Networked Cows: Virtual fences for Controlling Cows

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1. MOTIVATION

Our goal is to develop computational approaches for studying groups of agents with natural mobility and social interactions. Such systems differ in many ways from engineered mobile systems because their agents can move on their own due to complex natural behaviors as well as under the control of the environment (for example drifting to follow wind patterns). We wish to model such systems using physical data and to use the models for controlling the movement of the mobile agents and the information propagation between them using virtual fences, implemented on smart networked collars attached to the animals. Our main motivation and application is in the agricultural domain. Herds of animals such as cattle are complex systems. There are interesting interactions between individuals, such as friendship, kinship, group formation, leading and following. There are complex interactions with the environment, such as looking for a water source in a new paddock by perimeter tracing along the fence and random walking within the perimeter. Such behaviors are well known to farmers but not so well documented. Furthermore, limited control can be exerted whose effect is to move the animals around. This could be greatly beneficial in terms of reducing the amount of expensive fence maintenance and mustering required by ranchers.

In this work we combine robotics, networking and animal behavior to create a fence-less approach to herding cows called *control by virtual fences*. The cow society can be viewed metaphorically as well as physically as a network. By endowing each animal with the computation, sensing, and networking capabilities needed to drive virtual fencing we will obtain a networked system that can function as an information backbone for the group. Information can flow across this group to update individual parameters and programs (for example the motion plans for the virtual fences), coordinate tasks, and aggregate data collected by the individuals. However, because the system is large in numbers and spread, information flow has to be regarded as a group operation. It is impossible to physically connect to each animal at any one time. This suggests that it is important to know how long it takes for one message to reach the entire group.

The group is connected with wireless capabilities, but the transmission range for each animal is limited. When two animals are within transmission range, they can exchange messages. Thus, we implement message transmission with a multi-hop routing model. A complication is the natural mobility of the system. Since communication is predicated on animal proximity, movement may disconnect the network and prevent information from being propagated. Connectivity is important because it allows data and program transmission across the network. Because the size of such networks is large, it is impractical to expect that each animal will be programmed individually; rather new programs will propagate through the network using ad-hoc networking.

Two fundamentally different approaches to controlling animal position are a physical agent such as a sheepdog or robot, and a stimulation device worn by the animal. In the first category there is the pioneering work of Vaughan [6] who demonstrated a mobile robot that was able to herd a flock of ducks to a desired location within a circular pen. In the second category there are a number of commercial products used to control domestic pets such as dogs. These typically employ a simple collar which provides an electric shock when it is in close proximity to a buried perimeter wire. The application of smart collars to manually control cattle is discussed in detail by Tiedemann and Quigley [4, 5]. The idea of using GPS to automate the generation of stimuli is discussed in [1, 3]. In [2] we describe our first experiments to controlling a herd of cows with a single static virtual fence using an approach that relies on ad-hoc networking.

2. TECHNICAL APPROACH

Our virtual fences combine GPS localization, wireless networking, and motion planning to create a fence-less approach to herding animals (see Figure 1). Each animal is given a smart collar consisting of a GPS unit, a Zaurus PDA, wireless networking, and a sound amplifier. The animal is given the boundary of a virtual fence in the form of a polygon specified by its coordinates. The location of the animal is tracked against this polygon using the collar GPS. When in the neighborhood of a fence, the animal is given a sound stimulus whose volume is proportional to the distance from the boundary, designed to keep the animal within boundaries. Cattle domain experts have suggested using a library of naturally occurring sounds that are scary to the animals (a roaring tiger, a barking dog, a hissing snake) and randomly rotating between the sounds. Our prelim-

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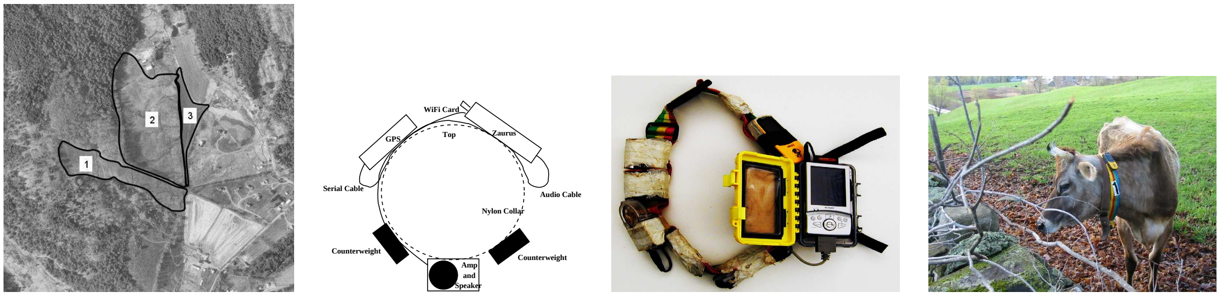


