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Activity Monitoring and Motion Classification of the Lizard *Chamaeleo jacksonii* Using Multiple Doppler Radars

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Abstract— **We describe a simple, non-contact and efficient tool for monitoring the natural activity of a small lizard (*Chamaeleo jacksonii*) to yield valuable information about their metabolic activity and energy expenditure. It allows monitoring in a non-confined laboratory environment and uses multiple Doppler radars operating at 10.525 GHz. We developed a classification algorithm that can differentiate between fidgeting and locomotion by processing the quadrature baseband signals from the radars. The results have been verified by visual inspection and indicate that the tool could also be used for automated monitoring of the activities of reptiles and other small animals.**

I. INTRODUCTION

Activity monitoring of animals in their natural environment can yield important information about energy expenditure, thermoregulation, behavioral patterns, and even population health [1], [2]. As energetics plays a large role in ecology, behavior, and physiology, accurate methods for activity monitoring are critical for a wide range of animal studies. The standard technique for measuring Field Metabolic Rate is the doubly-labeled water technique which involved injecting animals with radio-labeled water and observing the rate of CO_2 production over several weeks [2]. Because the technique relies on the biological half-life of ^{18}O, which is long relative to the duration of specific behaviors, it is not possible to measure the cost of specific activities such as foraging, mating, or locomotion. Recent advances in the miniaturization of electrical circuits have allowed measurements of activity using continuous heart-rate monitoring, but as this technique uses implantable data-loggers, it is limited to animals 1 kg or larger [3]. For smaller animals, the only available techniques are visual inspection or video recording. Both are extremely time-consuming, labor-intensive, and require extensive post-experiment effort in recording, transcribing, or analyzing the raw data.

Doppler radar motion sensing can provide a better tool for the automated activity monitoring in animals, as well as the detection of multiple behavioral events in real-time [4]-[6]. However, previous systems used only one Doppler radar and were not capable of classifying different states of activity, such as fidgeting, walking, or running, which differ tremendously in energetic cost and are important to distinguish in studies of activity.

This paper describes the use of a multiple radar system to monitor and classify different activity levels of a small animal (the lizard *Chamaeleo jacksonii*) in a non-confined laboratory environment. The classification algorithm detects the motion as either fidgeting or locomotion. The value of such a system also lies in the fact that it is able to detect very slow movements of the chameleon and can be tuned to specific behaviors of different species. The resulting data has been verified by visual reference and video recording. Factors that go into selection of right Doppler radar system have been discussed.

II. DOPPLER RADAR FOR MOTION CLASSIFICATION

Continuous wave Doppler radar is a very useful tool for tracking motion and can be used to extract information about an objects velocity. Quadrature Doppler radar provides two baseband output as in-phase (I) and quadrature phase (Q), that when plotted against each other form an arc of a circle in response to ideal linear motion. The amount of arc transcribed is a function of detected motion and the frequency of operation of the radar. For a given displacement x, and transmitted frequency $f_2 > f_1$, x would result in a bigger arc for baseband data obtained from f_2. In order to better detect signals reflecting off an object with a small radar cross-section, Doppler radars operating at frequencies of 24 GHz and 10.525 GHz have been used. Two Doppler radars, one each for detecting motion in x-plane and y-plane were employed. With the information received, the target movement can be extracted from the change in frequency of the received signal to the Doppler shift of the moving target.

III. MOTION CLASSIFICATION

Target motion can be classified based on the changes in the amplitude of baseband signals. A simple way to detect large motion is by the use of Eigen demodulation. A sudden change in Eigen vectors will indicate non-sedentary motion. Motions can also be classified based on movement relative to the radar that can be deduced by observing a given amount of radar data samples and calculating the phase angles of the arc transcribed in the I-Q plane. If the phase angles are rotating in the clockwise (CW) direction, the

