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Identifying opportunities for emerging technologies to monitor cattle health and welfare in outdoor farm habitats

Kassidy Marsh, Stacey D. Scott
School of Computer Science
University of Guelph, Guelph, ON, Canada
{kmarsh08|stacey.scott}@uoguelph.ca

INTRODUCTION

Public consumers of meat are becoming increasingly concerned with the health and welfare conditions of the animals which they intend to eat (Cornish et al., 2016). In addition to this, the global demand for meat rises substantially each year and is predicted to continue this trend (Godfray et al., 2010). These two factors combined are causing livestock farmers to feel pressure to increase their herd sizes and farm productivity while simultaneously improving the health and welfare conditions of their animals (Cornish et al., 2016). Managing larger herds increases the animal-to-farmer ratio which results in a large number of health and welfare issues going undetected. With herd numbers reaching well into the hundreds, even a highly trained livestock farmer can have considerable difficulty noticing the subtle signs and symptoms of illness and injury (Berckmans, 2014).

Precision Livestock Farming (PLF) aims to automate the detection of illness, injury, and reproductive cycles in livestock animals through the use of continuous, real-time monitoring systems (Berckmans, 2014). It is a relatively new field that is rapidly developing. These monitoring systems assist farmers to provide optimal care for their animals by notifying farmers of health and welfare issues which can then be treated (Hostiou et al., 2017). A main goal of this research project was to conduct a literature review on the field of PLF in order to gain an understanding of currently existing technology in the field. The research focused on technology for monitoring cattle that could have potential use in outdoor environments; several PLF technologies that had no practical use outdoors were omitted from research. Another project goal was to identify future opportunities for research, particularly relating to monitoring animals in outdoor, free range habitats.

PLF TECHNOLOGY

There is a wide variety of sensor technology that has been used in the creation of PLF monitoring systems. Several of these systems can only exist in indoor, constrained environments. An example of this would be the use of automated feed bins which can accurately monitor how much feed each individual cow eats (Beaudoin & Cimon, 1991). While a valuable tool in indoor environments, automated feed bins are less practical in outdoor environments where cattle feed off of grass. Studies which utilized such systems were omitted from literature review, as a main goal of this research was to identify opportunities for future PLF research in outdoor, free range habitats.

The literature review focused on three types of sensor technology that have potential use for monitoring cattle in outdoor, free range habitats: wearables, infrared thermography, and visible light cameras.

Wearables

Wearable devices which have been engineered for the monitoring of cattle exist primarily in the form of ear tags (Figure 1, left), collars (Figure 1, right), and leg bands. These wearables continuously track the movements of a particular cow and classify them as walking, lying, standing, and feeding (Martiskainen et al., 2009; Diosdado et al., 2015; Wang et al., 2018). Ear tag devices typically contain RFID (radio-frequency identification) technology for identifying animals at the individual level; in Canada, all cattle are legally required to be wearing an RFID ear tag before leaving any given farm (Canadian Food Inspection Agency, 2010). Collars and leg bands are commonly equipped with tri-axial accelerometers in order to classify different movement behaviours (Vázquez Diosdado et al., 2015; Wang et al., 2018), while a few PLF companies have recently released 'smart' ear tags which are equipped with accelerometers and are designed to fit around standard RFID tags (Pereira et al., 2018). Certain wearable devices are GPS-enabled and measure the daily distance travelled by cattle instead of measuring steps taken (Ungar et al., 2005).

