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An Investigation of Predator Response in Robotic Herding of Sheep

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Abstract. Research into robotic herding of farm animals has so far been restricted to simulations or very limited artificial environments. Models of herd response to herders as perceived predators vary greatly in complexity but all assume a 'flight distance' at which an animal will regard the threat as great enough to warrant movement. In this paper we report on an experiment to measure the flight distance for a flock of sheep with a robot herder in a real farm environment. Our results show that, rather than being stable, the flight distance decreases rapidly as the sheep become accustomed to the presence of the robot. This has significant implications for future work on intelligent robotic herding.

Keywords: robot, herding, sheep, flight zone

1. Introduction

Autonomous robotic systems are finding increasing use in many different areas of human activity, including surveillance, search and rescue, domestic tasks and agriculture. In agricultural production, applications of robotic technology now include automated tractors, milking equipment, fruit-picking and weed control. The adoption of such systems can potentially provide benefits not only in terms of overall cost reduction but also in terms of safety, environmental impact and animal welfare.

In general, the use of robots in animal management is a more challenging task than their use in crop management due both to the difficulties in predicting animal behaviour and the difficulties involved in constructing mobile robots which are capable of working in the environment in which the animals are located. One such challenging area is the mustering and movement of groups of farm animals by either a single robot or a set of cooperating robots in order to bring them to some desired location on the farm. For large flocks of animals like sheep, robotic mustering and herding has the potential to provide significant savings in human labour and also to enable a cheaper and lower-stress form of animal movement than the use of sheepdogs.

As yet, research projects in this area have been limited to either pure software simulations, robots simulating animal behaviour or a very limited use of real animals in an artificial environment. In each case, these projects are dependent on some form of model of how the animals will behave in responding to the robot as a perceived predator, and one of the fundamental parameters of the models is the 'flight distance' parameter, i.e. the maximum distance at which an animal will regard the predator as a great enough threat to require movement away from it.

The aim of our investigation has been to gather initial field data on the flight distance of sheep when responding to a robot 'predator', using an actual robot, a herd of 30 sheep and a real farm paddock environment. This investigation forms the basis for further work on robotic sheep mustering and herding on farms.

In the following section, we review related work in the areas of herd simulations, shepherding robots and sheep reaction to predators. In section 3 we review the key elements of a number of proposed models for sheep response to predator threat. Sections 4 and 5 present the design and results of our experiment while section 6 discusses the implications for future work.

2. Related Work

The behaviour of animals in herds has been studied in a variety of contexts and for a variety of reasons. These include investigations of emergent properties in agent-based systems for graphics (Reynolds, 1987), realistic simulations of fleeing animals for computer games and animated films (Fungi, 1999) and modelling of the spread of animal diseases (Dion, 2011).

A number of models have been developed for describing the interactions between herds and herders, focussing either on the response of the herd to threats from perceived predators (Buckley, 2008) or on the behaviour of the predators or herding animals (Lien, 2005)(Cowling, 2010), but this work has generally involved only software simulations using no data from experiments with real animals. An exception is (King et al., 2012), in which GPS tracking equipment was attached to a sheepdog and to each of the sheep in a flock in order to measure the level of flock cohesion (mean sheep distance to flock centroid) as a function of perceived threat (dog distance to flock centroid).

Research projects involving the use of autonomous robots in agriculture have so far focussed mostly on crop management rather than animal management. An example is (Bakkar, 2006) which describes an autonomous weeding robot. (Thakkar, 2005) reports on an autonomous herding robot developed to recognise gestures from a human and work together with the human to move a 'single cattle-type animal' but the experiments were conducted by using a further robot to simulate the behaviour of the animal.

The only research to have been conducted involving robot herding of real animals is (Vaughan, 2000). In this project, a robot was able to autonomously move a flock of 12 ducks to a predetermined location on the rim of a small circular enclosure.

As yet, there do not appear to be any data describing the reaction of a sheep flock to a herding robot. This data is essential as the basis for future work on the intelligent robotic herding of farm animals.

3. Models of Herd Predator Response

All of the work described in the previous section depends on some form of model of the behaviour of herd animals with respect to their alignment to the herd and/or avoidance of a perceived predator. These models vary considerably in complexity and it is an open research question what complexity of modelling is required to successfully move a flock of sheep with a single or multiple robot herders.

