AUTONOMOUS MOBILE ROBOT ASSISTED HERDING

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Abstract: In this paper, we describe work that begins to address some of the issues related to developing an autonomous mobile robotic capability to assist humans with herding animals. A novel aspect of this work is the development of a capability to convey instructions to the robot via movements of a "toy human." In this work, no other explicit form of communication from the human to the robot is required. Furthermore, the robot is able detect if the human is absent or is unable to herd, and to herd the animal autonomously if required. We developed a herding framework that is based on low stress herding techniques. The robot uses a pan-tilt-zoom camera and a laser ranging sensor to track the human and interpret the human's movements. We conduct two sets of experiments that demonstrate autonomous and co-operative herding behaviour of the robot. We conclude by presenting experimental results that suggest our approach to developing a service robot with assistive herding capabilities holds promise for scaling to more complex and sophisticated tasks.

1 INTRODUCTION

Developing autonomous mobile robots that are capable of assisting humans with complex tasks within minimally instrumented environments and with minimal communication remains a challenge. Having such a capability is potentially beneficial in a variety of situations ranging from stealthy military and law enforcement activities through civilian activities such as herding domesticated livestock. The focus of the work reported here is two-fold; to develop an autonomous mobile robot that is able to perceive and interpret the movements of a human as a means to communicate instructions and the human's intentions to the robot, and to carry out autonomous herding at the direction of or absence of the human. An innovation of the work described here involves developing cattle and human behaviour models, perception techniques, and using them along with a specific herding technique, called low-stress herding (Smith, 1998), to carry out assistive or autonomous herding activities. Some researchers have attempted to communicate with assistive robots by developing speech and gesture recognition systems, to convey their intentions to the robot (Fischer et al., 1996, Topp et al., 2004, Yoshizaki et al., 2001). One differentiating aspect of our work is that no overt speech or gesture communication between the human and robot is used. Rather, just human motion relative to the animal and robot is used to communicate intentions and instructions to the robot. Although this work involves herding a single cattle-type animal, and the human is modelled by a remotely controlled toy, it represents an important incremental step toward developing a scaled up approach that can handle multiple animals and real humans. While we have reduced the complexity of a real-world context by using a "toy human" and colored objects, this allowed us to focus our investigation more on approaches, techniques, and methods that an autonomous robot might employ to interpret human movements. Such interpretations will be used to direct the robot's goals and locative movements to carry the desired assistive behaviour. Once significant progress is made on this aspect of our efforts, then we can focus on removing the simplifying constraints and simultaneously improving our "interpretation" capability as we approach a more real-world context.

2 RELATED WORK

Vaughan et al. demonstrated an automated herding capability in a simulated as well as real world context. They employed a potential field technique to herd a flock of ducks to the desired location. Their approach used an overhead camera to track the position of the robot and the entire flock. Butler et

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al. attempted to herd animals with the help of a dynamic virtual fence that moved slowly and automatically to herd animals to the desired location. Shultz et al. developed a system that used genetic algorithms to learn the complex task of shepherding, in which, one mobile robot attempts to herd another mobile robot to a desired area. Potter et al. accomplished herding using computer-based simulations to demonstrate the advantage of heterogeneity over homogeneity in control systems. Lein et al. used computer-based simulations to compare the various shepherding behaviours, in which, one or more shepherds control the motion of a flock.

Considerable research has also been done in the area of service robots that assist humans by fetching objects and delivering them to a human. Yoshizaki and Topp developed speech and gesture recognition modules that the robot can use to help understand the intentions of the user. Yoshizaki used Motion Processor (Numazaki et al, 1998) to detect a hand of the user, whereas, Topp used vision based gesture recognition algorithms to track a face and a hand. Fischer utilized a high-level natural language processing, augmented with CCD camera and a 3D environmental model to assist in screen based monitoring.

