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► **To cite this version:**

Jordan Drapin, Santiago Arroyave-Tobón, Jean-Marc Linares, Vincent Fourcassié, Pierre Moretto. 3D kinematic of the leg joints at the ant scale. *Computer Methods in Biomechanics and Biomedical Engineering*, 2021, 46th CONGRESS OF THE SOCIÉTÉ DE BIOMÉCANIQUE, 24 (sup1), pp.S61-S62. 10.1080/10255842.2021.1978758 . hal-04551112

HAL Id: hal-04551112

<https://hal.science/hal-04551112>

Submitted on 18 Apr 2024

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3D kinematic of the leg joints at the ant scale

J. Drapin^a, S. Arroyave-Tobon^b, J-M. Linares^b, V. Fourcassie^a and P. Moretto^a

^aCentre de Recherches sur la Cognition Animale (CRCA)- Centre de Biologie Intégrative (CBI) 169, avenue Marianne Grunberg-Manago-CNRS – Université Toulouse Toulouse cedex 09, France; ^bAix Marseille Univ, CNRS, ISM, Marseille, France

1. Introduction

Insect locomotion is inspiring robotics because it seems stable whatever the support type. The alternating tripod gait of these multi-legged hexapod invertebrates require ability and stability (Vincent and Wegst 2004, Taylor and Dirks 2012). Recent studies showed however that this tripod coordination of the ant gait is sensitive to the load carried (Merienne et al. 2019). However, analyzing ant gait is challenging due to its scale and current works are often reduced to the stepping pattern that consider only the metatarsal joint locations (Reinhardt and Reinhard 2014). To overcome this limitation, the aim of this study is to perform kinematic analysis of leg segments of a seed-harvesting ant *Messor barbarus*. We developed with Vicon Motus® a setup including a high-speed imaging that allows the 3D tracking and quantification of gait parameters in freely walking ants with high temporal and spatial resolution. Using this method, we present a first quantification of the angle range and evolution along a gait cycle.

2. Methods

2.1. Setup

The setup has been designed and built by a private company (RD Vision, France). It includes a walkway (20x5cm) surrounded by five high-speed synchronized video cameras sampled at 300 Hz (Figure 1a). Three infrared strobe spots, synchronized with the cameras, were used to illuminate the walkway from above,

allowing better contrast and revealing joint and cuticle details.

2.2. Tracking system calibration

The X, Y and Z axis define the medio-lateral, antero-posterior and normal directions of the walkway, respectively. To obtain 3D coordinates from multiple 2D views Vicon Motus uses the Direct Linear Transformation (DLT) method (Abdel-Aziz and Karara 2015). A control object (Lego® brick) of known dimensions was digitalized to calibrate a 30x15x15 mm³ tracking volume.

On average on the different lengths of the Lego brick, the calibration error in the X, Y and Z directions were 2.67%, 4.87% and 3.13% respectively.

2.3. Spatial model

A set of 47 points of interest allowed digitizing the ant joints and determining 40 segments used to define a 3D stick model of the whole ant body.

2.4. Tracking and coordinates

The semi-automatic tracking algorithm finds the outline of the pattern based on the intensity threshold of the initial pixels. The algorithm averages the pixel values in X, then averages the pixel values in Y that make up a pattern. It then records the final centroid of the point then calculates the position at the next time step by comparing step by step.

If the algorithm does not find a specified pattern, it stops automatically and a new initial position of the point of interest allows it to be restarted. The procedure to obtain the 3D coordinates is illustrated in Figure 1. The tracking, the filtering (butterworth 4th order) and the computation of the 3D coordinates of the different points were performed using Vicon Peak Motus Software (V10). One video recording of a medium ant walking forward along the Y axis has been retained for the analysis. A total of 370 images per camera were required to obtain two gait cycles.

