ITS INSTITUTE
Intelligent Transportation Systems

Infrared Thermal Camera-Based Real-Time Identification and Tracking of Large Animals to Prevent Animal-Vehicle Collisions (AVCs) on Roadways

Final Report

Prepared by:

Debao Zhou

Department of Mechanical and Industrial Engineering
University of Minnesota Duluth

Northland Advanced Transportation Systems Research Laboratories
University of Minnesota Duluth

CTS 12-15

Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
CTS 12-15		

4. Title and Subtitle	5. Report Date
Infrared Thermal Camera-Based Real-Time Identification and Tracking of Large Animals to Prevent Animal-Vehicle Collisions (AVCs) on Roadways	May 2012
	6.
7. Author(s) Debao Zhou	8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Mechanical and Industrial Engineering University of Minnesota Duluth 1303 Ordean Ct., 105 VKH, Duluth, MN 55812	10. Project/Task/Work Unit No. CTS Project #2011016
	11. Contract (C) or Grant (G) No.
12. Sponsoring Organization Name and Address Intelligent Transportation Systems Institute University of Minnesota 200 Transportation and Safety Building 511 Washington Ave. SE Minneapolis, Minnesota 55455	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes
http://www.its.umn.edu/Publications/ResearchReports/

16. Abstract (Limit: 250 words)
Animal vehicle collision (AVC) is constantly a major safety issue for the driving on roadways. It is estimated that there are over 35,000 AVCs yearly resulting in 3 to 11 deaths, over 400 personal injuries, and close to 4,000 reported property damages of $1,000 or more. This justifies the many attempts that have been tried to detect large animals on road. However, very little success has been achieved. To reduce the number of AVCs, this research used an infrared (IR) thermal imaging method to detect the presence of large animals and to track their locations so drivers could avoid AVCs. The system consists of an infrared-thermal-image grabbing and processing system and a motion control system to track the objects. By analyzing the infrared thermal images, the presence of deer in surrounding areas have been identified, and thus tracked. Since the IR thermal imaging is independent of visible light, the system can work both day and night, even in bad weather. The system can cover a circle area up to 1,000 feet in radius for the identification of an object the size of an adult human being.

17. Document Analysis/Descriptors	18. Availability Statement
Collisions, Thermal imagery, Tracking systems, Object identification, Collisions, Roadside fauna, Proximity detectors	No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	23	

Infrared Thermal Camera-Based Real-Time Identification and Tracking of Large Animals to Prevent Animal-Vehicle Collisions (AVCs) on Roadways

Final Report

Prepared by:

Debao Zhou

Department of Mechanical and Industrial Engineering
University of Minnesota Duluth

Northland Advanced Transportation Systems Research Laboratories
University of Minnesota Duluth

May 2012

Published by:

Intelligent Transportation Systems Institute
Center for Transportation Studies
University of Minnesota
200 Transportation and Safety Building
511 Washington Ave. S.E.
Minneapolis, MN 55455

Acknowledgments

The author wishes to acknowledge the support from Prof. Eil Kwon, Mr. Matt Dillon, and Mr. Jingzhou Wang, who made this research possible. The study was funded by the Intelligent Transportation Systems (ITS) Institute, a program of the University of Minnesota's Center for Transportation Studies (CTS). Financial support was provided by the United States Department of Transportation's Research and Innovative Technologies Administration (RITA).

The project was also supported by the Northland Advanced Transportation Systems Research Laboratories (NATSRL), a cooperative research program of the Minnesota Department of Transportation, the ITS Institute, and the University of Minnesota Duluth College of Science and Engineering.

Table of Contents

List of Figures

Executive Summary

It is estimated there are over 35,000 deer-vehicle collisions (DVCs) yearly in the U.S., which results in about 200 deaths and close to 4,000 property damages of $1,000 or more. These shocking statistics justify the many attempts that have been tried to detect deer on roads to avoid such accidents.