In (Reynolds, 1987), the author describes his "boids" particle-based model for characterising the behaviour of flocks, herds and schools of animals. The overall herd behaviour emerges from the decisions of individual members of the herd based on the three basic principles of collision avoidance, velocity matching (to nearby members of the herd) and flock centering (the desire to be near the centre of the nearby members). He further describes a steer-to-avoid model for environmental obstacles but does not address the issue of predator avoidance.

Thakkar (2009), in his robotic simulation of low-stress robot-assisted herding, uses an animal model based on a flight zone. If a herder moves within this zone, the animal will begin to move, otherwise it will remain stationary. The flight zone is a circular area defined by the flight distance radius but with a blind zone at the rear. If the herder enters the blind zone, the animal will turn in order to keep the herder in view.

Wood and Ackland (2007) use an evolutionary model with 12 parameters to investigate whether flock formation is driven primarily by foraging efficiency or by predator avoidance. These parameters include nested radii defining an inner zone within which individuals move away from each other, a middle zone within which individuals move parallel to each other and an outer zone in which individuals move towards each other. The zones are defined as circles with an area to the rear excluded as a blind region. The model also incorporates movement vectors towards a food source and away from a predator.

Buckley (2008) presents three possible models for sheep flock behaviour in increasing order of complexity. The first model is based on (Reynolds, 1987) and defines movement of individuals in terms of attractive/alignment force vectors (for other sheep and food sources) and repulsive force vectors (for predators and obstacles). The sum of the force vectors determines the direction of movement. The second model defines five priority levels of behaviour with the sheep following the rules of the highest-priority level determined as applicable for the current state of the environment. Highest priority are rules for collision and predator avoidance down to the lowest priority for random wandering. Buckley's third model uses a more complex state vector for each individual including both 'emotional state' (e.g. fear, hunger) and 'personality' (e.g. dominant, outlier).

Regardless of the complexity of the model, it can be seen that those models which describe the reaction of the herd animals to a perceived predator involve the assumption of a relatively stable flight distance which defines when the perceived threat is great enough to induce an animal to move away.

4. Experimental Design

Our experiment involved the use of 30 merino wethers in a 2.5 hectare treeless, grassy paddock at the Kirby Research Farm outside Armidale, NSW. For each trial, the sheep were collected into a loose flock around a food source. Three trials were run in which a SCRUPAL robotic unit (Fig. 1) was slowly driven towards the flock. The SCRUPAL robot is a general-purpose outdoor research robot which is being developed for autonomous team operation, but in this case a single robot was just remotely controlled towards the flock from a distance of 100m.

Fig. 1: The 'SCRUPAL' unit

Markers were placed at 25m distances in order to give a visual reference. The aim in each trial was to observe and record on video the distance from the robot to the flock when the sheep first became alert to the presence of the robot and the distance at which the sheep began to move away from the robot (i.e. the flight distance). Distances were measured from the robot to the closest sheep of the flock, rounded to the nearest 5m.

Fig. 2: The 'SCRUPAL' approaches the flock

As a control, three trials in which a 4WD vehicle slowly approached the flock were interspersed with the robot trials and the same data were recorded. The six trials were conducted over a total period of approximately two hours

Fig. 3: The 4WD vehicle approaches the flock

5. Results and Discussion

The alert distance and flight distance for each of the robot trials is shown in Fig. 4. The most striking result is the steep decline in both of these distances as the trials progressed. On the first trial, the sheep became wary of the robot as soon as they heard the sound of the motor, at a distance of some 90m, and then began moving away at 60m. By the third trial, the sheep completely ignored the robot until it was only about 10m away.

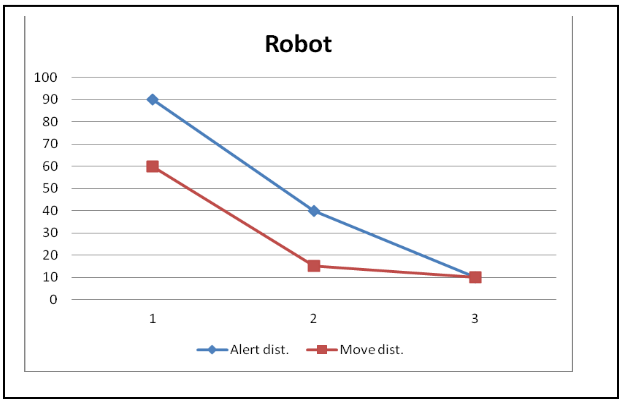

Fig. 4: The alert and movement (flight) distance in metres for the robot

The control results with the 4WD also show a decline over the course of the three trials though much less marked. This is presumably because the sheep are familiar with this kind of vehicle whereas the robot and in particular the sound of its motors was unfamiliar.