Despite the advances of previous work, some technical gaps remain. Ultimately, truly purposeful and autonomous robot assisted herding must be accomplished within un-instrumented environments. Furthermore, it must be anticipated that herding in outdoor natural environments will require robots to carry out tasks in contexts that present varying degrees of perception and terrain challenges. Dust, precipitation, and noise can impair perceptions. Terrain elevation changes and obstacles can preclude line-of-sight perception and movement along optimal paths. Being able to carry out assistive herding tasks when communication is limited or absent, presents challenges that have not been completely addressed to date. Indeed, the work described here does not completely address these herding challenges. However, it does begin to bridge some of the technical gaps that remain between successful previous work and a truly autonomous assistive herding capability. This is accomplished by significantly limiting the amount of "instrumentation" that is required to identify the animal and human, as well as limiting the communication between human and robot.

3 HERDING BACKGROUND

Humans have been domesticating animals for many years. It has brought prosperity to society and has been one of the cornerstones for human progress, trade and commerce. One of the most critical aspects of domesticating animals has been the actual upkeep of the stock. Herding animals is a very important part of the domestication process, whether it is for point-to-point transport of livestock, grazing, commerce, or predator avoidance.

Traditionally, herding was accomplished by the brute force approach of inducing fear in the animal, which can cause significant stress in animals. Stress causes reduction in weight gain, meat quality, milk production, reproduction performance and immunity from diseases. In the work reported here, herding is accomplished by using the low-stress herding technique where the flight zone of an animal is used to control and manoeuvre the animal in the desired direction. The key here is that the animal is herded from the boundary of its flight zone, which causes anxiety, not fear, in the animal. Thus the animal perceives the human as its protector, and not its adversary. Additional advantages of low-stress herding techniques are that they facilitate improved performance with respect to weight gain, feed efficiency, reproduction performance and immunity (Blezinger, Gadzia, 1999 and Grandin 1989).

4 ANIMAL MODEL AND LOW STRESS HERDING TECHNIQUES

In this section, we introduce and briefly describe the animal model and the low-stress herding technique employed in this effort. A glossary of herding terms that are used here can be found in the section entitled "10 Herding Glossary."

Remote controlled small toy vehicles were used in place of real livestock and a human. The robot recognizes the animal (i.e., one of the toy vehicles) with the help of a very small coloured tag that is attached to the vehicle. In a real world context, we anticipate using the actual colours(s), shape, and size of the livestock. In addition to colour, the animal model consists of the following properties:

1) Flight distance: The distance from the animal that will induce anxiety in the animal if the robot or human is closer than that distance. The robot determines this value before it actually attempts to herd the animal.

2) Minimum flight distance: The minimum distance the robot is required to keep, from the animal.

3) Blind-zone: This is the angle behind the rear of the animal. The robot takes care to not enter it, except when it has to turn the animal, in which case, the robot attempts to enter it.

4) Movements: We define the following three temporal movements of the animal relative to the robot:

a. Moving Forward: When the distanceY, in Figure 1, remains within a pre-specified range, the robot perceives this as a “moving forward” type of movement.

b. Turning: When the distanceY between the animal and the robot is outside a pre-specified range, the robot perceives this as a turning type movement.

c. Stopped: When the animal is neither moving forward nor turning, then the robot perceives that the animal has stopped moving.

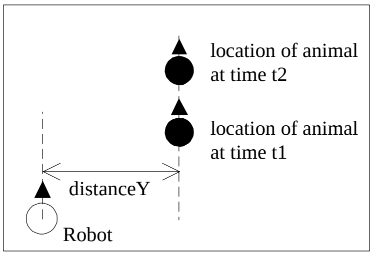


Figure 1: Moving forward

In low-stress herding techniques, the animal is always herded from the edge of the flight zone. Hence, the first step toward herding is to determine the flight zone of the animal. When herding multiple animals the flight zone is determined by a zigzag motion. However, when herding an individual animal, the flight zone is determined by making a slow diagonal approach toward the rear of the animal, as shown in Figure 2(a). When the animal moves forward, the herder has reached the edge of the flight zone. Other approaches to determining the flight zone might be equally or more effective, such as the shoulder approach. However, because of the geometry of our animal model, we are employing the diagonal approach.