The approaches to reduce such accidents can be categorized into either passive or active methods. The passive method, which has been proven either impractical or inefficient, is to keep deer off the road by means such as electrical mats or fences, while the active approach is to alert drivers to the existence of deer near the roadside. Existing active approaches for deer detection can be further grouped into 'break-the-beam' method (BTB) and 'area-cover' method. The key component in the BTB method is a beam that is formed by infrared light. The blockage of the beam means there is an animal crossing the road, which results in the issuance of a warning signal. BTB methods have the following drawbacks: (1) An object exiting from the road to roadside can also activate the warning system, (2) Any other objects that are big enough to block the beam can activate the warning system, (3) It cannot detect the existence of roadside deer, which may jump onto the roadway later. In an area-cover system, a camera, radar or an ultrasound system is used to detect the presence of deer. Like with BTB, once an object, such as a deer, is detected, a warning signal will be issued.

In this research, thermal imaging method is used to detect the presence of big animals, such as deer. The main assumption in this research is that a deer's body temperature is higher than its surroundings such that it can be distinguished from its environment. Thermal cameras have the capability to display the temperature difference into a grey scale image. By analyzing the images from a thermal camera, deer can be identified.

A prototype has been built to realize the thermal image acquisition and processing and motion control. The system consists of an infrared-thermal-image grabbing and processing system and a motion control system to track the objects. By analyzing the infrared thermal images, the presence of deer in surrounding areas has been identified. In the motion control system, to enlarge the view range, two motors have been used to realize the yaw and pitch motion of the camera. A control algorithm has been developed to control the motion of the two motors. After an object is identified, the control algorithm has the capability not only to move the camera up/down and left/right, but also to point to the object. Thus the object can be tracked. Since the infrared (IR) thermal imaging is independent of visible light, the system can work both day and night, even in bad weather. The system can cover a circle area with up to 1,000 feet in radius for the identification of an object the size of an adult human being. Due to its tracking function, it can indicate whether there is an immediate threat to the vehicle.

Further pattern recognition algorithm will be developed to make the identification more efficient. After that, the system will be installed on roadsides to evaluate its applicability.

Chapter 1: Introduction

Four-percent of the 0.9 million motor-vehicle collisions annually involved an animal in the roadway [1]. Each year about 200 human deaths occur as a result of these accidents. Approximately half (54.4%) of these collisions involved a direct collision with animals, and the remainder (44.8%) resulted from the driver trying to avoid hitting animals [1]. Although deer top the list as the most common animal-related collision (ARC), they are not the only ones. In Maine and New Hampshire, there were more than 500 moose collisions in 1991 [2]. Other animals include the two types of Kudu, a type of antelope, Eastern Cape, etc [3]. In this research, the method to detect deer is investigated as well as the possibility of detecting other kinds of big animals such as Kudus and antelopes.

There are several methods of deer detection and deterrence that have been researched and tested, both roadside as well as on-vehicle. In the following, the research results for both roadside and on-vehicle technologies are reviewed.

1.1 Roadside Technologies

The roadside technologies include the methods to either deter or detect the deer to avoid collisions. The deterrence roadside technologies have been researched to attempt to dissuade the deer from approaching traffic to begin with. Although this idea is good, it has been proven to be a difficult challenge. Some of these technologies include roadside reflectors [4], animal reflectors [2], natural habitat prevention (predator scent [5], removal of roadside vegetation [6]) and electronic mats [7]. In addition to being difficult to implement, most proved ineffective.

Rather than attempting to dissuade the deer, it may be more effective to detect the deer and alert the drivers. There are a few roadside technologies that are being developed including flashing signs that are triggered to alert the driver when a deer is detected in the vicinity. Deer crosswalks [8] have been made that funnel the deer across one part of the road, marked so as to alert the drive of the possibility of the presence of deer. Underpasses and overpasses [9] have also been tried, although they are expensive.

1.2 On-Vehicle Technologies

With an estimated eight and a half million miles of lane roadway in the United States, installing the roadside technologies adequately would require the development of infrastructure. It is more feasible to develop a less expensive system and install them on the traveling vehicles themselves. The on-vehicle technologies also include the methods to either deter or detect the deer to avoid collisions. The first category of on-vehicle technology is deterrence. On-vehicle deterrence technologies include whistles [10] and TH - High Intensity Discharge lighting systems [11]. However, neither the audible nor visible methods of deterrence proved effective in any studies.

