design methodological traditions, PLF research has emerged largely from engineering fields and is largely technology-focused. This works-in-progress paper discuss the opportunities to apply research and methodologies emerging from the ACI field to help improve the usability and overall utility of PLF technologies for both its human and animal users. We also discuss several ongoing projects from our research group that take this approach.

Author Keywords
animal health and welfare; precision agriculture; smart farming; user-centred design; animal-centred design

INTRODUCTION
The field of animal computer interaction (ACI) [5] and precision livestock farming (PLF) [2] are both focused on developing technologies for animals and their caretakers to improve their welfare, health and interaction with computing systems and devices by leveraging various advance technology principles, techniques and innovations. PLF is an emerging and fast-evolving field of study focused on developing technologies to optimize and transform the livestock farming industry [2]. This field aims to improve animal health and welfare, environmental conditions on farms, farm efficiencies, and food quality, among other goals [2].

Despite the promise of PLF technololgies to improve animal health and welfare on farms, they also have to meet farmers' business needs, including the need to minimize farm operating costs [15]. Recent studies of PLF technology adoption in various cultural and animal farming contexts have revealed that a key factor motivating farmers' purchase and use of PLF technologies depends on the perceived return on investment [17, 22]. Given the tight profit margins in many farming sectors, this can limit innovators' willingness to develop technologies focused on improving the health and welfare of the animal if they cannot also increase farm profits or meet other real business needs of farmers [14]. Yet, recent research also indicates that existing PLF research has largely been technology-focused rather than user-focused, and that this issue may be contributing to its lack of adoption, or perceived value, by farmers in certain livestock sectors [8, 16].

ACI is also an emerging research field focused on studying interaction between animals and technology on their natural habitat, developing animal-centered technology and providing guideline or approaches to guide an effective design of technology intended for animals [18]. The field of ACI has three major goals: aiding animals in their daily task, improving human-animal relationships, and improving animal quality of life and welfare[18]. To achieve these goals, researchers adopt various Human-Computer Interaction (HCI) methods and user-centred design principles [25], interaction design [18], among others. Given the overlapping goals of ACI and PLF research, specifically to develop technology that interacts with animals, we believe that the ACI research and design approaches can offer significant contributions to the current state of the art in PLF technologies.

In this work-in-progress paper we provide some background on current trends in the PLF field, and overview existing findings from the literature of the usability of existing PLF systems used in practice. We then discuss potential opportunities to apply ACI research and methodologies to the design of PLF technologies to help improve its relevance for farmers and also for the animals the technologies are designed to serve. Finally, we overview several ongoing and planned projects from our research group related to the adoption and use of PLF technologies in the beef and dairy contexts.

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TRENDS IN PLF
Recent trends in PLF technologies can be broadly classified into several main areas, including herd-level management, in-

dividual animal-level health and welfare management, and data analysis and management.

Herd-level management

Most farms manage large herds of animals, sometimes involving hundreds or thousands of animals on a given facility. Managing daily feedings or barn conditions to create a safe, comfortable environment can take significant time and physical effort. Thus, many farms have adopted PLF technologies that help automated some of these frequent tasks that can benefit the whole herd. Examples of such technologies include installed environmental sensors that automatically control blinds or window coverings to help manage barn temperature or humidity [19]. Dairy farms are deploying all manner of robotic technologies to help feeding and housekeeping tasks, including robots that automatically push feed back toward the cattle pens to minimize waste and labour related to feeding a herd of cattle in indoor habitats (e.g. Lely Juno[1]) and robots that automatically circulate in cattle pens to clean manure (e.g. Lely Discovery[2]). Image-based sensors are being used in pig farms to monitor the overall weight of a herd of pigs within a housing pen (e.g. Weight-Detect by PLF Agritect[3]). While these systems can help in the daily management of a farm, a growing trend in "precision" farming is toward being able to manage farm operations at the individual animal level, as discussed next.

Individual animal-level health and welfare management

A key enabling technology for individualized animal health and welfare monitoring in many PLF systems is radio frequency identification (RFID) technology that is now integrated in to many forms of worn tags, such as a cow or pig's ear tag [19]. Once an individual animal can be easily distinguished from others in the herd, many forms of automated animal monitoring or interaction can occur.