To herd the animal forward, the herder turns in the same direction in which the animal is facing, takes up the outrider’s position and moves along with the animal (Figure 2(b)). To turn the animal, the herder employs the tail-head approach, in which, the herder turns towards the rear of the animal and slowly moves towards it (Figure 2(c)). When the herder reaches the blind zone area on the edge of the flight zone, the animal moves forward with a turned head to keep the herder in view, this causes the animal to turn. The herder continues to approach the animal until the animal has turned the desired amount.

To stop the animal, the herder stops following the animal. The animal continues its motion until the herder is out of the flight zone, at which point, the animal stops and turns to look at the herder. When it finds that the herder is not moving in its direction, it relaxes and engages in some other activity such as grazing.

5 HUMAN MODEL, DESIGN AND APPROPACH OF ASSISTIVE HERDING CAPABILITY

The robot identifies the human with the help of a colour tag that is attached to one of the toy vehicles. In addition to the colour tag, the human model consists of a specification of the temporal human movements relative to the animal and the robot.

1) Moving towards the animal: As illustrated in Figure 3(a), when the distanceY between the robot and the human reduces over time, and angle1 and angle2 are approximately equal, the robot perceives this movement of the human as moving towards the animal.

2) Moving away from the animal: As illustrated in Figure 3(b), when the distanceY between the robot and the human increases over time, then the robot perceives this human movement as moving away from the animal.

3) Stopped: When the human is at an angle equal to or greater than |85| degrees relative to the robot, the robot perceives this as the stopped movement.

The robot and the human are always on either side of the animal. When the robot perceives the human moving towards the animal, it interprets this as a command to initiate herding. Once herding initiation is successful (i.e., the animal starts to move), the robot begins to herd the animal in the forward direction.

To turn the animal, the human either moves toward or away from the animal depending on the direction in which the animal is to be turned. If the human wants to turn the animal, then the human moves towards the animal, or if the human wants the robot to turn the animal, it will move away from the animal to let the robot turn it. Hence, if the robot perceives that the human is moving towards the animal, then it interprets this as a command for it to move out of the flight zone so that the human can turn the animal. However, if the robot perceives that the human is moving away from the animal, then it interprets this as a command for it to turn the animal.

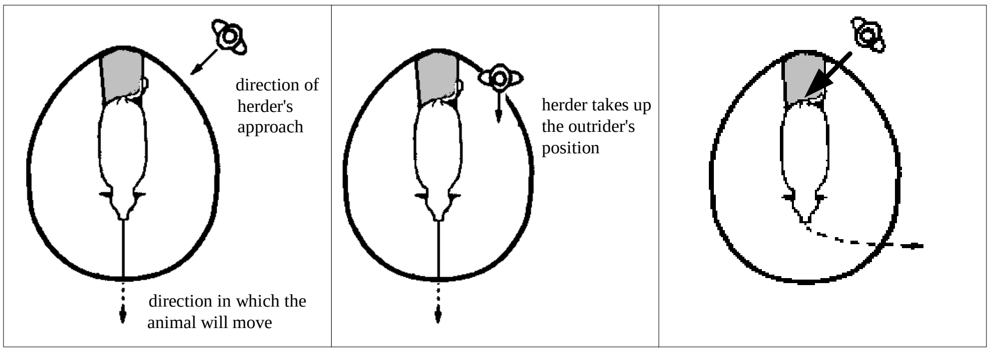


Figure 2: Low stress-herding techniques: (a) Initial Motion, (b) Herding forward, (c) Tuning the animal (Illustrations are slight modified from (Smith, 1998)