The second category of on-vehicle technology is detection. Possibly the best methods of DVC avoidance can be found in on-vehicle detection technologies. Several forms of these technologies are already in existence, including forward-collision sensors [12], ultrasonic sensors [13], and thermal cameras [14]-[15] that give the driver a thermal image of the road ahead. These detection technologies can improve the driver's awareness of the road in front of the vehicle. Unfortunately, the existing technologies only detect deer down the road and not to the sides from where deer can bolt from.

It is possible, however to develop a thermal detection system [16] that not only can detect deer at wider angles, but also track the deer and determine its speed, direction, and whether it is an immediate threat to the vehicle. On this aspect will be the focus of this research.

In the following, the method and the equipment to realize the detection using thermal images are discussed in Chapter 2. The control system and tracking realization are explained in Chapter 3. The obtained deer images processing results are shown in Chapter 4. The conclusions are then drawn in Chapter 5 which is followed by the future work of this research.

Chapter 2: Method and Equipment

This research will show the work about using infrared thermal imaging method with tracking functions to detect the presence of big animals, mainly deer, in the environment. The study will focus not only on incorporating the image acquisition with deer detection, but determining the effectiveness of the camera itself along with the performance of the motors and motion controller. The system is shown in Figure 1. It consists of an image grabbing and processing system connected to a thermal camera. The camera's direction of view will be driven by two stepper motors with motion control system to realize two degrees of freedom of motion, i.e. the lateral and vertical rotation of the camera's view.