(a) (b) (c) (d)

Figure 1: (a) Aerial view of Cobb Hill farm. The fields where experiments were conducted are outlined in black. North is up. The photo displays an area approximately 1 km on a side. (b) The components of the Smart Collar include a Zaurus PDA, WiFi compact flash card, eTrex GPS, protective case for the Zaurus, an audio amplifier with speaker, and various connecting cables. (c) A fully assembled Smart Collar, with PDA case open. (d) A cow with a collar.

inary experiments indicate that cows respond to sounds by moving in the direction in which they are heading. The collars are tasked with the virtual fence coordinates using multi-hop networking because the pastures are too large for single hop messages to reach all the animals. The messages propagate from animal to animal as they come within transmission region.

A virtual fence is defined by a point F_p and a normal vector F_n. This representation allows for an easy test to determine whether the cow is behind the fence. Several fences can be combined to represent an enclosed boundary. The startle/stopping function of the virtual fence can be implemented as a large force that stops or turns the agent and is delivered via a stimulus. One simple option is to produce a stimulus whose magnitude is proportional to the agent's distance behind the fence. This graduated stimulus will help the agent better understand the location of the fence [1, 2].

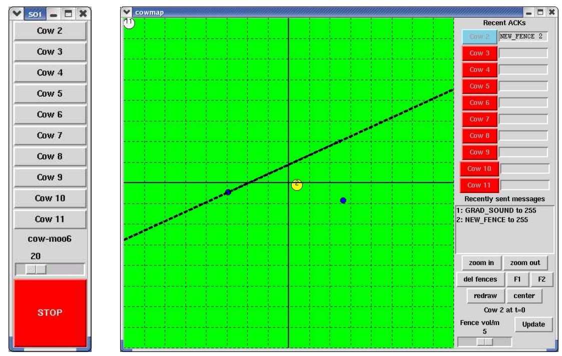
A static virtual fence can be used to constrain location. The virtual fence can be also be dynamic by automatically and gradually shifting its location. A moving fence can be instantiated with a non-zero velocity F_v, in m/s. The point F_p is then moved as a function of time along the normal, $F_p(t) = F_p(0) + \gamma F_n F_v t$. We have also begun to develop motion planning algorithms that can determine automatically how to move virtual fences as a function of the environment (with obstacles corresponding to trees, rocks, rivers, etc.)

3. EXPERIMENTS AND RESULTS

We have implemented a static virtual fence algorithm in simulation and deployed 10 smart collars on cows at Cobb Hill Farms in Vermont[1]. Our physical experiments targeted four issues: (1) collecting data to create a grazing model for the cows, which is used in the fence control algorithm; (2) collecting connectivity data and information propagation data, which is used to determine the multi-hop routing method for networking the herd; (3) collecting stimulus response data for individual animals; and (4) collecting response data for the virtual fence on single animals. We also implemented an interactive GUI, shown in Fig. 2, which allowed us to monitor the locations of the animals and their network connectivity as the experiments proceeded.

As far as the networking is concerned, we found that for the most part, the cows remained close enough to maintain overall connectivity, but not complete single-hop connectivity. These data were obtained by analyzing the reception of the "Alive" messages sent by each collar back to the base station once per minute. Any such messages heard directly by another collar represent a one-hop connection, while any collar not receiving such a message represents a lack of connection. A graphical presentation of this analysis is shown in Fig. 3, which shows the positions of the cows at a single point in time together with the one-hop connections present at that time. As in this snapshot, the herd was generally not sufficiently clustered to allow one-hop connectivity between all animals. Quantitative analysis for the duration of the experiment, showing the number of one-hop connections present as a function of time, is presented in Fig. 4.

We also used the GPS data collected by the collars together with the message logs to determine the range of the wireless system. In Fig. 5, we show the distance traveled by each hop of each message. Most messages travel a short distance between nearby animals, but others travel over distances up to about 100 meters. We do not achieve the maximum theoretical distance of WiFi, and we believe this to be the result of the antennas being around the cows' necks and often near the ground, so that the animals and wet ground absorb significant amounts of the signal.



