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A Data Efficient Method for Characterization of Chameleon Tongue Motion Using Doppler Radar

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***Abstract*— A new technique is described for study of the study of high velocity animal movements using a continuous wave Doppler radar operating at 24 GHz. The movement studied was tongue projection kinematics during prey capture by the lizard *Chamaeleo Jacksonii*. The measurements were verified with a high speed video reference, recorded at 1000 frames per second. The limitations and advantages of both the methodologies are compared and tongue speeds of 3.65 m/s were observed. These results show a useful application of radar to augment visual sensing of biological motion and enable the use of monitoring in a wider range of situations.**

***Index Terms*— Biology, Doppler Radar, Feeding, K-Band Radar, Movement, Physiology, Prey Capture, Zoology**

I. INTRODUCTION

Chamaeleonid lizards capture prey by projecting their tongues out of their mouth at high speeds. The kinematics of this activity are important to quantify because they provide clues as to how this unusual movement is produced. Through measurements of velocity and acceleration, we can explore such questions as which part of the behavior is powered versus passive and what types of control mechanisms these animals have for adjusting to moving or variable targets.

Researchers have studied prey capture kinematics of *Chamaeleo oustaleti*. The two individuals studied were found to project their tongues at a maximum of 5.8 m/s when striking prey at a distance of 35 cm using high-speed cinematography [1]. Chameleons judge the prey distance through optical focusing [2] and adjusts tongue projection based on this distance.

The basic components for kinematic analysis of this movement include one or more high speed cameras, lenses, high power lighting system, a computer and associated software. Such acquisition of detailed information on the dynamics and anatomy of tongue motion comes at a price of high data rate, bright lighting, relative inflexibility for camera positioning and time-consuming analysis of video data.

Doppler radar has been previously used for physiological monitoring [3] and motion sensing [4]. A continuous wave Doppler radar system provides us with a less intrusive technique to study the velocity profile of the tongue providing a good insight to its dynamics. This radar also allows us to record data for long periods of time while still providing fine temporal resolution.

Fig. 1. Chameleon poised to strike a cricket clipped in place above the radar (with a flat-head alligator clip). Note the ruler below the perch for length reference.

As the radar has low infrastructure requirements, it is easy to use it to augment a normal experiment by providing a complementary measurement and also providing indication of strikes on prey or to be used for recording feeding patterns without the need for video recording and its consequent data storage and analysis.

These experiments investigate the use of radar to profile tongue speed over time and can lead to the measurement of tongue projection kinematics and how it varies with target distance and motion to offer insight into the control mechanisms chameleons have for adjusting to and tracking moving targets.

II. BACKGROUND

A. Doppler Radar Theory

The Doppler effect is a change of frequency in a radio wave as a result of reflection off a moving object. Doppler radar operation involves transmitting a radio signal towards an object, receiving the reflected signal, and comparing the two. Using such a radar sensor, the speed of an object can be measured by comparing the frequency of the received signal to that of the transmitted signal. The frequency deviation is:

$$F_d \approx 2v\frac{F_0}{c} \tag{1}$$

with detected change in frequency F_d, object speed v, frequency of operation F_0, and the speed of light c. Measuring the frequency of the reflected signal can be difficult, many circuit devices do not work at such high frequencies. For a continuous wave system with a target position of $x(t)$ over

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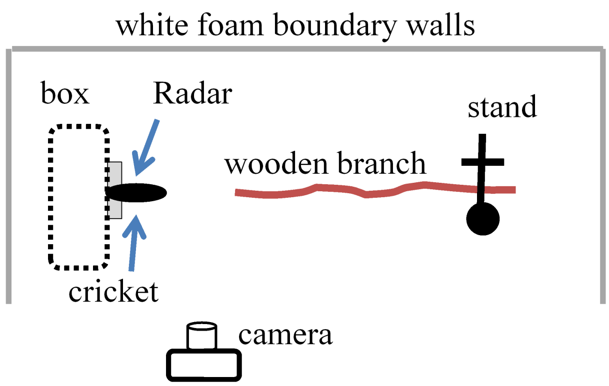