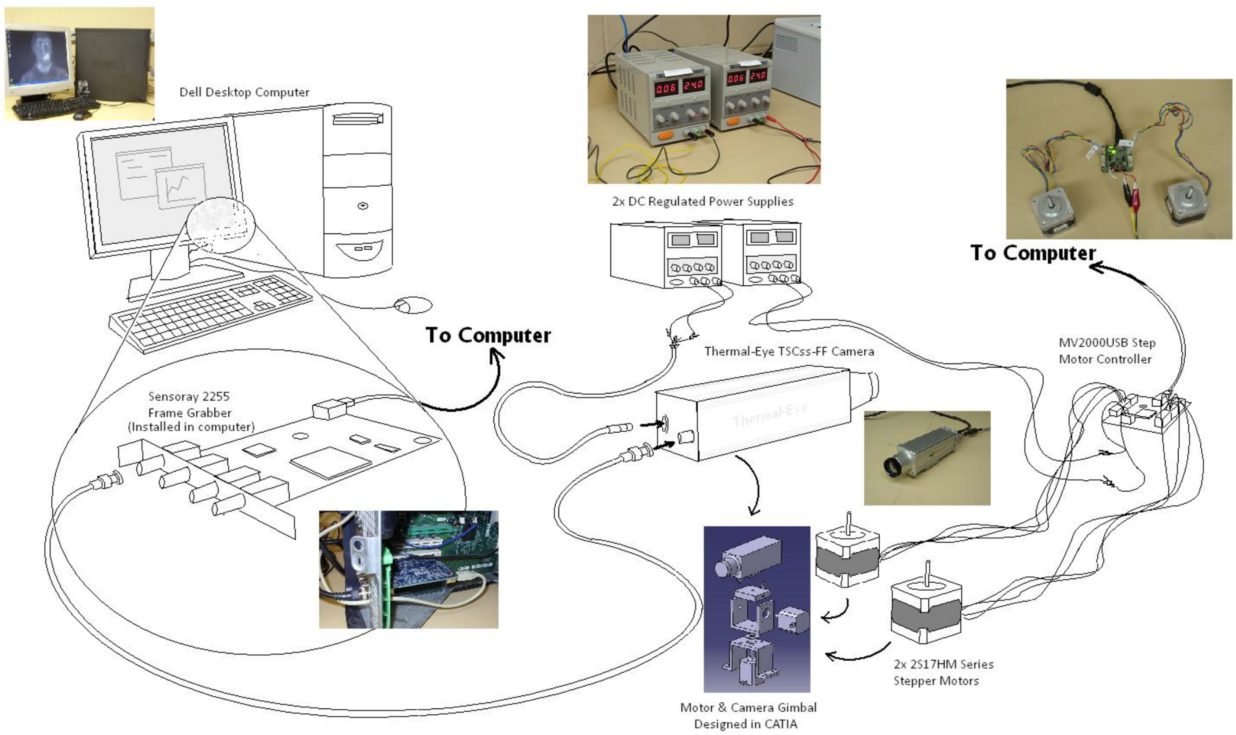


Figure 1 - System integration

The main component in the system is an infrared thermal cameral. As shown in Figure 1, the camera connects to the frame grabber through BNC connector. The frame grabber connects to the computer through USB. Two motors are used which connect to the computer via a motion controller card through a serial port. Both the camera and the motors need power supplied.

2.1 Camera

The infrared technology used for this research was the Thermal-Eye™ TSCss-FF camera [17]. This camera is specifically designed as a security camera, intended for non-horizon exposure, looking downward from the intended mounted situation. The camera has a 17.5° field of view which is adequate for this application due to the motion generated by the motors on both road-side and on-vehicle applications.

Figure 2 - Thermal Eye TSCss-FF

2.2 Camera Mount

The camera required a mount that incorporates the two stepper motors in a way that they can drive the camera with two degrees of freedom (lateral and vertical rotation of the camera's view). The mount was designed using a ¼"-thick aluminum square tubing as shown in Figure 3 and the camera- motor assembly is shown in Figure 4.

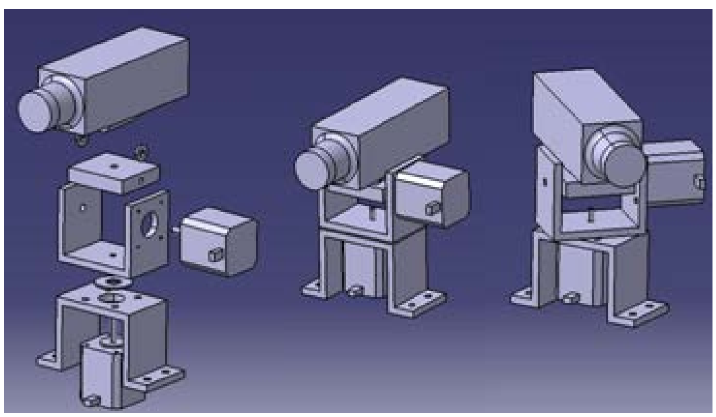


Figure 3 - Camera mount design

Figure 4 - Mount assembly

2.3 Power Sources

DC power supplies were needed for both the camera and step motor controller. The camera could use either AC or DC power supply. For the DC power supply, between 9 and 30V was needed. Exceeding this however, could damage the system. For the step motor controller, 8-35V of DC power was needed. It was determined that running both DC power sources at 24V was adequate for both the camera and step motor controller.

2.4 Motors

Two stepper motors from IMTT (Figure 5) [18] were use to drive the camera to realize the two degrees of freedom of motion. Two parameters need to be considered for the selection of the motors: torque and accuracy.