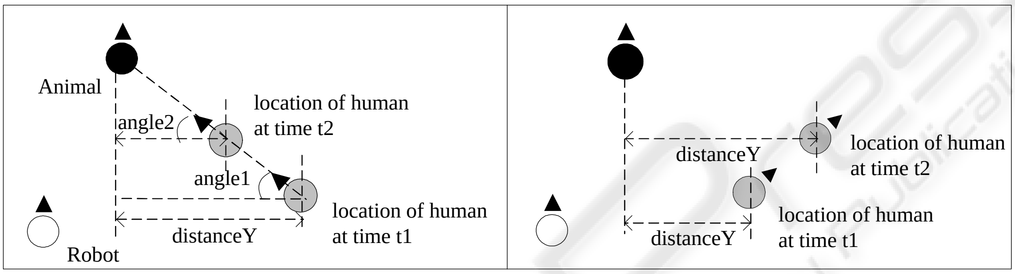


Figure 3: Human movements (a) Human is moving towards the animal (b) Human is moving away from the animal

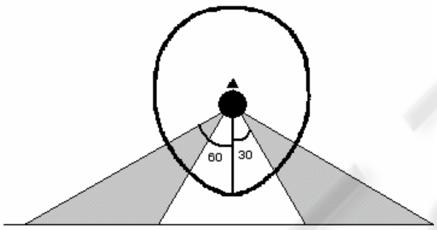


Figure 4: Initial herding position

When the robot perceives that the human has stopped moving then it interprets this as a command for it to stop herding.

6 IMPLEMENTING THE LOW STRESS HERDING TECHNIQUES

Our approach to implementing low stress herding techniques involves developing separate modules for initiating herding, moving the animal forward, turning the animal, and stopping the animal. We briefly discuss each of these in this section.

6.1 Initiate Herding

This module is broken into the following two sub-modules:

6.1.1 Initial Position

In this subroutine, the robot attempts to position itself diagonally, between |30| and |60| degrees, to the rear of the animal, as shown by the shaded region in Figure 4.

The robot scans the environment to locate the animal. With the help of a laser ranging sensor, it measures the angle between the direction to the animal and the current heading of the robot. If the angle is outside the range of |30| and |60| degrees, then the robot attempts to turn and move to the initial position as follows:

If the animal is at an angle between 0 and –30 degrees, then the robot turns -90 degrees and moves backwards until the animal is at an angle 45 degrees left or right of the robot's forward facing direction. For example, if the animal is at an angle –25 degrees, as shown in Figure 5(a), then the robot turns –90 degrees and moves backwards, Figure 5(b), until the animal is at an angle 45 degrees, as shown in Figure 5(c). Similarly, if the animal is at an angle between 0 and 30 degrees, then the robot turns 90 degrees and moves backwards until the animal is at an angle –45 degrees.

If the animal is at an angle less than -60, then the robot turns -90 degrees and moves forward until the animal is at angle of 45 degrees. For example, if the animal is at an angle of –70 degrees as shown in Figure 6(a), then the robot turns – 90 degrees and moves forward, Figure 6(b), until the animal is at angle 45 degrees, as shown in Figure 6(c). Similarly, if the animal is at an angle greater than 60 degrees, then the robot turns 90 degrees and moves forward until the animal is at angle –45 degrees.