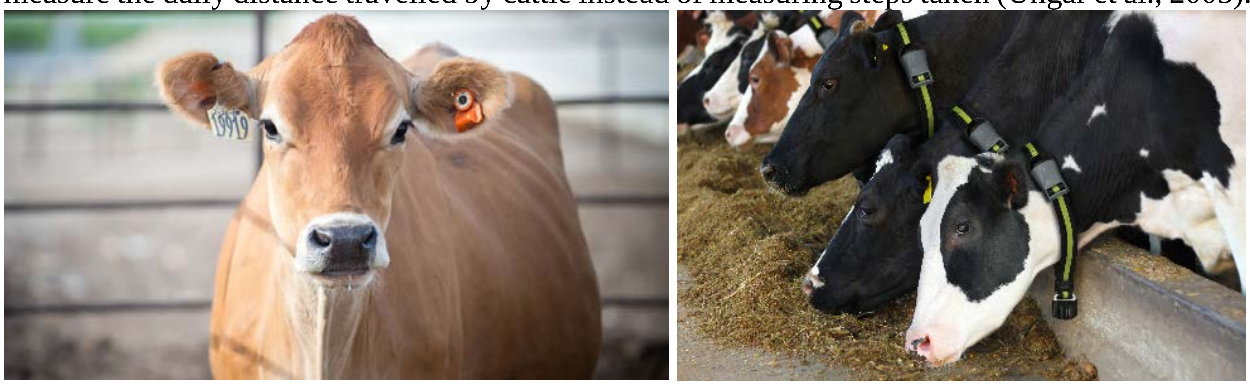

Figure 1. Wearables for cattle: ear tags (left; Image source: https://www.cowmanager.com/en-us/Solution), collar wearables (right; Image source: http://www.scrdairy.com).

Applications

Wearable sensors which track a cow's movements (lying, standing, walking, feeding) can detect a sudden decline in regular activity; a sudden decline in normal activity is normally indicative of illness or lameness (Weigele et al., 2018). One study attempting to automate the detection of Bovine Respiratory Disease (BRD) found that calves infected with BRD exhibited a detectable decline in activity 6 days prior to clinical diagnosis of the disease (Pillen et al., 2016). On large scale farms with hundreds of cattle, it is extremely difficult for a farmer to notice that a single cow is less active than usual. Monitoring systems which employ wearable sensors can detect that a cow is less active and send a notification to the farmer to check if the cow appears ill or injured on closer inspection. Such systems are already commercially available and are internationally deployed by PLF companies such DeLaval Inc. and SCR (DeLaval, 2018; SCR, 2013).

Limitations

The use of wearables involves hands on interaction with every single cow on a farm, in order to equip them with the sensor technology. Not only does this result in a significant amount of time and labour costs, it creates additional risks for the farm worker who is equipping the animals with the technology. Cows are very large, sometimes unpredictable animals which means there is always a degree of danger when interacting with them. For this reason, wearables in the forms of collars and ear tags are more commonly equipped than leg bands, as there is a reduced risk of being kicked.

Wearables can be an additional way for cows to injure themselves due to the fact that the equipment is often quite bulky. Cattle naturally exhibit a variety of social behaviours when interacting with one another, and aggressive social behaviours are not uncommon (Rousing & Wemelsfelder, 2006). During aggressive interactions, the cow involved may be injured by any wearables on the animals.

It is also possible that a wearable device on a cow may become caught on a fence or other piece of farm equipment. In this situation, if a cow is unable to free itself of the wearable then it will likely panic and cause serious injury to itself or others.

Finally, GPS-enabled wearables require considerable power consumption to enable the necessary communications signals. Thus, battery life is a particular concern for these specific types of wearables (Nixon et al., 2016).

Future research directions

Current studies using wearables for lameness detection focus on tracking a cow's daily activities and then detecting when there is a change in the trend (Thorup et al., 2015). By definition, a cow that is lame will walk with an abnormal gait as opposed to a regular gait (Sprecher et al., 1997). A study on lameness detection in sheep was able to use a collar equipped with an accelerometer to detect an abnormal gait as opposed to detecting a reduction in activity (Barwick et al., 2018). In cattle, this method for lameness detection has been successfully implemented using an accelerometer attached to the hind leg of a cow (Alsaaod et al., 2017; Chapinal et al., 2011; Haladjian et al., 2017), however there is greater risk associated with attaching leg devices to cattle (due to possibility of being kicked). If gait anomaly detection could be achieved using data from a collar-mounted accelerometer, this could improve the specificity of lameness detection algorithms; the algorithms may be able to better distinguish between mild and severe lameness.

Infrared thermography

Infrared thermography (IRT) is a method which detects infrared energy emitted from objects, converts it to temperature, and displays an image of temperature distribution (Stelletta et al., 2012). It is performed with infrared or thermal imaging cameras and is a useful method for determining the surface temperature of objects, people, and animals (Stelletta et al., 2012). In studies on human medicine, IRT has been used to detect fever (Chiu et al., 2005). Fig. 3 is from a study which attempted to use IRT to detect fever in Polish children (Ring et al., 2008). In Fig. 3 the child on the left has a fever whereas the child on the right does not, and upon visual inspection it is clear that there is a noticeable difference in facial surface temperature between the children.