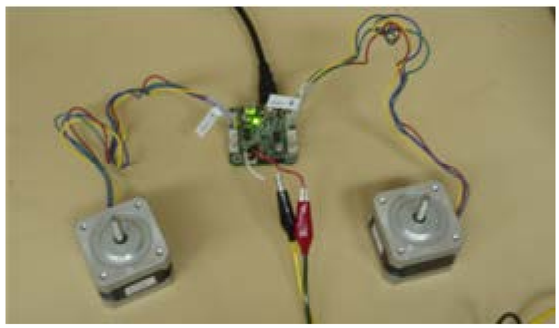


Figure 5 - Motor controller

For the required torque, the following method is applied. First, according to the mass distribution of the camera provided by the manufacture and the location where the gimbal connects to camera, the rotational inertia matrix is calculated. Second, based on the application circumstance of the camera, the trapezoid moving trajectory is designed with the maximum rotation angle at 180 degree. Thus the angular velocity and angular acceleration of the motion can be figured out. Next, the torque needed to drive the camera to realize the desired motion can be calculated as $M = I\alpha$, where M is the torque provided by the motors and I is the inertia and α is the angular acceleration. Finally, according to the motor specification provided by ITMM and given a safety coefficient as 1.4, the motors which can generate 1.4M can be selected. However, there is another factor need to consider: for a stepper motor control, the actual torque is realized by multiplying the motor current with a user defined constant, or $\tau = kA$, where τ is the torque, k is a user-defined constant ($1 > k \geq 0$) and A is the motor coil current. In our application $k = 0.6$ is selected for the best performance of the motor. Then the actual torque used to select a motor is $1.4M/k$.

The next issue is the accuracy problem since a stepper motor is a digital device, which means that motor shaft rotation is not continuous, but instead is step by step. The minimum moving angle of the motor shaft is one step. On the market, the motors can only be found with resolution at 0.9° and resolution at 1.8°. To our image based control problem, we need to know how many pixels will be equivalent to one step. To take a better look at how these steps translate to the displacement of the camera's image, the correlation between motor steps and image pixel displacement was determined. The step/pixel ratio was experimentally obtained by rotating the motor variable step values, and finding the pixel displacement of an object on the image generated in MATLAB. For a motor with 1.8° resolution, with an image resolution of 640x480 pixels, the average ratio was 0.232 steps/pixel, or 4.30 pixels/step. In other words, if the camera moves 1 step left, an object centered on the image will move about 4.30 pixels to the right of the center. However, better resolution can be obtained by using the controller software. Most of the stepper motor controller can realize whole step, half step, quarter step and 1/16 step. If the quarter step are used, the minimum step angle is 1.8°/16 = 0.1125°. Note that this resolution is almost equivalent to a brushless motor control with 4000 lines resolution encoder feedback, where the resolution is 360°/4000 = 0.09°. Thus with a 1.8° resolution motor and a good stepper motor controller, the resolution can be ensured.

After selecting the motor and the camera, the final mechanical system is designed and shown in Figure 6.

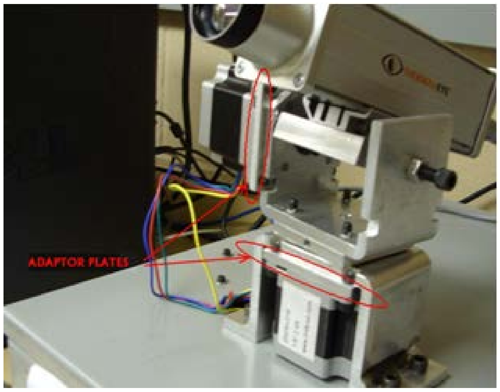


Figure 6 - Camera installation

2.5 Step Motor Controller

IMTT's MV2000USB motor controller (Figure 5) [18] was used to control the two stepper motors. The connection between the motors and the controller is shown in Figure 5 also. With the command set, various properties of the motor's performance can be adjusted. Current, position, speed and acceleration can all be specified.

2.6 Frame Grabber

The frame grabber used to capture the video output from the thermal camera was the Sensoray 2255 [19] (Figure 7). The card acquires and captures frames from up to four video inputs. Note that the card is connected to the camera via a BNC connector and connected to the computer through USB. The acquisition speed of the card can reach 30 frames per second in case of a JPEG format. The captured images can be in color or monochrome. Since the camera is in gray scale, the monochrome format is used on this application. One of the captured images is shown in Figure 8. From the image, it is seen that through the display of different temperature, a human positioned in front of camera can be easily identified. Since deer's body temperature will be different from its surroundings, it can be expected that the images from this camera can be used to identify the presence of deer.

Figure 7 - Sensoray 2255 Frame Grabber

Figure 8 - Thermal image

2.7 Enclosure and Cooling System

With the system being made up of several components, an 8.75”x12”x16” NEMA1 electrical enclosure (Figure 9) was used to contain the bulk of the system and reduce the clutter. The enclosure was modified to contain and provide access to the two power sources and motion controller. Holes were installed to read displays, access switches, pass wires and cords through, and to provide ventilation. The camera mount assembly was fastened to the top lid of the enclosure, making these system components all one contained unit. The only part of the system separate from this is the computer connected to it (which also contains the Sensoray 2255 frame grabber).

