Thermographic Image Analysis as a Pre-screening Tool for the Detection of Canine Bone Cancer

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ABSTRACT

Canine bone cancer is a common type of cancer that grows fast and may be fatal. It usually appears in the limbs which is called "appendicular bone cancer." Diagnostic imaging methods such as X-rays, computed tomography (CT scan), and magnetic resonance imaging (MRI) are more common methods in bone cancer detection than invasive physical examination such as biopsy. These imaging methods have some disadvantages; including high expense, high dose of radiation, and keeping the patient (canine) motionless during the imaging procedures. This project study identifies the possibility of using thermographic images as a pre-screening tool for diagnosis of bone cancer in dogs. Experiments were performed with thermographic images from 40 dogs exhibiting the disease bone cancer. Experiments were performed with color normalization using temperature data provided by the Long Island Veterinary Specialists. The images were first divided into four groups according to body parts (Elbow/Knee, Full Limb, Shoulder/Hip and Wrist). Each of the groups was then further divided into three sub-groups according to views (Anterior, Lateral and Posterior). Thermographic pattern of normal and abnormal dogs were analyzed using feature extraction and pattern classification tools. Texture features, spectral feature and histogram features were extracted from the thermograms and were used for pattern classification. The best classification success rate in canine bone cancer detection is 90% with sensitivity of 100% and specificity of 80% produced by anterior view of full-limb region with nearest neighbor classification method and normRGB-lum color normalization method. Our results show that it is possible to use thermographic imaging as a pre-screening tool for detection of canine bone cancer.

Keywords: Thermographic images, Canine bone cancer, CVIPtools, CVIP-FEPC, Feature extraction, Pattern Classification

1. INTRODUCTION

Bone cancer in dogs is a fatal disease that grows very fast on middle to old age dogs both large breed as well as smaller breed [1]. Osteosarcoma (osteo = bone, sarcoma = cancer) is a common type of bone cancer that usually appear in the limbs which are called "appendicular osteosarcomas." The nature of this kind of cancer is they grow from inside to outward and destroy the bone from inside to out. A common symptom is lameness after one to three months after first swelling is seen. The tumor that grows is not strong and breaks with slight injury and never heals. These fractures confirm the diagnosis of bone cancer and are commonly called "pathologic fractures". Early detection of cancer is necessary before treatment is started. Analysis of radiography, Magnetic Radio Imaging (MRI) and biopsy are being largely used in the imaging field for the detection of bone cancer. All of these techniques provide information about the anatomic information but they are not well suited for preliminary diagnostic of disease both logistically and economically. A technique called infrared thermography has been used as a tool for the preliminary detection of bone cancer in dogs. The main advantage of this technique is sedation in not necessary to perform the screening and changes in the thermographic pattern can be seen before they are actually confirmed using clinical signs and radiographic abnormalities [2, 3].

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The other advantages of thermography are portability, real time imaging which makes it useful for computer based application, non contact so hygienic and non invasive in nature.

Infrared thermography is a non-invasive, quantitative assessment of temperature, producing a color image called thermogram that represents the surface temperature of an object. Plank's radiation law states that any object above absolute temperature emits radiation. The radiation power and the distribution is given by planks radiation law [4].

$$W(\lambda, T) = \frac{2\Pi hc^2}{\lambda^4}\left[exp\left(\frac{hc}{\lambda kT}\right) - 1\right]^{-1} Wcm^{-2}\mu m^{-1} \quad (1)$$