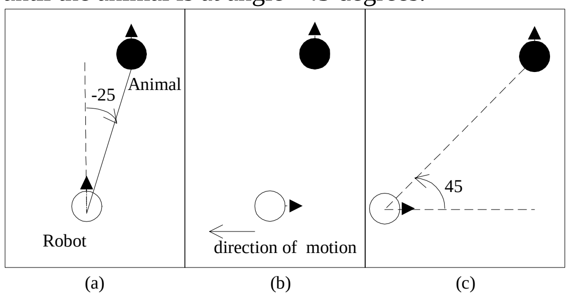


Figure 5: Moving to initial position when the animal is at –25 degrees

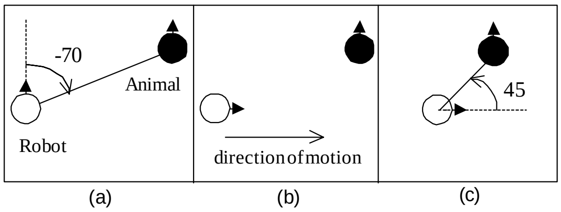


Figure 6: Moving to initial position when the animal is at –70 degrees

6.1.2 Initiating Movement

The robot turns in the direction of the animal, Figure 7(a), and slowly approaches it, until the animal moves forward, as shown in Figure 7(b). The dotted circles in this figure indicate the forward motion of the robot toward the animal. The robot notes the flight distance and the flight angle, and calculates the flightX and flightY distances as shown in Figure 7. The dotted circle shows the location of the animal before it moved forward. The distance flightX is used to keep the robot on the edge of the flight zone. The distance flightY is used in the Herding forward routine to herd the animal in the forward direction.

6.2 Herding Forward

To move the animal forward after arriving at the initial herding position, the robot turns in the direction that the animal is facing, takes up the outrider's position, and slowly moves along with the animal, as illustrated in Figure 8. As seen in Figure 8(a), the robot is outside the flight zone and so it moves forward and reaches the edge of the flight zone, as shown in Figure 8(b). As a result the animal moves forward, leaving the robot outside the area of the flight zone, as shown in Figure 8(c). Hence, the robot moves forward to reach the edge of the flight zone, as shown in Figure 8(d). This process is repeated until the animal has moved the desired distance.

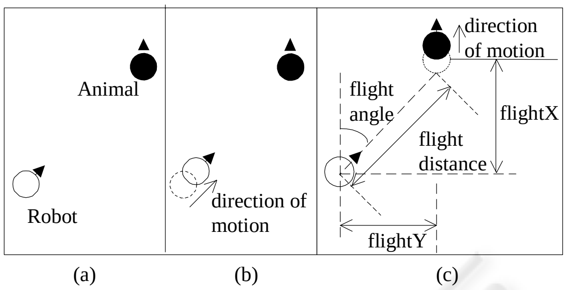


Figure 7: Initiating movement

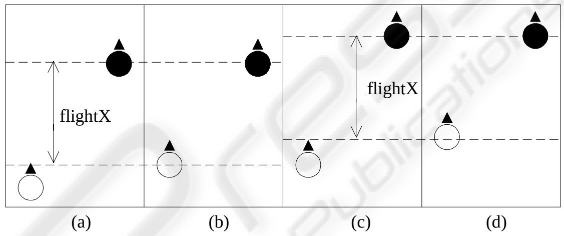


Figure 8: Herding forward

Since the size of the flight zone is dynamic, it may change in size during the herding process. Flight zones that become larger do not present a problem, as the animal will move forward before the robot has reached the edge of the flight zone. If the flight zone becomes smaller, then the animal will not move forward when the robot reaches the edge of what it perceives or recalls as the flight zone. In this case, the robot moves forward for a pre-specified distance. If the animal resumes its forward motion then the robot updates its flight zone (flightX) value, but if the animal still does not move, then the robot invokes the Initial Motion routine to recalculate the distances, and subsequently invokes the Herding forward routine.

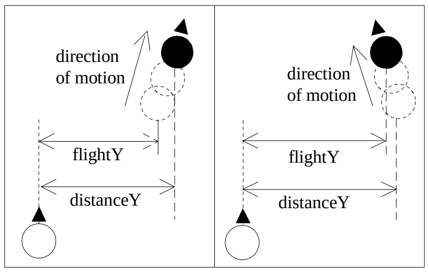


Figure 9: Animal moving at an angle

Complicating this task is the requirement that the robot recognize when the animal might not be heading in the desired direction, but may be moving at some angle relative to the desired direction, as shown in Figure 9. The robot recognizes this behaviour by comparing the difference between distance Y and flight Y with a pre-specified value.