Figure 9 - Electrical enclosure

Once the electrical enclosure was obtained, an issue of overheating became apparent. The DC power supplies had heat sinks that reached up to 150° F and if enclosed, could overheat the components contained in the metal enclosure. The solution to this problem was the installation of a 6” cooling fan (Figure 10). To decrease the fan speed, a Skylark® Fan Controller (Figure 11) was installed. At the lowest setting, the fan was still moving enough air to adequately cool the power supplies. With the fan came a safety concern in which only the outer side of the fan was guarded. The fan was exposed inside the enclosure, providing opportunity for a cord or even the operator’s appendages to slip into the spinning fan and receive damage or injury. To guard against this, welded hardware clothe (essentially chicken wire) was installed in between the fan mount and the enclosure (Figure 12). The final system construction is shown in Figure 13.

 Figure 10 - Cooling system	 Figure 11 - Fan control
 Figure 12 - Fan guard	 Figure 13 - Final system

Chapter 3: Motion Control Realization

The automatic deer detection and tracking is realized based on the continuous image processing and motor motion control. There are three main phases that have to occur for the system to successfully track a target: image acquisition, image processing, and motion control. Figure 14 shows the procedure to realize the automatic dear detection and tracking.

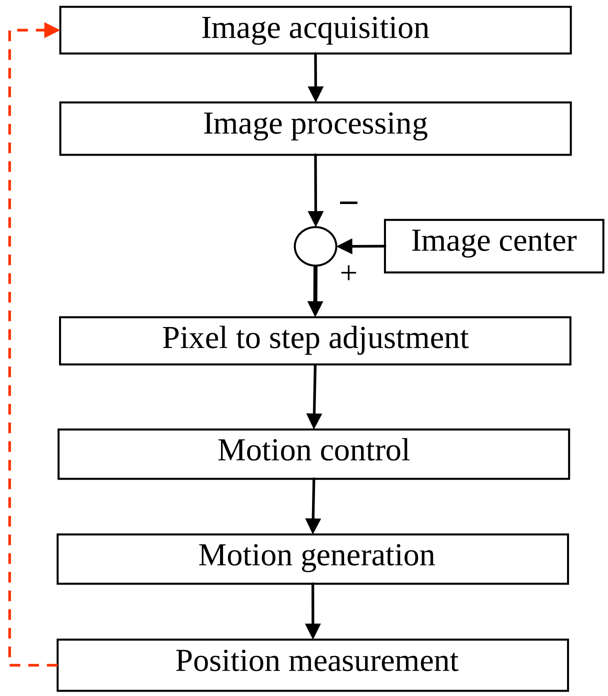


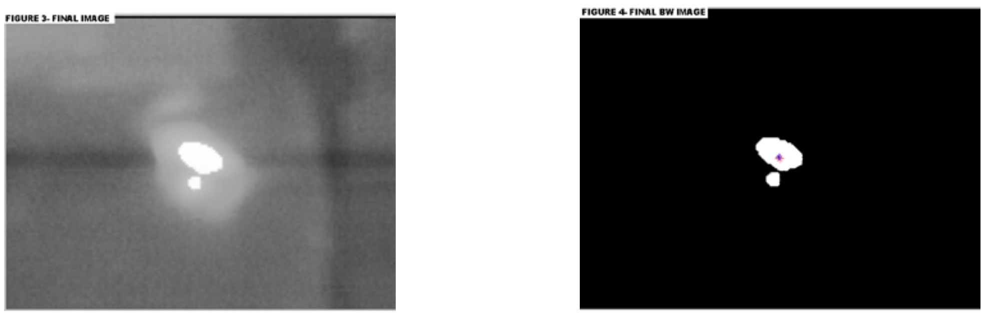
Figure 14, Motion control and tracking realization diagram

The first phase is image acquisition. In this phase, the system continuously grabs frames from the video input from the thermal camera. In Figure 15 (a), a grabbed frame of a hot soldering iron on a cold desk is shown.