A variety of biosensors and wearable sensors have been developed for both commercial and research use [19]. The main purpose of using these sensors is to detect abnormalities of an animal's health or behaviour at an early stage to improve quality of life for the animals and reduce treatment costs for the animals [14]. Wearables and biosensors can help the early detection of contagious diseases to help farmer isolate the animal for treatment to minimize overall pain and suffering, or unnecessary death [19]. Such early detection can also prevent pain and suffering in other animals as quick isolation of a sick animal can help prevent disease spread.

Beyond RFID technology, ear tags have also been equipped with various sensors for monitoring body temperature, motion, and animal sounds to infer an animal's health and behavioural patterns, for instance, how much time a cow is spending eating versus ruminating (cud-chewing) [22].

Wearables equipped with accelerometers have also been developed to be worn on animal limbs to monitor activity and lameness [20]. Leg worn sensors have also been developed to help control the automatic opening and closing of gates to and from grazing areas to improve efficiencies around the feeding and milking of dairy cows, or explicitly control which cows can access certain areas of the facility [23]. Electronic collars similar to Fit-Bit® for humans which have been developed to monitor animal activity in cows, including estrus detection to determine availability for artificial insemination [19].

For outdoor habitats, virtual fencing is an emerging technology to ensure that animals do not go out of range. Through virtual fencing farmers can specify the directions of animals to ensure animals get proper food and also ensure that animals are not lost [23]. For instance, the commercially available GPS Cow Bells system can also be used to protect animals from being lost because it will make terrifying alarm and flash light when animal will go out of range [3].

Beyond externally worn sensors, some PLF technologies are even more invasive. For example, an electronic "pill", also called a bolus, is ingested by a cow and remains in the rumen of the cow and is used wirelessly to transmit data related to heart rate, PH levels, body temperature, respiration rate continuously to the cloud [22]. Farmers and veterinarians can access these data remotely and perform necessary action based on data. Vel Phone is a commercially available vaginal sensor that wirelessly transmits a cow's temperature to alert a farmer when it predicts calving is about to begin [22].

Overall, various sensor technologies have also been developed to detect health and welfare concerns in animals [22]. Sensor-based systems in PLF can measure physiological or behavioural states in animals, interpret detected changes in an animal, give advice to farmers about the status of an animal's health and welfare based on available sensor data and other sources of available data, automatically make a decision on behalf of the farmer or allow the farmer to make a decision based on information provided [1].

Automatic Milking Systems (AMSs) are a culmination of many of the aforementioned technologies. An AMS can identify a cow based on their RFID tag and automatically attach and control the milking unit to the cow via a robotic arm if it is time for the cows feeding or deny the cow milking (or the special food it receives while milking) if it is too soon for another milking. An AMS contains an array of sensors both at the milking robot and along the milk collection and storage system that ensures quality milk because it automatically tests for anomalies within the milk after every milking session [24]. AMS also can detect certain health issues based on a content analysis of the milk including, the color of milk, amount of milk, milk fat, milk protein, and presence or amount of certain biologicals in the milk. AMS can ensure safe amount of milk yield so that milk production is maximized, and the cow is also in good health [24].

Data analytics and big data

The above technologies collect and generate large amounts of data, often in real-time, and often for long periods of time. A growing trend is to collect and store the data to look at herd and individual-animal level trends over time to help in over-

[1] https://www.lely.com/ca/en/solutions/feeding/juno
[2] https://www.lely.com/ca/en/solutions/housing-and-caring/discovery/
[3] https://plfag.com/technology/

all business decision-making and animal health and welfare management. Moreover, many livestock farmers also grow crops. Thus, they collect data from various sources including information on planting, spraying, yields, weather, soil types, animal health, feeding, and breeding. Consequently, PLF researchers have begun leveraging various big data techniques to process the diverse machine-generated, process-generated and human-generated data related to their farms [26]. While this important, and large topic is beyond the scope for this paper, we acknowledge that advances in this field can definitely influence the overall utility and usability of PLF technologies.

USABILITY OF PLF TECHNOLOGY

Research has shown that usability of PLF innovations is the key factor limiting the adoption and level of use of those technologies [10, 4]. In this section, we discuss several key usability problems that have been identified in farmer and animal encounters with PLF technologies.

Research has found that some PLF technology designed to assist with on farm decision making provide only limited utility to farmers in practice because their output is not synchronized with the output of other technologies [10]. Therefore, to ensure PLF innovations provide maximum utility to farmers, standards must be established to guide the design and integration of the various PLF innovations for effective decision-making by farmers [4].