Fig. 2. Sketch of test setup seen from above. The cricket is located just above the radar antennas and the perch (wooden branch) is situated to locate the chameleon's head at the level of the radar antennas. The camera is about 1 m away from the radar antenna and perch.

time, the baseband radar output signals B_I and B_Q can be expressed as:

$$B_I = A_I cos\left(\frac{4\pi x(t)}{\lambda} + \phi_I\right) + D_I \quad (2)$$

$$B_Q = A_Q sin\left(\frac{4\pi x(t)}{\lambda} + \phi_Q\right) + D_Q \quad (3)$$

with received signal amplitude A, wavelength λ, phase offset ϕ, and DC offset D. For an AC coupled system, $B_I = B_Q = 0$. A 24 GHz radar module was chosen for this application owing to its low cost, small form factor and higher resolution.

B. Video measurement background

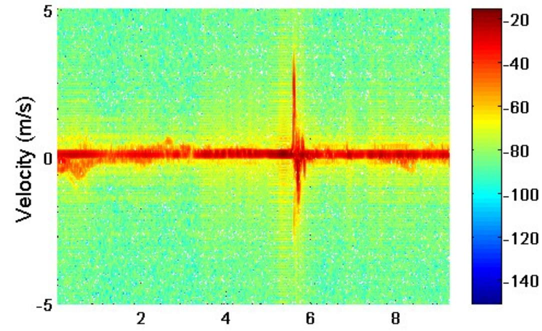
High speed video recording of the chameleon's tongue projection and retraction allows for non-realtime analysis of the motion and extraction of the tongue position over time for use as a reference for the radar measurements. Visual analysis of chameleon feeding has been used to investigate visual pursuit [2] and tongue projection kinematics [1].

III. Experimental Setup

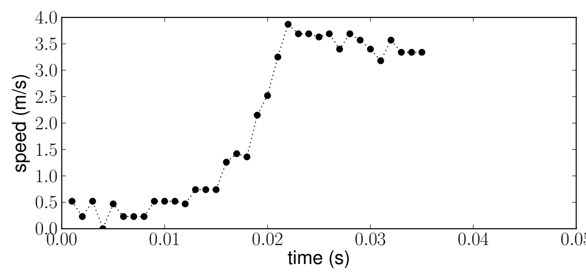
A. Radar

A miniature radar transceiver (K-LC2 from RFbeam Microwave GmbH) operating at 24 GHz was used to measure the Chameleon tongue motion. An adjustable perch for the chameleon was made by using a metallic stand with a small wooden branch. The radar was affixed to a cardboard box facing the branch. The height of the branch was adjusted to have the mouth of the chameleon face the antenna. A photograph of the setup is shown in Fig. 1.

The baseband outputs from the radar were connected to Low noise amplifiers and then digitized using an National Instruments USB-6009 data acquisition device at 1000 and then 4000 S/s. Data was collected using software written in LabVIEW, with a live display for instant feedback and traces stored as for offline analysis.



(a) radar



(b) video

Fig. 3. Plots of tongue speed for the second experiment as determined from (a) radar and (b) video data. The tongue motion appears as a short spike of motion in the radar data and not like the step seen in the video data because the radar monitored the chameleon for a much longer time than the high speed video camera. Even at this higher sample rate and longer duration of observation the data from the radar system is much more manageable. The reported maximum speed for both the radar and video measurements (with equivalent sample times) showed excellent agreement at 3.64 m/s and 3.65 m/s, respectively.

B. Camera Details

A video reference was provided in the form of an IDT MotionXtra N4 gigabit camera with a 45 mm lens. This camera captured megapixel greyscale images at first 500 fps and then 1000 fps. IDT MotionStudio capture software was used to control the camera and record the video while motion analysis was performed using Matlab and OpenCV. The testing area was lit with a tungsten flood lamp.

C. Testing Process

The cricket was held by the radar module in a clip as shown in Fig. 1 and Fig. 2. We found clipping both the hind legs with the alligator clip offered the best results. The alligator clip was stuck on top of the box using a double sided foam tape in order to hold the clip in place when the Chameleon grabbed the cricket. One cricket was used for each experimental trial.

