Ants Behaviors Exhibit Stokesian Qualities

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Abstract— **Legged locomotion, the most prevalent mode of terrestrial locomotion, involves the frequent making and breaking of contacts. These discrete events can make it challenging to have simple yet descriptive behavioral models. Motions that exhibit continuous contact often result in simpler representations. Such is the case for slithering systems like snakes. For these systems, analysis via observation and resistive force theory shows that frictional forces dominate those caused by inertia, constraining the motion to Stokesian behavior [1]. In our studies, we have found through qualitative and quantitative descriptors that ants, despite their fundamentally hybrid qualities, function as dynamical analogues to the friction dominated behaviors of continuous Stokesian movers.**

We collected ant walking data, including foot placement and body trajectory, via the process detailed in Figure 1 parts A-D. After grouping this motion capture data into behavioral categories (quartiles for speed and tertiles for turning), we see some informative initial trends. Supporting prior work [2] we see that stride frequency is a stronger indicator of speed than stride length. But furthermore, we can see by observing the distribution of both fast-straight and slow-straight behaviors across phase (in Figure 1 part F), the legs are tracing very similar paths no matter the speed. Tracing a similar shape motion at all speeds suggests that inertia may play a very small role in the ants locomotive model. This lack of momentum-based influence on shape expression could result from a few things, such as the ants control authority and friction bearing capacity of the ant, allowing it to cancel inertial forces.

We further investigate this by looking at a few additional aspects of the ant locomotion. First, we observe the no-slip quality of the ant locomotion, seen in the left part of Figure 2. Assuming a tripod gait, we can deduce a kinematic relationship from body angles to pose of the ant. While a tripod is in stance, a Jacobian like quantity governs the relationship between shape velocities and body velocities, resulting in an instantaneously Stokesian model of locomotion. Next, we see a distribution of body velocity changes from cycle to cycle in the right part of Figure 2. The ants' ability to speed up and slow down over the course of just a cycle supports the suggestion that ants have the control authority to cancel inertial influence.

Finally, we used the methods of [3] to build a data driven Stokesian model by training it on the third quartile of speed and middle tertile of turning behavioral data. We compare the predictive quality of this model with respect to a phase model (fits body velocity to phase) and a model that is linear in the norm of the shape velocity. We expect the latter model to me a reasonable approximation of speed variations. What we see is that the data driven Stokesian model not only surpasses this latter model in its ability to predict speed, it is the only model that provides any predictive information about turning. This tells us that when fitting ant motion to a Stokesian space of representations, the resulting model is able to predict behaviors that it has not been trained on.

In this work, we investigated the hypothesis that ant stepping, while discrete, should be included in the paradigm of Stokesian locomotion, which is typically reserved for systems experiencing continuous contacts. We found support for this hypothesis in three ways. 1) Across phase, ants modulate step frequency rather than step location to change speed. 2) Ants achieve sufficient friction that slipping is irregular, and this aids their overall ability to cancel momentum, achieving vastly different speeds over the course of a cycle. 3) Data driven stokesian models of ant behavior are strong predictors of body velocity for even unobserved behaviors.

In the future, we will investigate the broader role of Stokesian models in legged locomotion, as we have seen that these qualities translate to larger legged systems, such as the robot *bigAnt* [4].