6.3 Turning the Animal

To turn an animal, the robot turns and moves towards the rear of the animal until the animal is oriented in the desired direction, as illustrated in Figure 10. As sees in Figure 10(a), the robot is facing the animal and is outside the flight zone. The robot moves forward until it reaches the edge of the flight zone, as shown in Figure 10(b). Hence, the animal moves forward, and as a result, the angle made by the animal decreases, as seen in Figure 10(c). The robot continues moving in the direction of the animal and at some point in time, reaches the blind zone of the animal, as shown in Figure 10(d). To keep the robot in view, the animal moves forward with a turned head, as a result the animal turns, as shown in Figure 10(e). The robot continues to move toward the animal until the animal has made the desired turn, as shown in Figure 11.

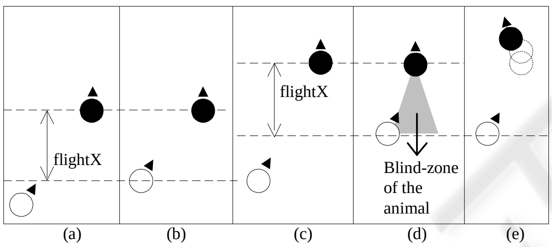


Figure 10: Steps to execute the turn routine

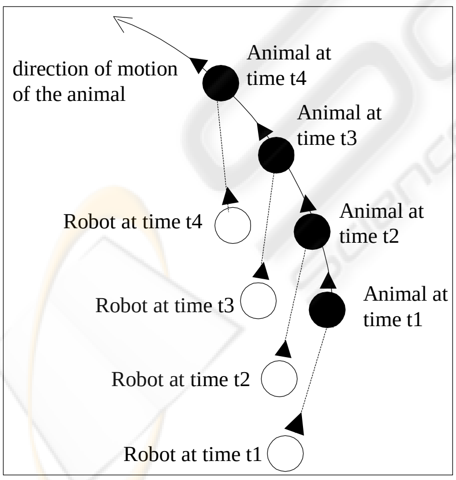


Figure 11: Turning the animal

6.4 Stopping the Animal

To stop the animal from moving, the robot removes itself from the flight zone of the animal.

7 IMPLEMENTING THE ASSISTING CAPABILITY

Our approach to implementing the assisting capability involves developing a module for perceiving human movements. Based on the value returned by the module, an appropriate herding module is invoked. Before the robot begins tracking the human, it executes the Initial Position routine to move to the initial herding position. Then, it scans the environment to locate and track the human.

1) Initiate Herding and Herding Forward: When the robot finds the human moving towards the animal, as shown in Figure 12(a), it stops tracking the human and executes the Initiate Motion routine, followed by the Herding Forward routine. It resumes tracking the human while herding the animal forward.

2) Turning the Animal: If the robot perceives that the human is moving towards the animal, it stops its motion to let the human turn the animal, as shown in Figure 12(b). However, if the robot finds the human moving away from the animal, then it perceives this as the human asking the robot to turn the animal, and so the robot executes the “Turning the animal” routine as shown in Figure 12(c).

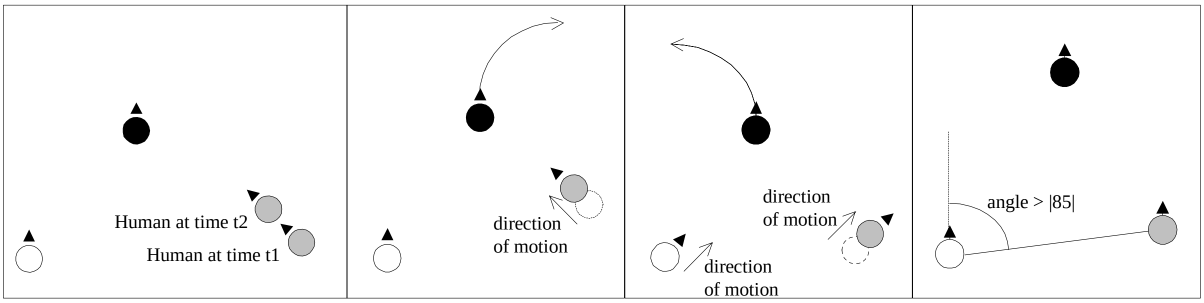
3) Stopping the Animal: To stop the animal, the human stops its motion. When the human makes an angle greater than |85| degrees relative to the animal, the robot perceives this as the human wanting to stop the animal, and so robot executes the “Stopping the animal” routine.