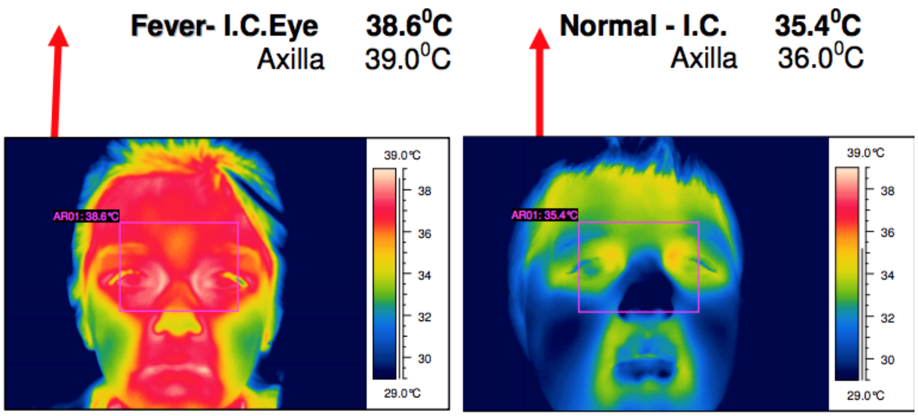

Fig. 3 Thermal images of a child that has a fever (left) and a child that has a normal (Ring et al., 2008)

Applications

Due to the success of using IRT for fever detection in humans, several studies have attempted to use IRT as a method of measuring core body temperature in cattle (George et al., 2014; G. Hoffmann et al., 2016; G. Hoffmann et al., 2013). However, in Fig. 3, note the drastic change in surface temperature between the children's foreheads and the hair on top of their heads. A cow's body is covered in a layer of fur that is often dirty. As a result, studies attempting to use IRT to predict core body temperature in cattle have produced highly inconsistent results and for the most part have concluded that IRT will never measure core body temperature with the accuracy of a rectal thermometer (Hoffmann et al., 2016; Lees et al., 2018). Different studies have attempted to use IRT to detect disease-associated fever in cattle as opposed to exact body temperature (Schaefer et al., 2007). These studies are still inconsistent but have had some success; one study determined that calves infected with Bovine Respiratory Disease did in fact have higher peak infrared thermal values than calves that were not infected (Schaefer et al., 2012).

IRT has been used with much more success for the detection of hoof lesions, a common health concern in cattle populations (Dutton-Regester et al., 2018). Hoof lesions cause a cow to be lame and can be symptomatic of a number of different hoof pathologies such as foot-and-mouth disease (Rainwater-Lovett et al. 2009). Studies on hoof lesions generally agree that hoof temperature elevates with the presence of a lesion, and IRT has been used successfully in studies for determining whether or not hoof lesions are present (Alsaaod & Büscher, 2012; Main et al., 2012; Stokes et al., 2012). These methods for automated hoof lesion detection through the use of IRT achieved sensitivities and specificities between 70% and 80%. Fig 4. demonstrates thermal images of a calf infected with foot-and-mouth disease (right) and a calf that is not infected (left). Note the elevated temperature on the hooves of the calf on the right.

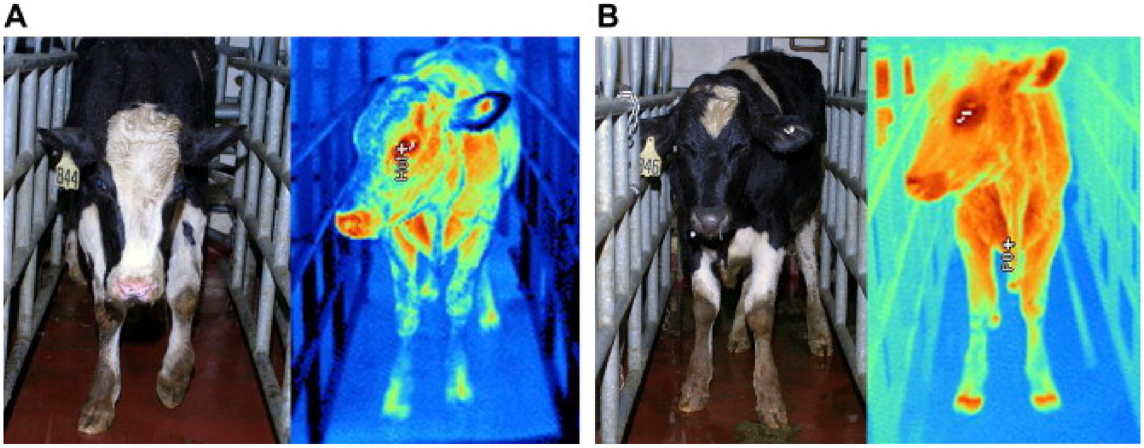

Fig 4. (Rainwater-Lovett et al., 2009). The calf on the right is infected with foot-and-mouth disease while the calf on the left is not.