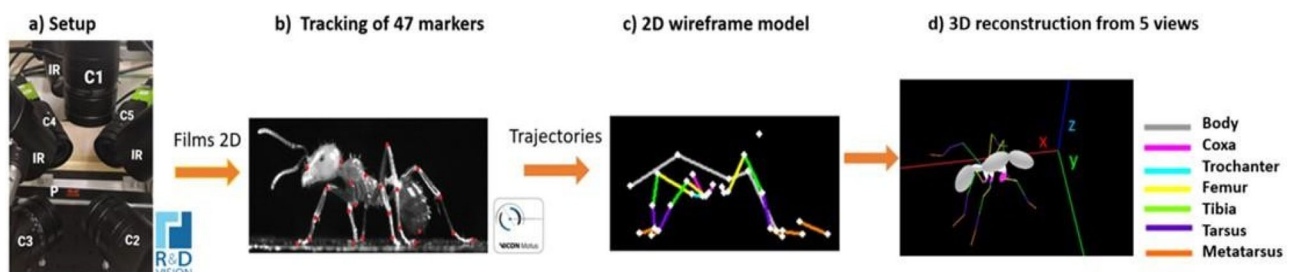


Figure 1. Visualization of the spatial model. (a) Experimental setup: 3 infrared strobe spots (IR), a walkway (P) and 5 synchronized cameras (C). (b) Anatomic points locations. (c) 2D stick diagram from camera 2. (d) 3D reconstruction.

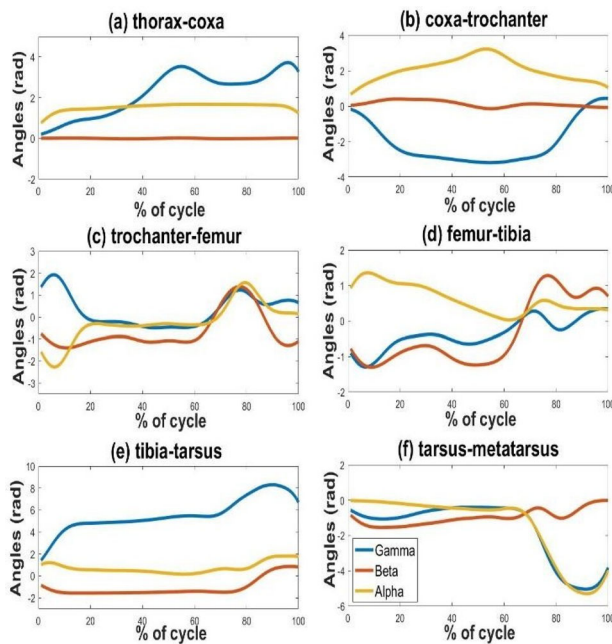


Figure 2. 3D Joint angles (rad) to percentage of the gait cycle of the left medial leg: (a) thorax-coxa, (b) coxa-trochanter; (c) trochanter-femur; (d) femur-tibia; (e) tibia-tarsus; (f) tarsus-metatarsus. Alpha, Beta and Gamma represent the internal(>0)-external(<0) rotations, the flexion(>0)-extension(<0) and the adduction(>0)-abduction(<0), respectively.

One cycle is defined as the time elapsed between two consecutive ground contacts of the right median metatarsus. All the points of the model were semi-automatically tracked (Figure 1) in each image of each camera views using the Vicon Peak Motus Software or manually. The 3D coordinates of the 47 points are then exported in a C3D file.

2.5. Body segment angles

The three Cardan-Euler angles of the segments were calculated using Matlab (V 9.2) following the ZYX rotation sequence to then define the angles at the joints of the left medial ant leg (Figure 2) according to the ant referential.

3. Results and discussion

The external-internal rotations cannot be quantified here because the segment is defined by only two points. The angles values close to zero reveal this limit. The flexion-extension and abduction-adduction measures are in good accordance with the type of joints (rotula and pivot) we suspected regarding the

joint shape observed on μ CT Scans. The ongoing inverse kinematics investigations may optimise the mark position to respect the segment size and determine the joint angles more precisely. A third mark per segment could also precise the rotation range at some joints (rotula) that could enable us to approximate the degrees of freedom and the joint functional limits.

4. Conclusions

The purpose of this study was to develop and validate a setup allowing 3D kinematic analysis of the whole ant segments. The results enable us to precise the joint degrees of freedom and amplitude. The setup appears valuable to study the kinematic at ant scale to address ecological and ethological questions so as to feed biomimetic applications in hexapod robotics.

Acknowledgements

This work has been supported by the CNRS AO MITI Biomim. The authors report no conflicts of interest in this work.

Disclosure statement

No potential conflict of interest was reported by the authors.

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KEYWORDS Ants; biomechanics; locomotor patterns; exoskeleton; modelization

✉ pierre.moretto@univ-tlse3.fr