8 EXPERIMENTS

8.1 Robot Hardware

The robot used in this work was a Pioneer2 AT robot from Activmedia Robotics. In addition, two remote controlled toy cars were used to represent the animal and human respectively. The robot has a pan-tilt-zoom (PTZ) camera, laser range finder (mounted in front of the robot), and 8 rear bumper sensors.

The PTZ camera is used to capture images that are processed in order to recognize the animal and the human. It can pan up to 180 degrees (-90 to 90 degrees) from the forward direction of the robot.



(a) Initiate herding (b) Turning the animal (Human is attempting turning the animal) (c) Turning the animal (Robot is attempting to turn the animal) (d) Stopping the animal

Figure 12: Assisting behaviour

Figure 13: Initiate herding

The laser range finder is used to help determine the angle and distance between the robot and the animal, and between the robot and the human. It is also used for object tracking. The laser can scan up to 180 degrees in the forward facing direction (-90 to 90 degrees). The bumper sensors are used to prevent damage to the robot by halting the robot when pressed. They are additionally used to command the robot turn the animal in some situations.

The toy cars can be moved forward, in reverse, turned left or right, and stopped by a joy-stick that is located on a remote control box. A pink-coloured stick is mounted on top of one car to identify the animal. Similarly, an orange-coloured stick is mounted on top of the other car to identify the human. Thus, the approach developed here assumes that the animal being herded can be discerned from the human by colour. In the future, colours will be replaced by shape, size, and texture recognition and tracking capabilities.

Two sets of experiments were conducted to demonstrate the autonomous and assistive herding capabilities of the robot. One experiment demonstrates the robot's autonomous herding capabilities, that is, without a human. The second experiment demonstrates the robot's ability to assist a human with herding.

8.2 Autonomous Herding Behaviour

In these experiments, the robot is initially placed at various locations behind the animal at a distance greater than the flight distance of the animal.

Experiment 1: The robot is placed in such a way that the angle it makes to the rear of the animal is approximately -20 degrees. The task for the robot is to herd the animal forward. When the robot is herding the animal forward, the flight zone of the animal is reduced. When this happens, the task for the robot is to re-determine the flight zone and begin herding the animal forward. The robot is asked to turn the animal by pressing one of its bumpers, (in a real-world context, a map of the terrain would be available for the robot to determine when to turn an animal toward the goal location). Hence, the task for the robot is to turn the animal 90 degrees. Once turned, the robot resumes herding the animal in the forward direction.

Result: The robot scans the environment to locate the animal. Once located, it attempts to move to the initial herding position by turning –90 degrees and moving backwards until the animal is at an angle of 45 degrees with respect to the robot, as shown in Figure 13. The robot scans the environment to locate the human. When it cannot locate the human, it turns to face the animal and slowly moves forward until the animal begins to move forward. The robot then turns in the direction in which the animal is facing and starts following it from the outrider's position.

In practice, environmental conditions such as the size and orientation of shadows, lighting, and other factors can dynamically change an animal's effective flight zone. At times, the robot can unexpectedly find itself outside or inside a flight zone due to these and other situational dynamics. It is, therefore, possible that if the animal stops while being herded, it might be because the flight zone has been reduced in size. Perceiving this, the robot then approaches the animal until the animal starts moving forward again.

After the robot has herded the animal forward for sometime, one of the bumpers of the robot is pressed to indicate that the animal should be turned. The robot then turns and moves towards the animal, as shown in Figure 14. When the animal has turned by an approximately -90 degrees, the robot turns –90 degrees and begins herding the animal in the forward direction.