Limitations

The single most debilitating limitation in the use of IRT is the degree to which external, environmental factors can influence IRT readings (Okada et al., 2013). The colour of a cow's fur, ambient temperature, humidity, distance between the cow and the infrared camera, and others are all factors that can influence the surface temperature measured by IRT (Okada et al., 2013). This limitation is significant enough that a few studies have suggested that IRT may have no practical use in the field of PLF (Lees et al., 2018).

Future research directions

Work must be done to determine the feasibility of IRT use in livestock environments. If a system for monitoring cattle which employed IRT was equipped to measure several environmental factors such as ambient temperature, humidity, etc. then perhaps an algorithm could be created which could adjust IRT readings accordingly based on these factors. Furthermore, future studies should focus on the use of IRT for fever detection as opposed to predicting exact core body temperature. It is possible that IRT may have more practical use in the field of PLF when used in conjunction with other types of sensors.

Visible light camera

In the field of PLF, visible light cameras are used for both 2D and 3D video or image analysis.

Applications

The most common use of video analysis in PLF is for the purpose of lameness detection, which has been accomplished with both 2D and 3D video (Viazzi et al., 2014). There are several visual cues that a cow exhibits when lame, and noticing these visual cues is the original method for lameness detection (Sprecher et al., 1997). Video analysis algorithms have been created which can detect specific symptoms of lameness that human farmers have trained to look for (Van Hertem et al., 2014; Zhao et al., 2018). In most cases, in order for the algorithm to work, a video of the cow walking at least one full gait cycle was necessary.

A particular symptom of a lame cow that is easy for the untrained eye to observe is the presence of an arched back (Sprecher et al., 1997). A cow that is walking normally will have a back that appears flat when looked at from the side, whereas a lame cow will have a noticeable arch to its back (Sprecher et al., 1997). Fig. 5 displays a sound cow with a flat back, whereas Fig. 6 displays a lame cow with an arched back. Several studies have created video analysis algorithms that can perform spinal analysis and determine if an arch is present in a particular cow's back (Jabbar et al., 2017; Van Hertem et al., 2014, 2017; Viazzi et al., 2014). For most of these studies, the experimental setup involves a 3D (depth sensing) camera positioned to have a top-view of the cow walking underneath. After a top-view video has been recorded of the cow walking, spinal analysis can be performed, and the algorithm can decide whether or not the cow is lame. An algorithm for spinal analysis which used side-view, 2D video recordings of the cow was created (Viazzi et al., 2014), however image segmentation had to be performed manually as opposed to the fully automated 3D video algorithms.

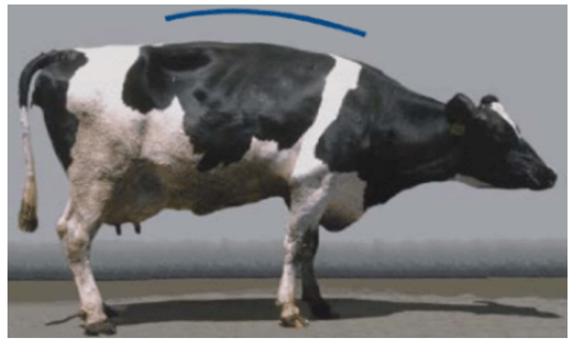

Fig. 5 (left) a sound cow with a flat back (image source: https://www.videoblocks.com/video/red-cow-walking-on-a-transparent-background-cyclic-animation-contains-an-alpha-channel-can-also-use-as-a-silhouette-szp-ugpnipevhjat)
Fig. 6 (right) a lame cow with an arched back (image source: http://www.thecattlesite.com/articles/3604/spring-and-lameness/)

Recently, a study was published in which researchers created an algorithm for automated lameness detection via analysis of a side-view, 2D video recording of the cow walking (Zhao et al., 2018). Instead of performing spinal analysis to determine the presence of an arched back, this algorithm performed leg swing analysis to determine symmetry of a cow's gait. Similar to a person with a limp, a cow's walking pattern will become asymmetrical when lame (Sprecher et al., 1997). The algorithm by (Zhao et al., 2018) was able to automate lameness detection based on the symmetry (or lack thereof) of a cow's gait.

All of the above algorithms for lameness detection via video analysis yielded accuracies upward of 90%, provided only perfect videos were used for analysis. See limitations below for further explanation.