(a) Original image, (b) Processed image

Figure 15 - Soldering iron

The second phase is image processing where the grabbed frames are analyzed. One of the image processing results is shown as follows. In this analysis, the image data is firstly converted into a black and white format where only the highest heat signatures are left white. The “center of mass” of the white, also called the centroid, on the image is then calculated and plotted according to its coordinate in pixels. The converted image of the soldering iron with only the image of the hot iron remaining white is shown in Figure 15(b).



(a) Original image, (b) processed image

Figure 16 - Soldering iron image after motion control

The third phase, motion control, takes the results from the image processing step and finds how many pixels the target is from the center of the camera. The program then converts these pixels values into how many steps and in what direction the motors need to move to center the camera on the target. The command with step numbers is then sent to the motion controller via RS232 serial port. The motion controller will then send the corresponding current wave to the motor to generate the suitable motion. Figure 16 shows the camera’s final position with the original image (a) and the processed image (b). In the final image, the system’s accuracy results in the iron’s centroid being only 3 pixels off of the center of the screen.

By continuously grabbing frames, processing them, and executing the corrective motions as a loop, the camera will follow the target as it moves along the plane of view.

One major problem that arose was a significant delay between the target’s motion and the camera’s execution of the tracking motion. This delay was caused by an “overweight” processing method. If the program has to save the images, upload saved images, display each frame, plot centroid coordinates, and display calculations or results, these processes all take additional time. Added together, this could result in more than a 0.4 second delay. By this time, the target could have moved well out of the camera’s view and been lost. Streamlining the program to eliminate excess processing steps and time was essential.

Chapter 4: Deer Identification Tracking Realization

When starting the system, the camera will rotate from -180° to 180° to search the presence of deer using pattern matching method. Once a deer is identified, the certain method in Section Chapter 3: will be activated to track the deer.

A deer posture database has been built-up for the detection of deer. In this database, some of the prominent body parts and postures are expressed in array format. Some of the patterns are shown in Figure 17.

An infrared thermal image with the processing results is shown in Figure 18(a). First the image is changed to black and white format and then Canny edge detection method [20] is used to get the results in Figure 18 (b).

(a) #1, (b) #2, (c)#3 (d) #4 (d) #5

Figure 17 - Some of the patterns in the deer shape database

(a) Original image (b) Processed image

Figure 18 - Deer image and edge detected using Canny method

The pattern #4 in the database is selected to do the shape recognition. The procedure first rotates the pattern 4.9° and scales it by 2.5 times. The matching results are shown in Figure 19. According the highest edge (vertical or y value) detected from the original image, the sum of the absolute distances x coordinate (horizontal distance) are calculated and averaged by the number of the points. A good match result is obtained. So it is identified that there is a deer in the image.

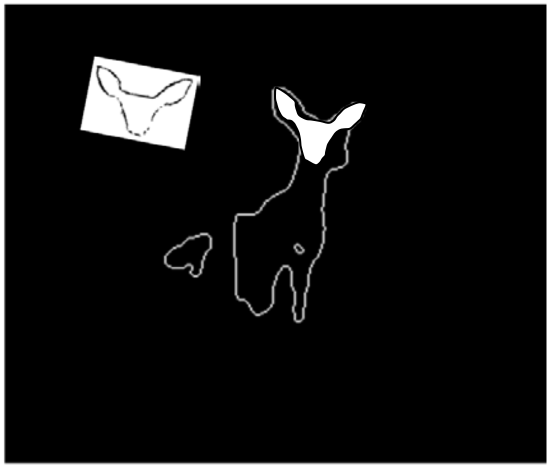


Figure 19 - Match of the #4 pattern with the higher part of the object

Chapter 5: Conclusion and Future Works

Deer-vehicle crash is one of the main accidents on rural way driving. To reduce vehicle-deer collisions, an automatic deer detection device with tracking function using thermal imaging has been developed in this research. The results showed the feasibility of such a method.

In the future, we will focus on the pattern matching algorithm to make the system capable of detecting the presence of deer.