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motion would be classified as moving away from the radar. On the other hand, phase angles in the counter clockwise (CCW) direction would be classified as moving towards the radar. The motion in front of the radar would result in the formation of an arc in the I-Q plane. The length of the arc is directly proportional the amount of the motion (motion component orthogonal to the plane of radar antenna). For a transmitted signal of 24 GHz (lamda=1.25 cm), a movement of approximately 0.6125 cm results in a complete circle. By counting the number of circles or closed loops in the I-Q plane, it is possible to quantify motion as fidgeting or locomotion. For our analysis with different radar modules, different threshold values were used and have been listed in section IV. The phase angles were calculated using MATLAB ©, however to obtain the correct phase values, the IQ plots were conditioned to be centered at the origin. After the phase angles were calculated, the algorithm determines the numbers of rotation by counting how many times it passed the initial value of each circular pattern. Two-dimensional movement was calcluated by comparing the data between the two sensors.

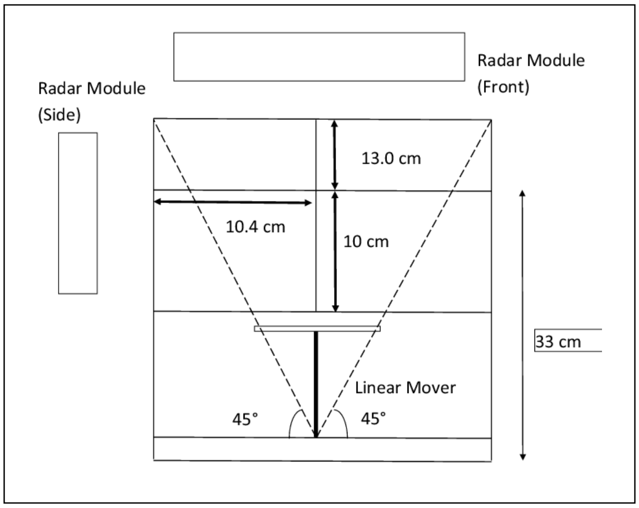

Fig.1. Figure showing a schematic of the experimental set-up using two radar modules and mechanical target/linear mover (linear servo with an attached plate as a scatterer).

IV. EXPERIMENTAL RESULTS

A. *Linear mover*

Experiments were initially performed with mechanical targets in the form of a linear mover. A p12 linear servo from Firgelli Technologies was used to move a plate covered with aluminum foil as shown in Fig.1. Two 24 GHz quadrature radar modules from RFbeam were used to sense the motion. The baseband output from the modules were connected to Low Noise Amplifiers (LNA's) for baseband signal conditioning and then fed to a NI-DAQ for data acquisition. The linear servo was programmed to perform two motions commonly observed in small reptiles, that are locomotion and fidgeting. The patterns of both the motion are tabulated in table 1.

Table I: Displacement values for linear mover for the simulated motion

Motion Pattern (Locomotion/ Fidgeting) (approximate values)		
	Locomotion	Fidgeting
Forward	2 cm	0.6 cm
Pause (~2 sec.)		
Backward	2 cm	0.6 cm
Forward	2 cm	0.6 cm
Backward	2 cm	0.6 cm
Delay for 6 sec.		

As shown in Fig.1, there are two 24 GHz radar modules mounted on cardboard stands and facing perpendicular to each other to record motion in two axes. To understand how multidirectional motion is detected by the system, the linear mover is placed at three different locations as showed above. In the first location, the linear mover was placed facing straight towards the front radar in order to simulate locomotion. The algorithm for detecting and classifying motion is shown in Fig.2. The time period containing significant motion was obtained by measuring changes in Eigen vectors and the phase values during that time period were calculated and analyzed to classify motion.