The main challenge of integrating technology with smart farming is to balance trade-offs between usability and complexity of the technology [7]. While creating a design and integration standard may help innovators to develop technologies that can easily be integrated with other technologies used on the farm for better performance, iterative development methods could also be followed to develop PLF technologies by keeping farmers in the loop. After deployment of technology, manufacturers could get feedback from farmers based on their knowledge and experience with the technology which will help them to redesign more accessible technologies [9].

Due to limited technology literacy among many farmers, they often require intense training to understand the features of PLF technologies and how to use those features [4]. For instance, a study of European farms found that farmers were excited about the cowView system – a system that monitors cow activity and fertility – but they were hesitant to invest in it due to a lack of knowledge of how to use it [13].

Notification management is also another usability issue that has been identified. A study of PLF deployment in the dairy industry found that farmers do not mind receiving important and urgent messages about the health and welfare of an animal in real-time, but they sometimes find it very frustrating when a system sends a notification to them about insignificant issues at an awkward time (such as the middle of the night) [14]. PLF systems sometimes generate a high number of false alarms which can affects farmers adoption, use, and trust in PLF technologies [21].

On the animal side, although animals can adapt quickly to new technologies – sometimes faster than humans [15] – some of the existing PLF technologies can be highly invasive such as ear tags, E-pills, robotic grazing systems, and others discussed above. Animals sometimes get injured while interacting with a technology that is intended to improve their health and welfare due to the invasive nature of the technology and these technologies also affect their normal interactions and behaviours [6]. To date has been little research on how these technologies impact the health and welfare of the animals they are monitoring [23].

We posit that the methodology research emerging from the ACI community is highly applicable to the PLF field, and can help address this research gap in understanding the impact of PLF technologies on the animals they are designed for by developing methods to evaluate the Non-Human Animal (NHA) user experience, including methods for assessing usability, user satisfaction, and accessibility from the animal's perspective [6]. We present other opportunities for ACI to improve the effectiveness of PLF innovations in the next section.

OPPORTUNITIES FOR ACI IN PLF

There is tremendous potential for ACI methodologies to improve the comfort, satisfaction, health, and welfare of animals on farms adopting PLF technologies. Thus far, PLF design has been largely technology-centric, but the field is beginning to self-reflect and recognize that adoption of this emerging technology may be hampered by the lack of user-centred (farmers and animals) design [16]. To date, some ACI research has focused on precision farming, or smart farming contexts[5, 11], but we argue that more could be done to bridge the gap between these two distinct research fields and help improve both the welfare of farm animals and overall farm operations.

A PLF adoption study in Australia found that farmers believe that involving them more directly in the design process of PLF innovations would help to make PLF technologies easier to learn and use, and to better address their farm operation needs [16]. Participatory design in HCI and ACI is a design approach in which stakeholders are actively involved in the design process to ensure the research meets their needs and expectations and is also usable by the intended users. While HCI focuses primarily on human users, ACI aims to actively involve animal users in the research process as much as possible [25]. Adopting similar participatory design methods in to the PLF design process would help include farmers' deep knowledge of farm operations and animal health, welfare, and husbandry practices into the developed technologies. Similarly, including the impacted animals directly into the design process, especially for emerging wearables and other technologies that animals interact directly with, would help ensure that the technologies meet the animals' needs as well.

Evidence is emerging from the PLF literature that many PLF innovations are difficult to use and learn. For instance, a review of confined animal housing system found that managers of this system are unable to fully utilize the system because of information overload from the system, which makes it difficult for them to identify which of the information is most relevant for their decision making [10]. Most ACI researchers have a solid background in HCI and share similar interest in improving animal health and welfare with PLF researchers. ACI research and methods can contribute to the adoption of PLF research and adoption of PLF technologies by bring more human- and animal-centred design approaches. Animal-centric design approaches are particularly relevant for PLF, given the moving trends towards wearable and robotic systems that interact directly with individual animals. Two specific specific design approaches prominent in ACI and HCI research we feel are particularly relevant to PLF are interaction design and research through design.

Interaction design is a design approach used when designing a system that users are expected to interact with, interaction design which is one of the skills set common among ACI and HCI researchers is aimed at exploring how users interact with software and hardware innovations. For instance, as the acceptance and use of automatic milking system becomes more prominent, it is crucial to understand how users (animal and human) interact with this system to assert if there is a need for an improved design and what specific aspect needs to be improved upon for more satisfactory interaction. According to Mancini [18], interactive design can improve life expectancy of animals by aiding the fulfilment of their physiological and psychological needs through the design of technologies that motivates them to engage in healthy habits or interactive technologies that reduces the potential of harm to the animal,assist animals in their activities and functions,and foster human-animal relationship by optimising communication and promoting understanding.