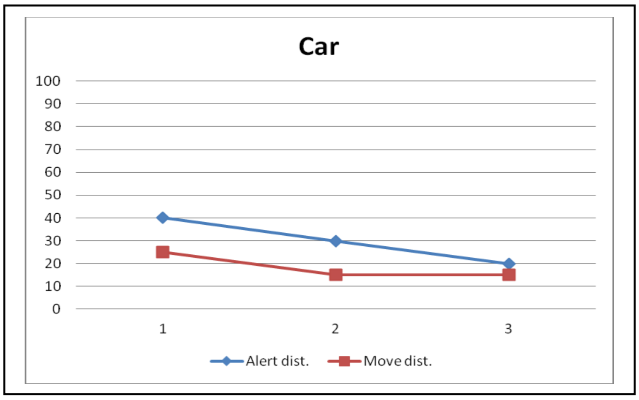

Fig. 5: The alert and movement (flight) distance in metres for the 4WD

It is instructive to compare these results with those from a recent experiment in which a sheepdog was used to move a similar-sized flock of merino sheep (King et al., 2012). In this experiment, GPS tracking equipment was attached to the dog and each of the sheep in order to measure the flock cohesion as a function of perceived threat. The supplemental data published in connection with this experiment includes videos of an animated visualization of each of the three trials. A still image taken from one of these videos is shown in Fig. 6.

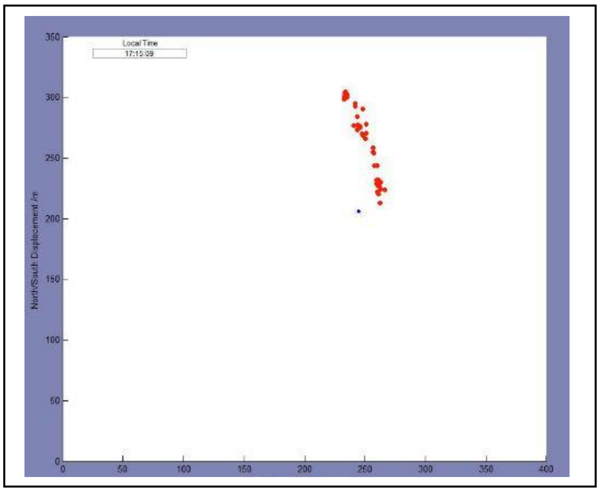

Fig. 6: Still image from sheepdog data video

An analysis of the videos allows the flight distance for the sheep in each of the trials to be extracted. These results are shown in Fig. 7.

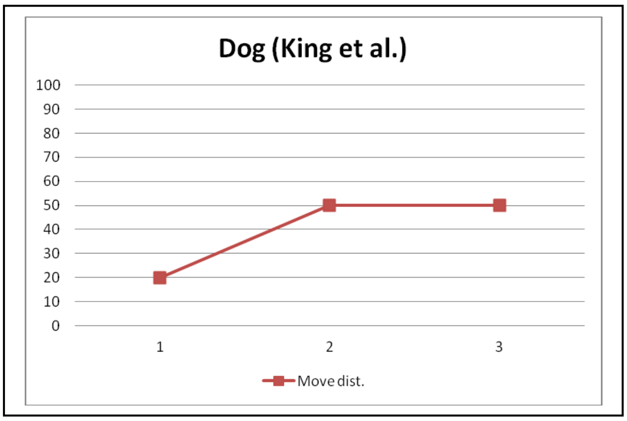

Fig. 7: The movement (flight) distance in metres for the sheepdog

It can be seen that the flight distance in this case actually increases from the first trial to the second and then remains at some 50m. The comparison with our results is less than perfect since the trials in this experiment were conducted over three successive days, but it is an indication that the response of the flock to an approaching robot is quite different from the response to a real perceived predator.

6. Conclusion and Ongoing Work

The results of our experiment show a clear accustomisation effect where the distance at which a flock of sheep will move away from a herding robot drops from an initial 60m to only 10m after two further trials. This result calls into question the assumption that sheep will react to autonomous herding robots as perceived predators, with a stable, predictable flight distance. In fact the reaction to the robot is so weak after the accustomisation that it can perhaps ultimately be better characterized as a collision avoidance behaviour rather than a flight behaviour.