Where,

h is plank's constant $=6.6256 \text{ X } 10^{-34}$ Js

c is velocity of light$=2.9979 \text{ X } 10^{8}$ m/s

k is boltzman's constant $=1.38054 \text{ X } 10^{-23} \text{WsK}^{-1}$

λ is wavelength in μm

T is temperature in K

So a thermographic image is a display of temperature distribution profile from the subject using different colors to represent different temperatures. The temperature that is measured on the surface is not the heat conducted from the internal body and hence is the function of the sympathetic nervous system. As this heat is not from the internal body, it is not affected by the heat of deeper parts. The local temperature is however affected by disease or injuries which cause local dermal microcirculation to vary. Thermography is useful because of its sensitivity to pathology in the vascular, muscular, neural and skeletal systems. The correlation between the surface temperature recording with disease or injury is the clinical basis of thermography. The increase or decrease in the amount of infrared radiation from body is indicated by the spectrum of colors. For a normal body there is high degree of thermal symmetry and hence any change in temperature asymmetry represents abnormality. The pattern of the color map represents the heat gradient where white or red region being the most hot and blue or black is the coolest region. Use of thermography has been proven valuable for diagnosing several problems in horses, equids, llamas, cattle [5-13] and also in human medicine for diagnosis of breast cancer [14-19], burn patients [14], joint disease [20], vascular disorder [21], pnemothorax [22], intervetibral disk disease [23], lumbar disc herniation, peripheral neuropathy, cardiovascular disease [24-28], and bowel ischemia [29]. The advantages of thermography include the possibility of diagnosis, evaluation, monitoring and documenting a large number of injuries and conditions, including soft tissue injuries and sensory/autonomic nerve fiber dysfunction.

In this research study the use of thermographic images as a pre-screening tool for the detection of bone cancer in dogs has been studied. In addition to other tools, image analysis and data analysis tools was developed for this research study.

2. MATERIALS AND METHODS

2.1 Experimental Animals

Forty dogs regardless of sex were used. The images were taken from both healthy limbs as well as cancerous limb confirmed using biopsy. The images were taken at laboratory of Long Island Veterinary Specialist (LIVS).

2.2 Digital infrared thermal imaging system

Digital infrared thermal imaging (DITI) system used is the Meditherm Med2000 IRIS, which is only DITI system that is based on clinical requirements and is designed for medical application. This system has accuracy of 0.01° C and it can measure temperature from 10° C - 55° C. The thermograms generated are TIFF images and has choice of six palettes in full color, isotherm or grayscale. The system is capable of focusing to small areas down to 75 × 75mm. The program was preset for temperature range of 8°C with a 16 shade color map. The warmer regions were represented by white and red color while the cooler regions were represented by black and blue color. The image of ROI will be focused and image taken will later be adjusted in temperature scale of 8°C range.

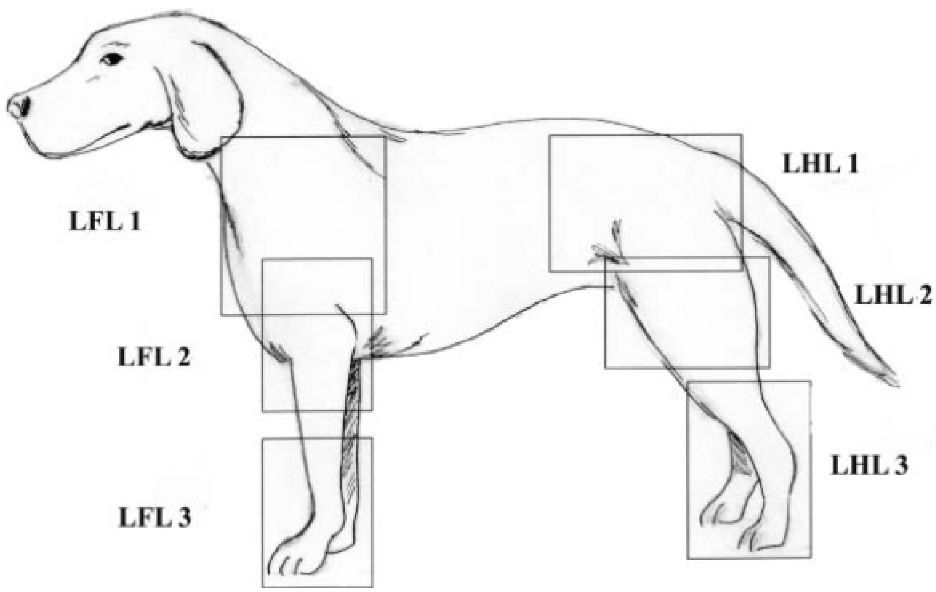

Figure 1. Position of dog during thermography showing different position of limb from left side (LHL = left hind limb, LFL= left front limb).