IV. Results

A. Video

Position data from the high speed video camera was digitized to determine the speed of tongue. The tongue tip was manually located in successive frames, and converted from coordinates in pixels to mm. A frame-by-frame estimate

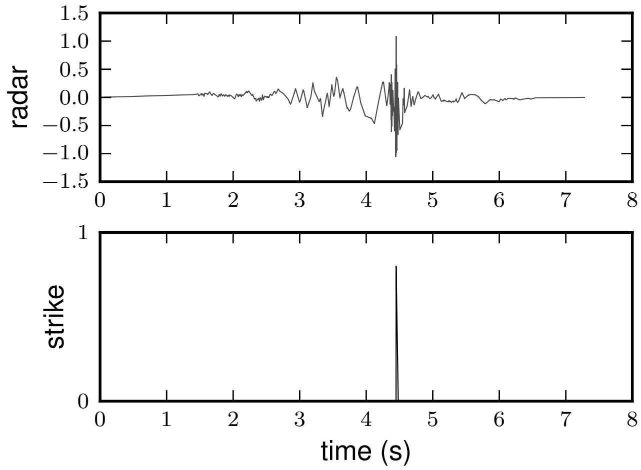


Fig. 4. Radar output of chameleon striking bait with indications of automatically determined strike time(s). This information can be used to quickly focus attention on times for analysis and saving video. Though the data was analyzed after the experiment, the strike indication could be generated in real time using a similar algorithm.

of tongue speed was calculated by measuring the difference in the location of the tip of the tongue between successive frames and dividing by elapsed time. This process was performed over the duration of the tongue's initial strike movement and a plot of speed over time can be seen in Fig. 3b.

B. Radar

The recorded radar data was processed using Matlab. The baseband outputs (In-phase and Quadrature-phase) were represented in complex form as $I + jQ$ and a Doppler spectrogram was plotted. A window of 256 data points were padded to 512 points for calculating the Fourier transform and successive windows had 224 points of overlap. Fig.3a shows a spectrogram of the radar output with the tongue motion clearly visible just before $t = 6$ s.

The tongue motion as seen by the radar and video sensors is shown in Fig.3a and Fig.3b. A Velocity profile was extracted from the spectrogram by selecting the velocities having a relative power level between -60 to -66 dB. An algorithm was developed to extract the tongue speed from this spectrogram data by selecting the highest frequency bin (maximum velocity) at each spectrogram time point that was within the velocity profile. The tongue speed from the video was averaged over 7 frames while comparing the measured motion. The peak velocity from the radar plot is 3.64 m/s and from that of reference video is also 3.65 m/s.

V. Discussion

The chameleon tongue motion was visible in both the radar output and the video recording and both techniques reported 3.65 m/s speeds.

An alternative technique for calculating the tongue speed involves combining the radar outputs and finding the angle they form, visualized in Fig. 5 and then combining the radio carrier wavelength (1.25 cm for a frequency of operation 24 GHz) with the angle over time to determine the position for each point in time. The difference in position from one sample to the next then provides the tongue velocity.