Limitations
Although the above algorithms for video analysis boasted high accuracies, they only function in highly constrained settings which require a cow to walk alone down a narrow chute (Van Hertem et al., 2017; Viazzi et al., 2014; Zhao et al., 2018). It is also noteworthy that in most of these studies, any imperfect videos were discarded and not analyzed. Some algorithms only performed properly at night (Van Hertem et al., 2014; Viazzi et al., 2014), while in another study the algorithm only functioned properly during daylight when it wasn't raining (Zhao et al., 2018). For most studies, if there is more than one cow in the video or the cow stops, slips, or speeds up, then the video is discarded and not analyzed (Van Hertem et al., 2017; Zhao et al., 2018). Because of the highly constrained settings necessary for these algorithms, implementation in free range habitats would be difficult.

Future research directions

As previously mentioned, video analysis algorithms for lameness detection boast high accuracies but only under highly constrained conditions. In dairy barns, there are likely already narrow chutes setup for entrance into milking areas. These could be used to duplicate the lameness detection algorithms; however, the algorithms must be trained to automatically discard imperfect videos so as not to create false positives.

It is worth investigating if lameness detection via video analysis is possible in an outdoor, free range setting. There is great potential for the use of Unmanned Aerial Vehicles (UAV) in the field of PLF. UAVs have been used to count cattle and collect data from wearables (Chamoso et al., 2014; Webb et al., 2017), and these studies noted that cattle adjust remarkably fast to the presence of a UAV and will not react at all once they are used to it. If this is true, then a UAV which is equipped with a 3D camera could hover above a cow that is walking, record a video, and send the video to a base station where spinal analysis can be performed using one of the top-view algorithms. The success of this method would depend on the stability of the UAV.

OPPORTUNITIES FOR MULTI-SENSOR SYSTEM

After conducting a literature review on the field of PLF which targeted technology for monitoring cattle that had potential to be implemented in outdoor, free range habitats, there were two main gaps identified in the research. First, there is a lack of research which attempts to combine multiple different types of sensors into a consolidated monitoring system; most of the experimental studies on PLF are focused on investigating the potential of one particular type of sensor. Second, there is a lack of research to implement PLF solutions in outdoor, free range habitats; most of the experimental studies are focused on innovating solutions for indoor livestock habitats. There are some recent studies which address both of these research gaps, but they are limited.

Integration of multiple sensors for outdoor monitoring

Due to the lack of research in the two areas mentioned above, we present a multi-sensor system for monitoring cattle in outdoor, free range habitats. We hypothesize that analyzing data from many different sensor sources, as opposed to one, could improve the performance of currently existing algorithms for the automated detection of health and welfare problems in cattle. The proposed system is illustrated in Fig. 7. There would be multiple stationary sensors positioned around the inside of the cattle enclosure, while a UAV would be stationed right beside the enclosure. Both the stationary sensors and the UAV would be equipped with infrared cameras, depth sensing cameras, microphones, and Wi-Fi capabilities for transfer of data. Additionally, each cow in the outdoor habitat would be equipped with collars which contain accelerometers.

Our hypothesis is that an increase in the number of sensor sources that a PLF system is able to obtain data from will result in an increase in the performance of that system. Different types of sensors used in conjunction with one another could help to address the limitations of individual sensors. For example, it is possible that PLF systems which use only wearable sensors generate a significant number of false positives; they notify the farmer every time a particular cow has become less active than usual. In our proposed system, if a wearable device detects that a cow is less active than normal, the UAV equipped with depth sensing camera could hover above the cow in question and perform top-view spinal analysis to determine if the cow is in fact lame. This would greatly reduce the false positives of automated lameness detection. A main goal of the amalgamated system would be to increase the confidence levels of all previously existing algorithms for the automated detection of health and welfare issues.

It is possible that the use of infrared thermography in PLF would be much more feasible if used in conjunction with other sensors. If infrared cameras could be used outdoors to detect that a cow has fever, perhaps by comparing its thermal values to that of nearby cattle, this would have highly positive implications for the treatment and prevention of disease. In the scenario described earlier of a wearable device detecting a reduction in activity, a UAV that was equipped with a depth sensing camera as well as an infrared camera could inspect a cow for presence of fever, in addition to performing spinal analysis for lameness detection.