REFERENCES

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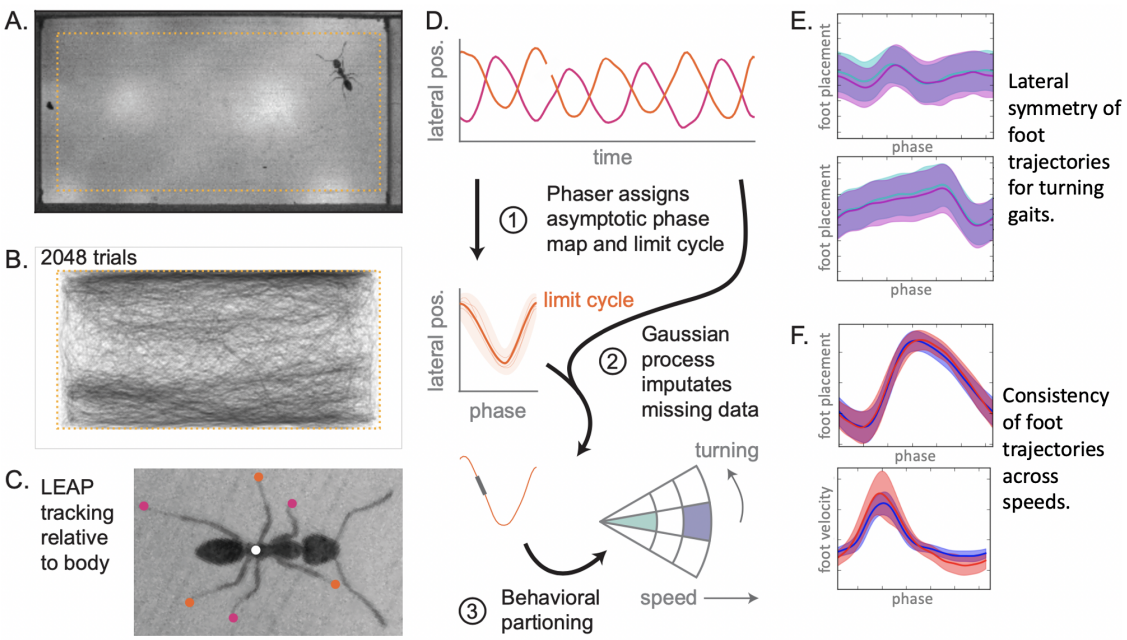


Fig. 1. In A we captured ant motions in a static motion arena and in B logged the paths traced by the ants, including points on the body (white) as well as the locations of their feet (red). A deep learning algorithm was used to detect these points, missing the locations of feet in some frames, as seen in D1. We used a Gaussian process regression to impute the missing foot data with a phase based kernel in D2 and partitioned the data into various behavioral categories of speed and turning rate in D3. E demonstrates that the mid-limbs of the ants undergo fairly symmetric operations when turning left (pink) versus turning right (cyan). The top figure shows the left mid-limb behavior when turning left versus the right mid-limb turning right. The right mid-limb is phase shifted half a cycle and flipped over the sagital plane of the ant. The bottom graph in E demonstrates the same relationship, but for the left mid-limb turning right and right mid-limb turning left. In F, we show that the midlimb traces a similar path in shape space at fast (red) and slow (blue) speeds, while passing through these speeds at a fast rate.

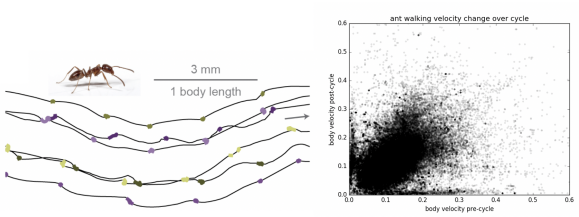


Fig. 2. Ant feet do not slip very often, as shown by the foot steps on the left. The foot step data on the left shows that while the feet are on the ground, (non-black, colored trajectories), they do not slip noticeably. On the right, we see the change in forward velocity that can occur for the ants between the beginning and end of a cycle.

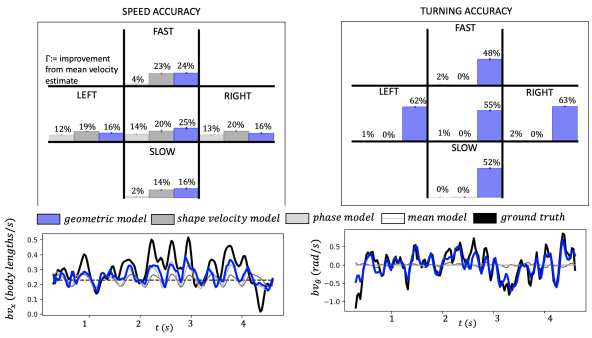


Fig. 3. A data driven Stokesian model [3] trained on the third quartile of speed and middle tertile of turning rate was used to predict motions when speeding up or down (left) and turning right or left (right). Below, we see that the data driven Stokesian model (blue) tracks the ant motion with higher predictive accuracy than the other models.