2.3 Thermographic images

All the images used in this research were obtained from LIVS. For each dog thermographic images were taken from different views, in a temperature controlled room at 21°C. Latex gloves were used by the technician to hold the animal for positioning to prevent thermal artifacts from manual contact. The camera position was typically 1.5 to 4.6 meters from the dogs depending on camera view. The maximum temperature, minimum temperature and average temperature for the region of interest were also noted for each image taken. There were 140 normal images and 141 abnormal images. The images were first divided into four groups according to body parts (Elbow/Knee, Full Limb, Shoulder/Hip and Wrist). Each of the groups was then further divided according to three camera views (Anterior, Lateral, and Posterior).

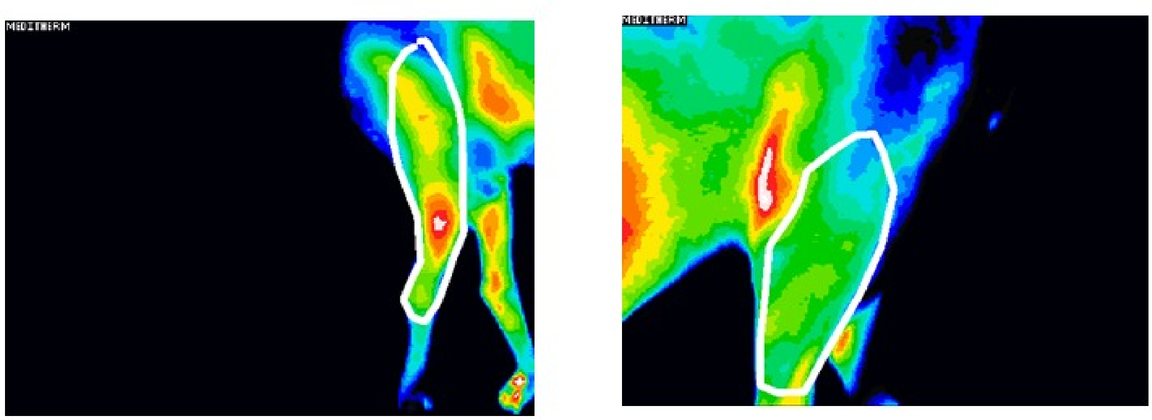

Figure 2. Thermographic image of normal right hind limb with indicated ROI (left) and cancerous left hind limb (right) of same dog.

2.4 Software tools used

Different tools and materials have been utilized for this research study which includes software tools that were developed at Computer Vision and Image Processing (CVIP) lab of Southern Illinois University at Edwardsville (SIUE). These tools include CVIPtools, Computer Vision and Image Processing Feature Extraction and Pattern Classification (CVIP-FEPC) and Color Normalization tools for themographic images [30]. Other tools used were Partek Discovery Suite, Microsoft Visual studio 2010, Microsoft Excel and Matlab.

2.5 Mask creation

The primary purpose of the mask is to extract the area of interest. The mask for individual thermographic images were created using CVIPtools based on the region of interest determined by the veterinary specialist. Once the mask is overlapped with the image, only the area of interest is left for further analysis.

2.6 Color normalization

The thermograms were remapped based on the maximum and minimum temperature of the experimental set. Four different color normalization techniques, Luminance, Norm-Grey, Norm-RGB and Norm-RGB-Lum were used and obtained using the software developed at CVIP research lab [30]. The reason behind the use of color normalization is to take an account of camera setting. This means one color may represent different temperatures in the image depending upon the camera settings, which is adjusted to maximize the visual information. The Lum method is to generate grey image from the color image using the linear equation

$$Grey\ Level = 0.3 * Red + 0.6 * Green + 0.1 * Blue \tag{2}$$

The Norm-Grey method maps the minimum and maximum temperature to grey level value of 0 to 255. The pixel value of resultant image represents the pixel's temperature of the corresponding original image. The Norm-RGB method works the same way as norm-Grey, but it uses color palatte. The Norm-RGB-lum method is obtained after applying lum method followed by Norm-RGB.