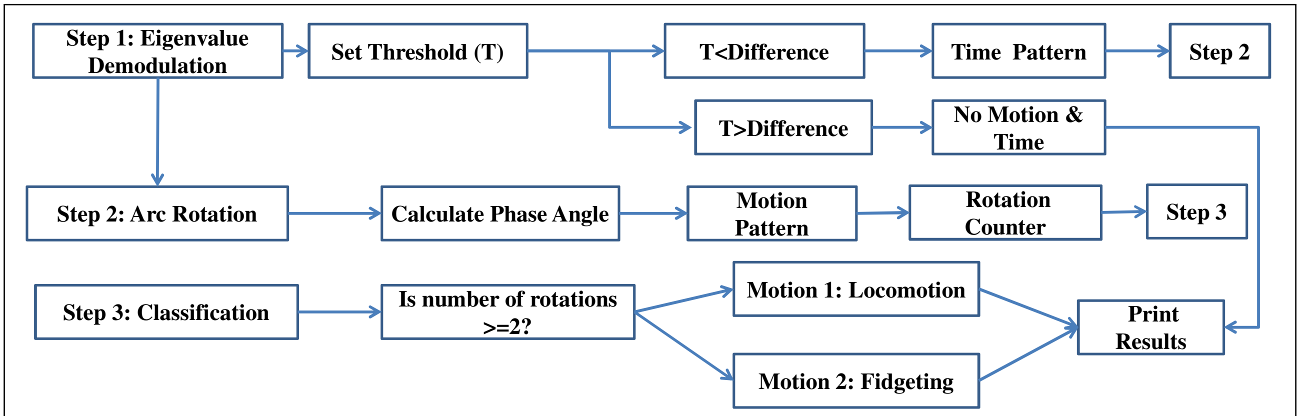

Fig.2. Classification algorithm used for each radar to characterize motion.

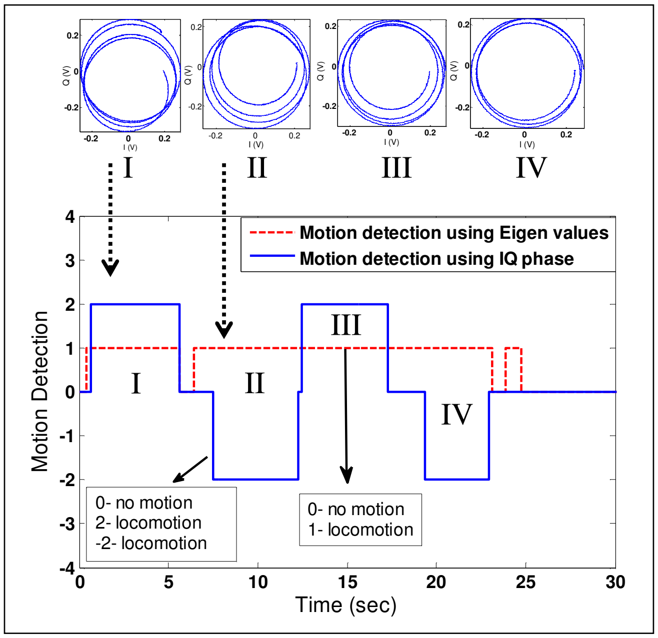

Fig.3. Plot showing motion detection using Eigen vector and classification using angle estimation and rotation count for locomotion in front of front radar module. The I-Q plot ‘I’ corresponds to the motion period ‘I’. For motion detection using phase, a value of 2 indicates motion and -2 indicates motion in the opposite direction as described in the text.

The results for straight motion for front radar are shown in Fig.3. Two or more complete rotations were classified as locomotion. For 24 GHz, a motion of approximately 1.2 cm should result in two rotations. From Fig. 3, we can observe four to five rotations in each time segment where motion was detected.

After testing for locomotion, the mover was placed facing straight towards the side radar to simulate fidgeting or swaying of the body. The resulting analysis is shown in Fig. 4. As can be seen from the I-Q plots of Fig. 4, there are less than 2 complete rotations transcribed.

Another important aspect to be considered for this system is to observe the effect of motion at an angle towards both the radars. In such a situation, the motion content along their respective axes will be seen by the front and side radar. However, the motion content seen will be a function of the target’s angle to both radars and its shape that will determine the effective cross-section presented to the radars. In order to observe the effect of such a motion, the linear mover was moved with locomotion pattern at approximately 45° to both radars. The results are shown in Fig.5. For motion classification, a value of 1 corresponds to fidgeting and a value of 2 corresponds to locomotion. The motion pattern detected from changes in Eigen vector was same for both radars. Due to the position of the plate, the motion component detected by the front radar is less for I and IV and hence it detects the motion as fidgeting. As the plate moves closer in II and III, more motion content is visible to front radar and hence it can detect locomotion. However, information from front and side radars can be analyzed to classify motion in broad terms of energy expenditure.