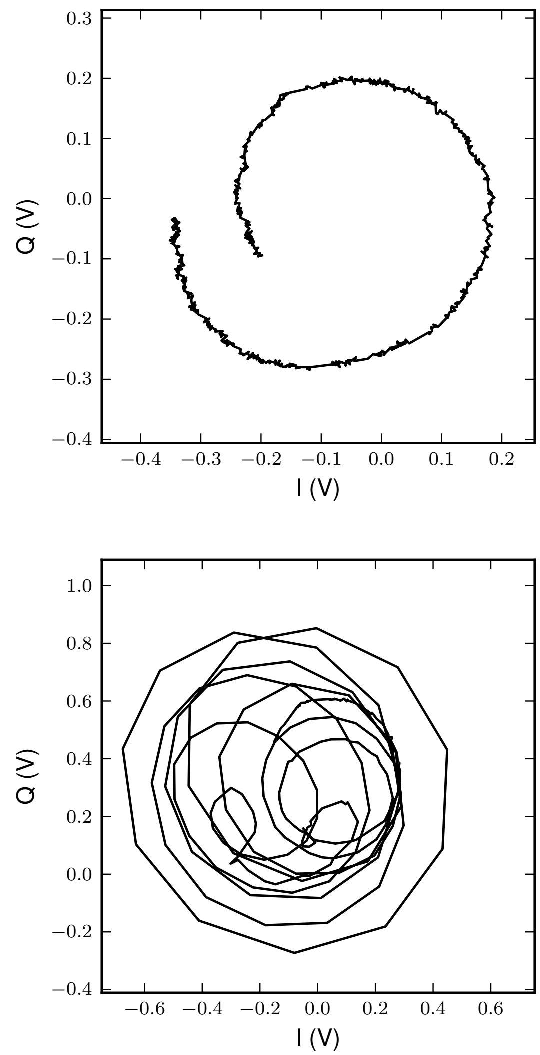


Fig. 5. Radar baseband output signals I and Q plotted for 300 ms (top) and 100 ms (bottom) showing the speed difference between tongue protrusion and tongue projection during the strike.

Comparing the radar and video measurements, the high speed video showed greater detail of tongue position and provided information about multiple sources of motion and tongue shape during retraction. Fig. 6 shows multiple parts of the tongue moving at different speeds and in multiple directions in a pattern difficult to measure with a single radar sensor. With careful antenna placement, a single radar system can measure the chameleon tongue velocity as it strikes bait even when the bait is moving on multiple axes – to measure these kinds of motion, multiple video cameras with 3D reconstruction would be required. The cricket motion

Fig. 6. Chameleon shortly after striking cricket, in the process of drawing its tongue (and the now attached cricket) back to its mouth. Visible in this still frame are parts of its tongue moving in different ways: what little motion the base has is generally vertical (waving it up and down) while the thinner middle portion is behaving more like a cable or rope and the thicker part at the end with the cricket is swinging back like a weight. Unlike the earlier tongue projection, this set of motions do not appear independently in the radar output and measuring this interplay during tongue retraction would be very difficult if not impossible with a single radar system.

used for assessing visual pursuit [2] fit in a plane with the chameleon itself, with the camera located on an axis normal to the plane – with multiple radar sensors, additional patterns of bait motion could be investigated.

Radar offers the capability of measuring some motions without a camera and also that of accurately sensing faster motion and less intrusive operation for light sensitive situations. Modifying the DAQ software for the radar system to automatically trigger recording when fast motion occurs could offer expanded capabilities with a camera – the radar could be used to trigger the camera, enabling shorter recordings that focus on just the activity of interest or alternately radar could be used for long term monitoring over an extended period of time with a camera used for spot verification of interesting motion.

In this experiment, we determined the speed from the radar signal by analyzing frequency deviation of the received signal. Radar data can also be used to obtain displacement information as can be done from the video. The use of radar to obtain displacement information has been described in [5] and involves tracking the center of the circle formed by the IQ plot (see Fig. 5). Detecting the instantaneous phase between the transmitted and received signals to determine relative position can offer finer resolution in time.

While the radar systems used here do not distinguish between multiple sources of motion, they can effectively monitor over an extended range with useful accuracy — a multi-sensor system would be able to monitor motion over an even larger volume of space. Visual monitoring presents many limitations: high-frame rate cameras are very expensive, with costs increasing substantially for higher pixel density or memory capacity; the data are labor-intensive to analyze; and impose optical limitations such as requiring unnaturally bright illumination and a clear field of view to observe the motion. When the movement itself blocks the camera view, the only remedy is to use multiple cameras, multiplying all of the attendant costs. Radar systems present an attractive alternative to video kinematic systems, offering a wider range of speed measurements at relatively low cost, longer recording durations, and under more naturalistic conditions.

VI. Conclusion

These results demonstrate the feasibility of using small radar sensors to measure the tongue speed of a chameleon and work in concert with video motion analysis. Follow on work will entail refinement of the system and its use to provide data to researchers studying high-speed animal movement. Additional work to combine the measurements from multiple radar sensors will allow monitoring of subject motion in an enclosure and also measurement of tongue speed in less constrained situations, allowing for the capture of natural behavior without training. This technology will allow the exploration of a broader range of behaviors, and allow great insight into biomechanical function such as which part of the behavior is powered versus passive though kinematic analysis.

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