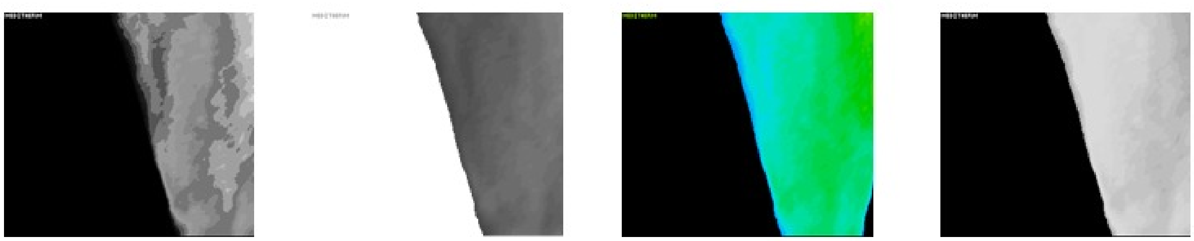

Figure 3. Color normalized thermographic image of normal right hind limb (from left to right Luminance, Norm-Grey, Norm-RGB, and Norm-RGB-Lum).

2.7 Feature selection and extraction

To analyze the temperature distribution pattern of the thermograms, different image features were extracted from the themographic images. The ten features used includes spectral, five texture features and 4 histogram features. The spectral features were measured for three rings and three sectors for each RGB color band. The texture features includes texture energy, inertia, correlation, inverse difference and entropy. These five features were calculated for four different directions. The spectral feature also includes the average DC values of RGB color band. The second order histogram of the grey levels based on joint probability distribution has been used to measure the texture. The statistics based on the pairs of pixel and their grey level can be obtained using the second order histogram, also called the grey level co-occurrence matrix. For a given distance and angle, the texture feature are calculated as below [31].

$$\text{Energy} = \sum_i \sum_j c_{ij}^2 \tag{3}$$

$$\text{Inertia} = \sum_i \sum_j (i-j)^2 c_{ij} \tag{4}$$

$$\text{Inverse Difference} = \sum_i \sum_j \frac{c_{ij}}{|i-j|} \text{ ; for } i \neq j \tag{5}$$

$$\text{Entropy} = -\sum_i \sum_j c_{ij} \log_2 c_{ij} \tag{6}$$

$$\text{Correlation} = \frac{1}{\sigma_x \sigma_y} \sum_i \sum_j (i-\mu_x)(j-\mu_{y)c_{ij}} \tag{7}$$

Where

c_{ij} is elements in the co-occurrence matrix normalized by number of pixel pairs in the matrix.

$$\mu_x = \sum_i i \sum_j c_{ij}$$

$$\mu_y = \sum_j j \sum_i c_{ij}$$

$$\sigma_x^2 = \sum_i (i-\mu_x)^2 \sum_j c_{ij}$$

$$\sigma_y^2 = \sum_j (j-\mu_y)^2 \sum_i c_{ij}$$

The histogram features were extracted for each RGB color band. Similarly the histogram features includes mean, standard deviation, skew and entropy. The histogram features were calculated after modeling the histogram as probability distribution of gray level. These feature are calculated using following equations [31].

$$Mean(\bar{g}) = \sum_{g=0}^{L-1} gP(g) \tag{8}$$

Where $P(g) = \frac{N(g)}{M}$ is first order histogram probability, M is number of pixel in the image, N(g) is number of pixel at grey level g , L is total number of grey level.

$$\text{Standard Deviation}(\sigma_g) = \sqrt{\sum_{g=0}^{L-1} (g-\bar{g})^2 P(g)} \tag{9}$$

$$\text{Skew} = \frac{1}{\sigma_g^3} \sum_{g=0}^{L-1} (g-\bar{g})^3 P(g) \tag{10}$$

$$\text{Energy} = \sum_{g=0}^{L-1} [P(g)]^2 \tag{11}$$

$$\text{Entropy} = -\sum_{g=0}^{L-1} P(g) \log_2 [P(g)] \tag{12}$$

With all these features there were 46 different feature values that were extracted for each thermograms. CVIP-FEPC was used to extract the features which provide a text file which can be used as feature files for other pattern classification tools such as Partek and Matlab.

2.8 Data normalization and pattern classification

Two data normalization methods were used to normalize the extracted feature data which were standard normal density normalization and softmax scaling with r=1[31,32]. Pattern classification was performed using nearest neighbor and K nearest neighbor with k=5 methods. With 11 feature types and two data normalization methods, there were 4096 single experiments. All the experiments used full leave one out testing. CVIP-FEPC was used for data normalization and pattern classification. The result from CVIP-FEPC not only provides the best classification success rate but it also provides the important feature sets that were used for pattern classification. The output from CVIP-FEPC provides the results of all experiments and this is helpful for selecting the best features for future experiments.