This result does not necessarily mean that intelligent robotic movement of sheep flocks is impractical. Further PhD research is being conducted to determine whether a cooperating team of robots is able to effect stable movement of a flock. If successful, this may enable flock movement in a way which does not require the presence of a human and which causes less stress to the animals than the use of a sheepdog. A further interesting possibility being investigated is that sheep may even accept a robot into the flock in such a way that, with some form of positive reinforcement, they can learn to view it as a leader and simply follow it to a new location.

7. References

[1] Bakker, T., van Asselt, K., Bontsema, J., Müller, J. & van Straten, G. An autonomous weeding robot for organic farming, *Field and Service Robotics*, Springer Tracts in Advanced Robotics, 25, 2006.

[2] Buckley, B. *Modelling Sheep Flock Interaction with Sheepdogs*, Honours Thesis, University of Bath, 2008.

[3] Burling, P. *Developing a Self-Contained Robotics Unit to Implement Intelligent Team Herding Based on Sheep*, Masters Thesis, University of New England, 2013.

[4] Cowling, P. & Gmeinwieser, C. AI for Herding Sheep, *Proc. 6th AAAI Conf. on Artificial Intelligence and Interactive Digital Entertainment*, 2010.

[5] Dion, E., Van Schalkwyk, L. & Lambin, E.F. The Landscape Epidemiology of Foot-and-mouth Disease in South Africa: A Spatially Explicit Multi-agent Simulation, *Ecological Modelling*, 222, 13, 2011.

[6] Funge, J., Tu, X. & Terzopoulos, D. Cognitive Modeling: knowledge, reasoning and planning for intelligent characters, *Proc. 26th Conf. on Computer Graphics and Interactive Techniques*, 1999.

[7] Kachroo, P., Shedied, S.A., Bay, J.S. & Vanlandingham, H. Dynamic Programming Solution for a Class of Pursuit Evasion Problems: The Herding Problem, *IEEE Trans. on Systems, Man and Cybernetics*, 31, 1, 2001.

[8] King, A.J., Wilson, A.M., Wilshin, S.D., Lowe, J., Haddadi, H., Hailes, S. & Morton, A.J. Selfish-herd Behaviour of Sheep under Threat, *Current Biology*, 22, 14, 2012.

[9] King, A.J., Wilson, A.M., Wilshin, S.D., Lowe, J., Haddadi, H., Hailes, S. & Morton, A.J., Supplemental Data for "Selfish-herd Behaviour of Sheep under Threat", http://www.cell.com/current-biology/supplemental /S0960-9822%2812%2900529-5, *Current Biology*, 22, 14, accessed on Jul. 8, 2013.

[10] Lien, J.M., Bayazit, O.B., Sowell, R.T., Rodriguez, S. & Amato, N.M. Shepherding Behaviors, *Proc. IEEE Int. Conf. on Robotics and Automation*, 2005.

[11] MacWilliams, A., Sandor, C., Wagner, M., Bauer, M., Klinker, G. & Bruegge, B. Herding sheep: live system for distributed augmented reality, *Proc. 2nd IEEE and ACM Int. Symp. on Mixed and Augmented Reality*, 2003.

[12] Reynolds, C.W. Flocks, Herds and Schools: A Distributed Behavioral Model, *Computer Graphics*, 21, 4, 1987.

[13] Reynolds, C.W. Steering Behaviors for Autonomous Characters, *Proc. Game Developers Conf.*, San Jose, 1999.

[14] Thakkar, P. *Robot-assisted Herding*, Master's Thesis, San Jose State University, 2009.

[15] Thakkar, P. & Wesley, L.P. Autonomous mobile robot assisted herding, *Int. Conf. on Informatics in Control*, Automation and Robotics, 2005.

[16] Vaughan, R., Sumpter, N., Henderson, J., Frost, A. & Cameron, S. Experiments in Automatic Flock Control, *Journal of Robotics and Autonomous Systems*, 31, 2000.

[17] Wood, A.J. & Ackland, G.J. Evolving the Selfish Herd: Emergence of Distinct Aggregating Strategies in an Individual-Based Model, *Proc. Royal Society B Biological Sciences*, 274, 2007.