Research through design (RtD) is an approach to research that seeks to create a body of knowledge through reflective research practise and development of physical objects that embody a set of knowledge themselves [12]. The design and study of new technology is the main objective of design research and due to ACI researchers strong background in designing and studying the use of technologies they are the best group of experts to conduct this type of research or collaborate with PLF researchers to ensure a more effective outcome.

Finally, due to the interdisciplinary nature of PLF research, animal scientists, bio-technologies, computer scientists, and engineers are some of the many diverse groups of experts that have an interest in and work on PLF technologies. There is also room for HCI and ACI researchers to collaborate with these researchers to ensure state of the art PLF research leverages participatory, interaction and user-centred design principles to improve farm animal health, welfare, and experience.

WORK-IN-PROGRESS ON USER-CENTRED PLF DESIGN

We are an HCI research group with experience in the design of emerging technologies in a wide variety of application domains. The group's director, [removed for blind review, but a co-author], moved to [university and city name removed for blind review], Canada in 2016, and took advantage of the university's long tradition of agricultural sciences and veterinarian education to combine a personal passion for large animals and animal welfare with experience in HCI and technology design to mount a new research program in *User-Centred PLF Design*. Our research focuses on using HCI and ACI design methodologies to develop and study technologies to improve animal health and welfare in animal farming contexts. At present, our research primarily focuses on large-animal contexts including cattle, pigs, and horses, driven largely by access to on- and off-campus university-owned research facilities for these animals, as well as access to world-renowned animal nutritionists, behaviourists, and bioscientists with expertise on these animals and related farming practices.

We work closely with these animal scientists to understand these farming contexts and to help formulate our research questions. Here, we describe several of our ongoing projects focused on adoption of PLF technologies, and their usability, specifically in beef and dairy farming. We chose to focus first on the farmer's perspective rather than the animal's perspective because we are still developing our skills and knowledge related to farm animals and also our collaborations and access to on-farming contexts to enable research directly involving animals. As has been discussed at length in the ACI literature [18], there are both safety and ethical concerns in conducting research involving animals. In the case of large animals like cows there are also health and safety concerns for researchers in which our group is still gaining expertise. Thus, we focus first on human-based studies involving farmers and observations of farming practices, before foraying into animal-based studies. We discuss some future plans for the latter research direction later in the paper.

Systematic Literature Reviews in PLF

One of our ongoing projects involves analysis of existing PLF technologies, and studies of their deployment, from the literature with an eye toward user-centred design opportunities. Specifically, we are conducting two distinct systematic literature reviews, one focused on PLF technologies and their deployment in beef farms, and another on the type of notification mechanisms currently used in PLF systems on cattle, pig, and chicken farms. This research will contribute an in-depth analysis of the state-of-the-art in PLF technology and evaluations in the studied farming contexts, and identify opportunities for user-centred PLF design research in these contexts. We believe this will provide an important contribution for ACI researchers (or ACI-minded researchers) wishing to work in these animal farming domains, as the PLF field is highly interdisciplinary and relevant literature is spread widely across many disparate publication venues. Moreover, as much of the research is highly technology-focused, there is often little to no reflection in the papers on potential usability limitations from the human or animal users' perspective, or on opportunities for design improvement from this perspective. These reviews will provide detailed and concise background information for other researchers (such as other ACI researchers) wishing to conduct research in these domains.

Studying PLF Adoption on Beef Cattle Farms

Another ongoing research project is focused on understanding the adoption, or lack thereof, of PLF technologies in the beef industry. Our background research, including literature reviews and discussion with animal scientists and beef industry experts, indicates that the beef industry has been much slower to adopt PLF technologies concerned with monitoring individual health and welfare of beef cattle than other livestock sectors in Canada. There may be socioeconomic factors involved in this disparity, including regulatory differences between the beef and other sectors that may impact profit margins across the industries. It may also be possible that current PLF technologies simply do not meet beef farmers' needs. For instance, differences in farming practices across sectors may play a major role also. If PLF technologies are not valued or do not meet the needs of beef farmers and their cattle, there will be little incentive to adopt them. Thus, we are currently designing a study to better understand the key barriers for PLF adoption in the beef industry.