2.9 Experimental methods

Two sets of images were obtained from LIVS, one thermographic image and another with the ROI indicated by veterinary specialist. CVIPtools was used to create the manual mask based on the ROI indicated. The color normalization was performed using the color normalization software developed at SIUE. The software was written using Microsoft C# and it uses the temperature data of all the images provided by LIVS. The temperature data sheet was prepared manually which contains name of the dog, maximum temperature, minimum temperature and average temperature. The software outputs five folders with masks for the original and the four color normalized images. The CVIP-FEPC software was used for feature extraction and pattern classification. This software has specially designed for running multiple experiments by selecting multiple features, data normalization methods and pattern classification methods. The result of FEPC consists of three different files: 1) summary file, 2) feature file and 3) individual experiment result files. The summary file gives the classification success rate for each experiment along with the important features used for classification purpose. The feature file contains all the feature values extracted from all the images which can be used as input for other pattern classification tools. The individual experiment result file contains the details of each experiment along with sensitivity and specificity. These results were then analyzed to determine the overall success rate, sensitivity, specificity, useful feature sets and classification method that provide the best result.

3. RESULTS AND DISCUSSION

This research study uses thermographic images of healthy as well as cancerous limbs of forty dogs. The images were divided into four groups based on body parts and then further divided based on three camera views. Three groups were not considered for further analysis because the data sets were very small. Four color normalization methods were then applied to each subgroup, so including the original images, this makes forty five experimental sets. Ten features, two data normalization techniques and two pattern classification methods were used for each experimental set which results in total of 82,944 individual experiments. These individual experiments were then analyzed to find which camera view and color normalization method gave best classification success. Two important metrics, sensitivity and specificity, were also measured for the experiment that provides the best classification success.

Table 1. Best classification results for different body parts.

Body Parts	**Camera View**	**Color Normalization**	**Success Rate**	**Sensitivity**	**Specificity**
Elbow Knee	Anterior	normRGB	87.80 %	80.00 %	95.20 %
Full Limb	Anterior	normRGB -lum	90.00 %	100.0 %	80.00 %
Shoulder/Hip	Lateral	normRGB -lum	75.00 %	70.00 %	80.00 %
Wrist	Lateral	normRGB -lum	89.65 %	86.67 %	92.86 %

The table shows that, for example Elbow/Knee Anterior view, 87.8% overall success with sensitivity 80% and specificity 95.2% was achieved with normRGB color normalization. These results show that the NormRGB and NormRGB-lum color normalization methods provided the best results for this application. The best view is dependent on the body part, with the anterior view providing the best results for elbow/knee and full limb, and the lateral view had the best result for shoulder/hip and wrist image sets.

We analyzed the individual results from all forty five experimental sets. We analyzed the top three experiments in detail that provided the best result for each experimental setup. The purpose of this is to find which features, data normalization methods and pattern classification techniques were most often used for best classification results. It was determined that texture features and histogram features were equally important for pattern classification. The histogram features were used for best classification in 32 out of 45 experimental sets and the texture features were used in 33 experimental sets out of 45. Twenty seven of the 45 experimental sets show soft max as the best data normalization method, and 32 out of 45 experimental sets show that nearest neighbor is the best classification method.

4. SUMMARY AND CONCLUSION

This research investigates using thermographic imaging as a pre-screening tool for the detection of canine bone cancer. A computer based automatic method to classify image pattern was developed and used. Classically thermograms are analysed either by observation by specialist or statistical analysis of temperature data. A computer based tool was developed and used to automate the classification. Texture features, spectral features and histogram features were extracted from thermographic images and used to classify the images as normal or abnormal. In this research study experiments with different body parts, camera views and color normalization methods were performed and results analyzed. The images used in this research were not homogeneous and were from varieties of breed, size and length of disease first confirmed. These facts highly influence the nature and pattern of thermographic images. The overall results indicate the feasibility of using thermographic imaging as a pre-screening tool for detection of bone cancer in dogs; the highest success rate being 90% with 100% sensitivity and 80% specificity.

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