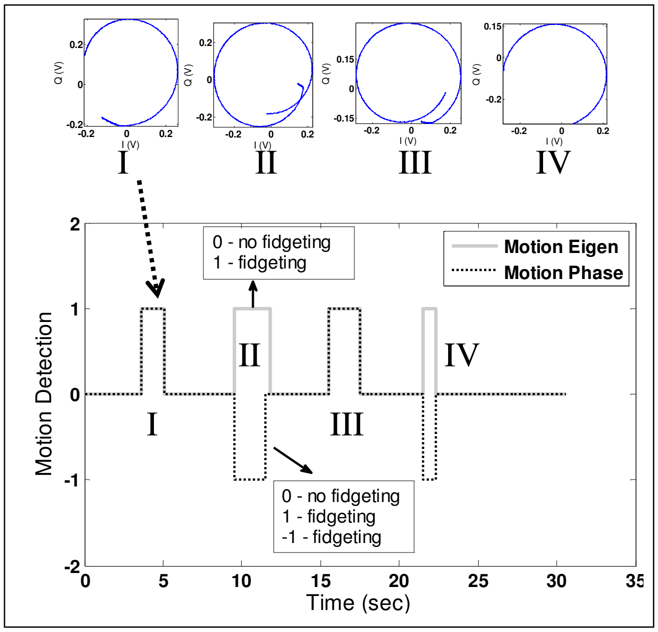

Fig.4. Plot showing motion detection using Eigen vector and classification using angle estimation and rotation count for fidgeting in front of side radar module. The I-Q plot ‘I’ corresponds to the motion period ‘I’. For motion detection using phase, a value of 1 indicates motion and -1 indicates fidgeting in the opposite direction.

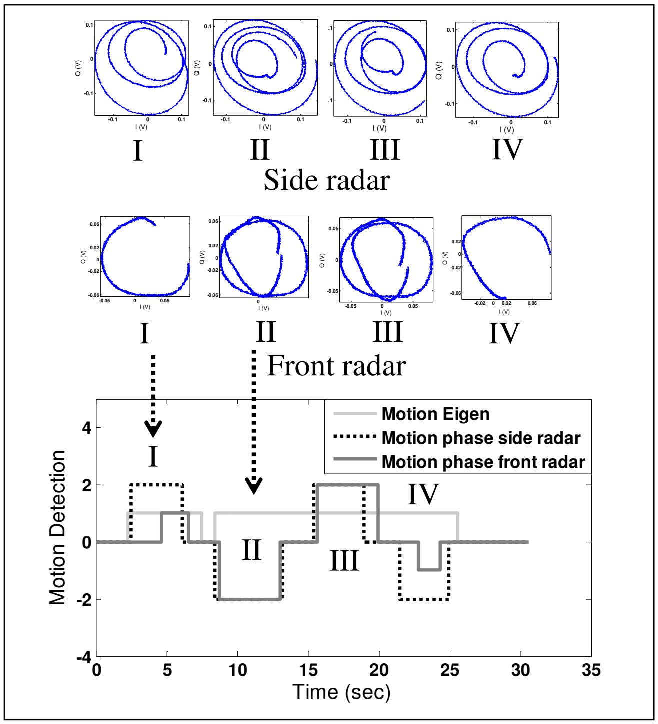

Fig.5. Plot showing motion detection using Eigen vector and classification using angle estimation and rotation count for locomotion at an angle of approximately 45°. The I-Q plot ‘I’ corresponds to the motion period ‘I’. For motion detection using phase, a value of 1 indicates fidgeting and 2 indicates motion.

B. Chameleon testing

After testing with linear mover, tests were performed with *Chameleo jacksonii*. The radars were set in similar configuration to Fig.1 but 10.525 GHz radar modules were used and a stand was used to hold a small branch on which the chameleon was let loose. The experiments were performed under natural light in the morning in a closed room. The sampling rate for radar data acquisition was set to 100 Hz. The photograph of the set-up is shown in Fig.6. Measurements were made for 5 minutes. A standard digital camera was used to record video (640 x 480) as reference. From inspection of the video, a table was created indicating the type of motion with time. These reference values were then compared with radar data analysis that has been presented in Fig.7 and Fig.8.