The study aims to elucidate beef farmers' perceptions of the benefits and limitations of current PLF technologies to assist in their farming operations and decision-making. The scope of the study will initially be on Canadian beef farms, specifically, in [province removed for blind review]. The study will use both surveys and interviews to gather both broad and deep insights. Both online and paper-based, mail-in surveys will be used to reach a larger population of potential farmers, especially those in remote, rural locations. In-person and phone interviews will be conducted to help gather more in-depth insights and uncover unexpected information.

We intend to explicitly include a sample of commodity beef farmers (i.e. those who raise beef for commodity food sales such as the grocery stores) and niche beef farmers (i.e. those who utilized specialized farming practices (organic or ethically-raised cattle farms) targeting direct-sales to higher-end restaurants) with the expectation that the latter may have larger profit margins and be more willing and able to adopt technologies that can help improve the health and welfare of their animals. This research is expected to contribute a better understanding of technology use on beef farms, of farmers' needs and challenges, and a better understanding of how to design PLF technologies to meet these needs and challenges.

Studying the Usability of PLF System Notifications

Our background research has revealed that few studies exist on the usability of deployed PLF systems, or particular aspects of these systems, in Canada. To address this issue, an additional ongoing project is focused on an issue that has been identified, but not indepthly studied, in prior PLF studies: The fact that farmers receive a wide variety of information notifications and alerts from PLF monitoring systems and these alerts can be overwhelming or stressful [13, 15].

Many farms have adopted different technologies at different times, each of which tends to communicate with farmers in different ways. For instance, some provide information through desktop or mobile phone dashboards, while others send text messaging alerts. Thus, farmers receive many types of information notifications from different devices with different levels of importance or urgency. This research will investigate PLF notification systems used in the dairy industry in [province removed for blind review], Canada, as an initial case study to help understand this issue. The study aims to identify the various notification mechanisms used by current PLF systems, and to understand their perceived usability and impact on farmers daily operations and decision-making.

We will use similar methods to our PLF adoption study described above. We will used online and paper-based surveys to collect data from a wide sampling of provincial dairy farmers, and conduct in-person or phone interviews to gather more in-depth information about farmers perceptions and lived experiences with these notification systems.

The survey and interviews will focus on understanding issues, such as: what types of system notifications they receive, how they receive them (e.g. device, types of interfaces), when they receive them, and how well they understand the notifications, what types of decisions farmers make based on the notification content, their perceived utility of current PLF notification mechanisms, and their thoughts for improvement.

This research is expected to contribute a better understanding of notifications generated from PLF systems, of mediums of notifications sending, and a better understanding of how to generate more farmer friendly notifications and communicate through more accessible mediums to farmers.

Future Work: Usability of Automatic Milking Systems

Our background research has revealed that automated milking systems (AMS), or milking robots, are among the most widely adopted PLF technology in the dairy industry in Canada. However, AMS adoption studies also indicate that they are complex to learn and use, and often require farmers to engage in costly after-purchase consulting contracts with retailers to help learn and use. Our own informal observations of these systems, as HCI experts but not farming experts, also reveal that AMSs have many complex components with various mechanical, robotic, and software interfaces (both at the robot and on networked desktop computers) to learn and use. The initial training and after-purchase (often months-long) consultation costs make up for a significant portion of the overall costs related to adopting AMS technology, and thus, warrants further investigation into whether the mechanical, mechatronic, or software interfaces could be improved, from the farmer's perspective, to help improve the overall learnability and ongoing usability of AMS. Moreover, the AMS also has signficant interfaces to learn and use from the cow's perspective. It typically takes several sessions to train a cow to use the system and some cows learn and become comfortable with the system faster than others. This aspect of AMS usability also warrants further research to determine whether improvements could be made. Both farmer and cow usability studies are planned future studies for our group.

CONCLUSION

To ensure a balance between efficiency of PLF technology and animal welfare, and to inform the design PLF technologies that are more accessible, usable and user (farmer and animal) friendly, HCI and ACI design methodologies can be adopted to develop and study PLF technologies. In this paper, we discussed potential opportunities to apply ACI and HCI research methodologies to the design of PLF technologies to help improve its relevance for farmers and also for the animals the technologies are designed to serve. We also overview several ongoing and planned projects from our research group related to the adoption and use of PLF technologies in the beef and dairy contexts.

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