References

[1] Center for Disease Control, *Nonfatal Motor-Vehicle Animal Crash-Related Injuries - United States 2001-2002*. Morbidity and Mortality Weekly Report, (2004), 675-678. Atlanta, GA.

[2] I. B. Pless, “Collisions with animals,” *Lancet*, vol. 53, no. 30, (1996), 348-492.

[3] P.J. Eloff and A. van Niekerk, “Game, Fences and Motor Vehicle Accidents: Spatial Patterns in the Eastern Cape,” *South African Journal of Wildlife Research*, vol. 35, no. 2, (2005), 125-130.

[4] G. J. D'angelo, J. G. D'angelo, G. R. Gallagher, D. A. Osborn, K. V. Miller, and R. J. Warren, “Evaluation of Wildlife Warning Reflectors for Altering White-Tailed Deer Behavior Along Roadways,” *Wildlife Society Bulletin*, vol. 34 no. 4, (2006), 1175-1183.

[5] T. W., Seamans, B. F. Blackwell and J. D. Cepek, “Coyote Hair as an Area Repellent for White-Tailed Deer,” *International Journal of Pest Management*, vol. 48, no 4, (2002), 301-306.

[6] R. Wangersky, “Too Many Moose?” *Canadian Geographic*, (Nov/Dec 2000), 44-56.

[7] T. W. Seamans, and H. A. David, “Evaluation of an Electrified Mat as a White-Tailed Deer (Odocoileus Virginianus) Barrier,” *International Journal of Pest Management*, vol. 54, no.1, (2008), 89-94.

[8] L. Stein, “Oh, Deer!” *U.S. News & World Report*, vol. 135, no. 17, (2003), 19.

[9] M. E. Lehnert and B. A. John, “Effectiveness of Highway Crosswalk Structures at Reducing Deer-Vehicle Collisions,” *Wildlife Society Bulletin*, vol. 25, no. 4, (1997), 809-818.

[10] E. Weir, “Collisions with Wildlife: the Rising Toll,” *Canadian Medical Association Journal*, vol. 166, no. 6, (2002), 775.

[11] B. F. Blackwell and W. S. Thomas, “Enhancing the Perceived Threat of Vehicle Approach to Deer,” *Journal of Widlife Management*, vol. 73, no. 1, (2009), 128-135.

[12] C. J. Murray, “Auto Industry Bows Technology to Avoid Collisions,” *Electronic Engineering Times*, vol. 24 (2001), 4.

[13] Rational consumer, “Just Click to Park,” *Economist*, vol. 390, no. 8621 (2009).

[14] T. W. Seamans and D. A. Helon. “Evaluation of an Electrified Mat as a White-Tailed Deer (Odocoileus Virginianus) Barrier,” *International Journal of Pest Management*, vol. 54, no. 1, (2008), 89-94.

[15] H. A. Jacobson, J. C. Kroll, R. W. Browning, B. H. Koerth, and M. H. Conway, “Infrared-Triggered Cameras for Censusing White-Tailed Deer,” *Wildlife Society Bulletin*, vol. 25, no. 2, (1997), 547-556.

[16] R. Boonstra, C. J. Krebs, S. Boutin and J. M. Eadie, “Finding Mammals Using Far-Infrared Thermal Imaging,” *Journal of Mammalogy*, Vol. 75, No. 4, (1994), pp. 1063-1068, Published by: American Society of Mammalogists.

[17] Raytheon Company, Thermal-Eye TSC, http://www.opticsbestbuy.com/shared/Optics BestBuy/HTML-Files/L3-Thermal-Eye/TSC4500Manual.pdf (2003), accessed May 22, 2012.

[18] IMTT Motion Control, (2009), http://www.imttusa.com/product.html, accessed May 22, 2012.

[19] Sensoray, (2009), http://www.sensoray.com/support/employment.htm, accessed May 22, 2012.

[20] J. Canny, “A Computational Approach to Edge Detection,” *The Institute of Electrical and Electronics Engineers (IEEE) Transactions on Pattern Analysis and Machine Intelligence,* vol. 8, no. 6, (1986), 679-698.