Figure 14: Turning the animal

8.3 Assisting Herding Behaviour

In these experiments, the assistive herding behaviour of the robot is tested where the robot herds the animal as per the intentions of the human.

Experiment 2: The robot has to assist the human in herding the animal. The robot is placed in such a way that the angle it makes to the rear of the animals is approximately, 20 degrees.

Result: The robot scans the environment to locate the animal. When the animal is located, the robot turns 90 degrees and moves backwards until the animal is at –45 degrees with respect to the robot.

The robot scans the environment to locate the human. When the human is located, it waits for the human to move in the direction of the robot. As soon as the human moves toward the animal, the robot begins to move toward the animal. From hereafter, the robot takes the same actions that it took in Experiment 1.

The robot starts tracking the human along with the animal. After herding for awhile, the human stops its motion. The robot continues to herd the animal forward until the human is at an angle 85 degrees with respect to the robot. The robot then stops moving to stop herding the animal.

Experiment 3: The robot has to assist the human in herding the animal as before. However, in this case, the herder moves away from the animal to let the robot turn the animal. The robot is placed in such a way that the angle it makes to the rear of the animal is approximately -50 degrees.

Result: The robot is already at the initial position, and therefore it scans the environment to locate and track the human. As soon as the human moves toward the animal, the robot begins to move towards the animal. From hereafter, the robot takes the same actions that it took in Experiment 2 and begins herding the animal forward.

After herding forward for a while, the human turns and moves at an angle of –45 degrees w.r.t the robot. Seeing this, the robot invokes the turn routine as it did in Experiment 1.

Experiment 4: The robot has to assist the human in herding the animal as before. However, in this case, the herder performs the turning operation. The robot is placed in such a way that the angle it makes to the rear of the animals is approximately 40 degrees.

Result: Since the robot is already at the initial position, it takes the same actions as described in Experiment 3 until the robot begins to herd the animal forward. After herding the animal forward for a while, the human turns and moves towards the animal in order to turn it. Seeing this, the robot stops its motion to allow the animal to turn.

9 CONCLUSION

We described a robotic system that is able to assist a human with herding an animal. We showed that the system is able to adjust its herding behaviour as per the intentions of the human that are conveyed to the robot by the movements of the human. A key factor here is that the assistive herding task is carried out with minimal communication and within minimal instrumented environments. We also demonstrated the autonomous herding capability of the robot, in situations where the human is absent.

We recognize that there remain complex challenges to herding real animals that we have not addressed now because, in part, we are using toy human and cattle models. However, this paper represents an initial step towards developing a purposeful assisted herding behaviour by designing and developing key representations of the animal and the human behaviour, and also the key herding strategies and techniques that will be useful and expanded in follow-on work that will involve live animals.

Our work described here is limited to herding a single cattle-type animal. In future work, we plan to develop methods for scaling our approach to handle multiple animals. The other limitation of our work is the use of colour tags to recognize the animal and the human. As part of our future study, we intend to develop more advanced object recognition algorithms that take into account several other attributes such as shape, size and so forth.

10 HERDING GLOSSARY

Herding: Controlling and maneuvering the animal in the desired direction.

Flight Zone: Also known as the flight distance, is the area around the animal which when intruded, causes anxiety in the animal and the responds by moving away. However, if this area is deeply penetrated, then the animal panics and flees. Its size is dynamic and changes depending on several factors, such as, the behaviour of the herder, weather conditions, state of excitement of the animal, and so forth. The animal's flight zone plays a key-role in low-stress herding techniques. (Smith, 1998, Grandin, 1989).

Animal Vision: Cattle have wide-angle vision and can see behind themselves without turning their heads. However, they have a small blind spot of about 15-30 degrees behind their rears. The handler avoids staying in the blind-spot area for too long as it can lead to panic in the animal.

Outrider Position: The outrider position is "the position the herder takes on or adjacent to the boundary of the flight zone.

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