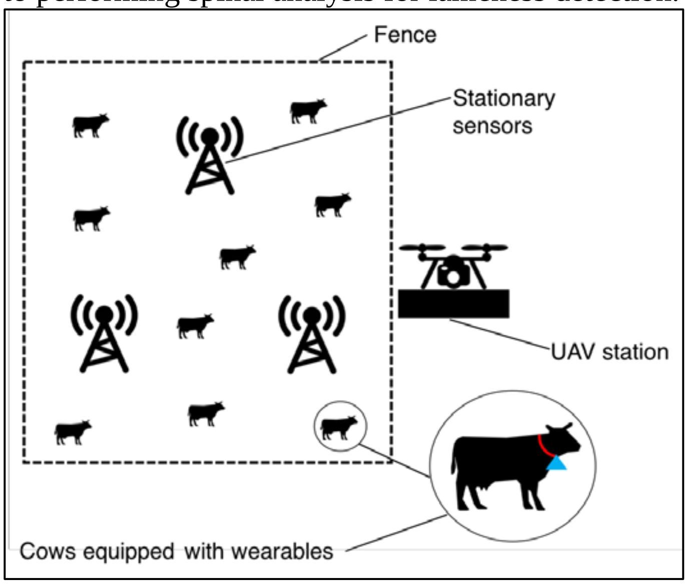

Fig. 7 A proposed multi-sensor system for monitoring cattle in outdoor, free range environments.

HUMAN COMPUTER INTERACTION AND PLF

While a main goal of PLF is to automate the detection of health and welfare issues in livestock environments for the purpose of improving conditions for the animals, farmers who choose to invest in these systems need to be able to interact with them in a user-friendly fashion. This is where the field of Human Computer Interaction (HCI) and PLF intersect.

Opportunities for HCI research in PLF

Most of the work done in the field of PLF has been focused on the development of new technology from a strict engineering perspective. Most studies on PLF involve researchers who have made assumptions about what type of technology would be the most useful for livestock farmers. There is a strong need for PLF research which attempts to innovate technology based on real concerns from livestock farmers who have been interviewed.

Surveys or “in the wild” studies which have been done on deployed PLF technology are extremely rare, likely due to the fact that PLF is a young field and commercialized systems are fairly new. It is difficult to find data on the number of farms which use PLF technology; however, the existence of multiple companies which produce wearables for cattle implies that PLF systems have been deployed enough to conduct surveys. These surveys could ask a number of questions, the answers to which could greatly assist in the development of new PLF systems. Potential questions are as follows:

1. How do farmers use the data collected from PLF technologies? It should be investigated whether or not farmers are using data in the way that researchers intended, or if they have found different uses for the data.
2. How do farmers manage the various notifications from different systems? It is important that farmers do not receive an excessive amount of notifications that will impede their regular work. It is also important that notifications are meaningful to the farmer.
3. Are PLF technologies actually solving problems faced by livestock farmer? If a PLF system works as intended, then a farmer should be able to say that the system has solved one or more of their pre-existing problems. Ideally the technology would not have caused any additional problems.
4. Are PLF technologies improving the health and welfare conditions of livestock animals? This question addresses a main goal of PLF. In addition to assisting the farmer with monitoring tasks, PLF systems are meant to cause an overall improvement in the health and welfare conditions of the animals being monitored.

Another opportunity for HCI research in PLF involves the development of user interfaces and visualizations of data. Due to the continuous nature of PLF monitoring systems, there is a large amount of data that needs to be stored and presented in a way that is useful for the farmer. A user interface that seems intuitive to a computer scientist may in fact seem counter-intuitive to someone else. For this reason, it is recommended that HCI specialists be consulted for the development of PLF interfaces. Additionally, involving multiple farmers in the development process would improve the chances of producing an interface with high usability.

CONCLUSION

Growing herd sizes have created high animal-to-farmer ratios, which has resulted in a need for the automated detection of health and welfare issues in livestock populations. PLF offers many solutions to assist farmers through the use of continuous, real-time monitoring systems. Literature review was conducted on the field of PLF, with a focus on technology for monitoring cattle which has potential to be implemented in outdoor environments. Extensive research has been performed in the field of PLF, but mostly in indoor, constrained environments; there is a lack of research which attempts to implement PLF solutions in outdoor, free range habitats. There is also a lack of research which attempts to combine multiple different sensor types into a consolidated monitoring system, in order to address the limitations of individual sensor solutions. For future research, we proposed one example of an amalgamated, multi-sensor monitoring system for outdoor cattle pasture habitats. We identified several opportunities for HCI research, indicating that development teams for future PLF technology should include HCI specialists.

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