(a) (b)

Figure 2: GUIs used on laptops to monitor field experiments. (a) Sound control GUI. Pressing a button triggers a sound on a specific cow. (b) Map control GUI. Shows the last reported position of each cow, whether it is currently playing a sound, and whether an Alive message has been received recently.

[1]This work was done under protocol assurance A3259-01 given by the Institutional Animal Care and Use Committee (IACUC) of Dartmouth College.

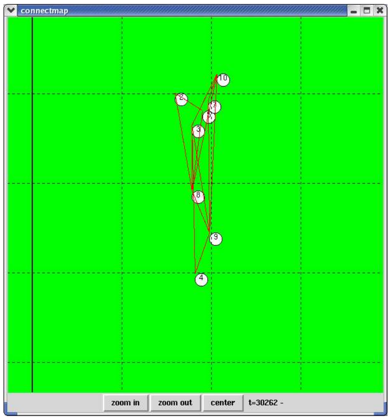


Figure 3: Network connectivity among the herd at one point in time during field experiments. It can be seen that many connections exist, but even some short ones do not, presumably due to the locations of the antennas relative to the animals' bodies and the ground.

Together these data indicate that a multi-hop protocol is required to disseminate information to the herd, since it is important that the control messages are received by all collars and acknowledgments of these messages get back to the basestation. However, we have also determined that sufficient connectivity exists (at least in small herds) to efficiently and effectively communicate with a multi-hop protocol and share data. We have also considered implementing store-and-forward protocols. These were not necessary in these preliminary experiments, but in future applications the herd may be significantly larger and form several cliques, so with a single fixed basestation store-and-forward may be necessary for efficient dissemination of control messages.

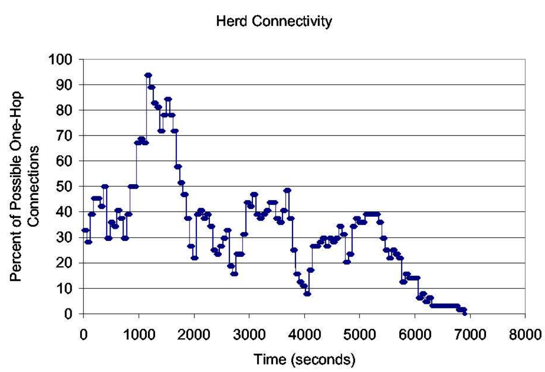


Figure 4: Connectivity among the herd, measured by the percentage of one-hop connections present relative to all pairs of cows. At the beginning of the experiment, the cows were tightly clustered, so that most collars could communicate directly with most others. In the field, the connectivity was less complete but still sufficient and fairly consistent.

Our preliminary results for the virtual fences are also encouraging. Animals respond to sounds generated by the virtual fence by moving forward if they are on their own, or toward the group if they are in close proximity to the group. This observed response serves as a basis for using an artificial potential of sounds as a stimulus model. We implemented virtual fences, and noted that the animals slowed down significantly when crossing fences and receiving the stimulus, but this was not sufficient to keep them on the desired side of the virtual fence. Alternatively, one can imagine augmenting the increasing sound stimulus with electric shock [1]. The animals responded to some of our sounds but habituation to stimuli remains a question. Details of these experiments can be found in [2]. Animal experts such as Dean Anderson believe when the sounds are graduated and accompanied by shocks habituation does not happen. We plan to conduct some joint experiments with his group to verify this.

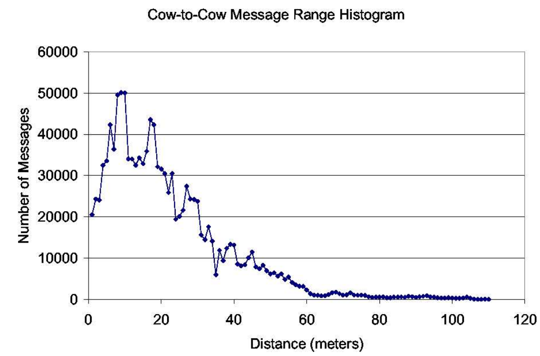


Figure 5: Distances over which messages were successfully sent. Range obtained from GPS positions of the cows sending and receiving messages.

4. CONCLUSION

In summary, we described a new application of robotics and ad-hoc networking to a system for controlling cows via virtual fences. Our simulation results are very encouraging. We also carried out a series of experiments in the field, with our prototype collar hardware functioning well. The results of both the networking aspects and the animal control aspects both show promise for this application, but much work remains to be done.

5. REFERENCES

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