Fig.6. Photograph showing the set-up for monitoring chameleon activity.

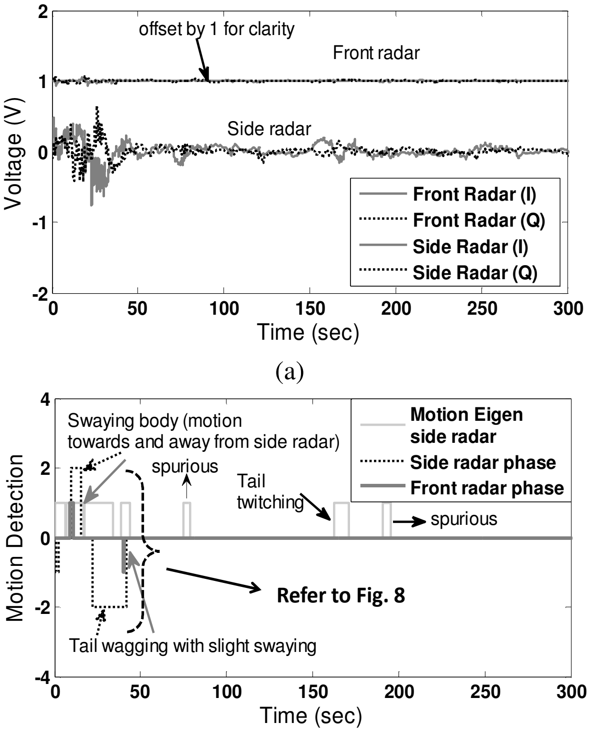

Fig.7. (a) Raw data from front and side radar showing changes in amplitude due to motion and (b) result of the detection algorithm for front and side radar. The swaying of the body is detected as locomotion by the side radar and fidgeting by the front radar as expected. A few spurious alerts were generated by the Eigen vector algorithm but were revealed as no motion by phase analysis and video reference.

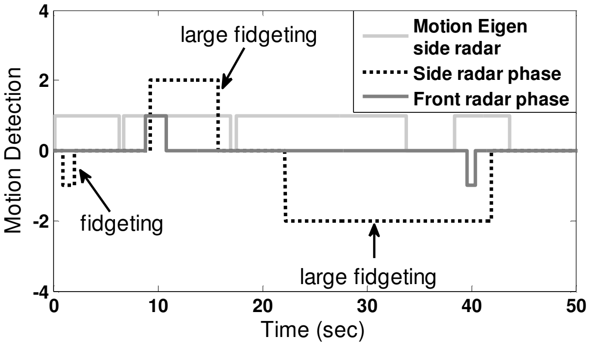

Fig.8. A plot of 0-50 seconds taken from Fig. 7 showing a new class of activity (large fidgeting motion) that cannot be considered as locomotion. But the radar has the capability to differentiate between small fidgeting and large fidgeting.

V. DISCUSSION

From the raw data and resulting analysis (Fig.7), it can be seen that phase analysis fails to detect the twitching of the tail at around 170 sec. This might be due to the fact the motion was up and down and not orthogonal to either radars. However, three radars could be used to cover all degrees of motion. Two other detections were made using Eigen vector that were revealed as no motion by both phase analysis and video reference. Fig.8. reveals that in addition to detecting regular fidgeting, the radar detects a large fidgeting motion occurring due to swaying of body by the chameleon. This extends the capability of the radar to resolve four states of activity. The current algorithm is designed to detect and classify large and small motion. The small motion can also include respiratory activity that was ignored by a set threshold. However, the algorithm can be applied to detection of sedentary motion that can possibly provide us with information about respiratory rates along with energy expenditure. Another decision step could be added in future where an algorithm will combine the two decisions of both radars to yield a single plot specifying the nature of activity.

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