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3D Trajectories of Multiple Untagged Flying Insects from Millimetre-wave Beamscanning Radar

Alexandre Dore¹, Dominique Henry², Hervé Aubert³

Laboratory for Analysis and Architecture of Systems
(LAAS-CNRS)

Toulouse, France

{¹adore, ²dhenry, ³aubert³}@laas.fr

Mathieu Lihoreau⁴

Research Center on Animal Recognition (CRCA), Center
of Integrative Biology (CBI)

Toulouse, France

mathieu.lihoreau@univ-tlse3.fr

Abstract— We report the tracking of untagged flying insects using a millimetre-wave Frequency-Modulated Continuous-Wave radar. Flight trajectories were derived with a Multiple Input Multiple Output radar front-end and a mechanical beamscanning. In contrast to existing approaches, such as the harmonic radar, our novel method does not require a transponder or tag on the insects, provides three-dimensional flight trajectories, and enables to track multiple individuals simultaneously. For illustration purpose, we reconstructed the 3D flight trajectories of two untagged bumblebees flying in a dedicated big outside tent.

Keywords— flight trajectory, MIMO radar, millimetre-wave, beamscanning, bumblebee.

I. INTRODUCTION

Recording the trajectories of flying insects (e.g. bees, hornets, butterflies) in the field is a well-known ethological challenge (see, e.g., [1]) due to the small size and fast movement speed of the insects. Current approaches require to equip insects with transponders [2] and are limited to tracking the 2D trajectory of a single individual at a time (e.g., [3]). For instance, harmonic radars have been used to track flying insects at distance up to 900 m, but this technique involves attaching a large vertical antenna on the insect back (16 mm, 3 mg), has a relatively low temporal resolution (1 measurement every 3 s), and operates with high microwave transmitted power of few tens of kW [4]. Radio telemetry functions over shorter distances (500 m), with a larger a radiofrequency tag (12 mm, 20 mg [2]), and also uses low frame rate (1 measurement per second for the best case) [5]. While these approaches have brought valuable insights into the behavioural and ecology of insects (e.g. [6]), knowledge about their 3D navigation and competitive interactions is still very poor. In addition, tagging insects is an invasive manipulation may importantly impact their behavioural.

Here, we introduce a new technique for the derivation of the 3D trajectories of multiple untagged insects, using a millimetre-wave Frequency-Modulated Continuous-Wave (FMCW) Multiple Input Multiple Output (MIMO) radar. This method uses a mechanical beamscanning of the 3D scene for determining the elevation angle of insects, while the 2D MUSIC algorithm is applied for estimating the azimuth angle and radar-to-insect distance.

II. MILLIMETRE-WAVE BEAMSCANNING MIMO RADAR FOR THE TRACKING OF SMALL-SIZED PASSIVE SCATTERERS

We chose a radar operating in the millimetre-wave frequency range ($f_c > 30$ GHz or equivalently, wavelength $\lambda_c < 1$ cm) to detect targets of about one centimetre long. Millimetre-waves enable to design radar with large bandwidth B and thus, high distance resolution, while using small transmitting (Tx) and receiving (Rx) antennas. We used the RBK_8 MIMO radar from *INRAS GmbH* [7] operating at $f_c = 77.5$ GHz ($\lambda_c = 3.9$ mm) for the proof of concept. The digital beamforming in the azimuth plane was achieved from 4 Tx-antenna arrays of (2x6) metallic patches (gain of 17.2 dBi, beamwidth θ_E in elevation plane of 13.2° and beamwidth θ_A in azimuthal plane of 51°) and 8 Rx-antenna arrays of (1x6) metallic patches (gain of 15.8 dBi). We added a large rotating metallic plate reflector (19 cm x 20 cm) in front of the radar antennas for mechanically steering the main beam (Figure 1). The distance between the rotation axis of the reflector and the radar patch antennas was set to 15 cm. For rotation speed of 500 revolutions per minute and for one radar measurement every millisecond, the azimuth and range of targets can be performed in 60 different azimuth planes per revolution or equivalently, from 1000 two-dimensional radar images per second. The resulting 3D frame rate was of 16 frames per second. This frame rate was found to be sufficient for tracking multiple flying insects, whose speed may reach 5 m/s [4].

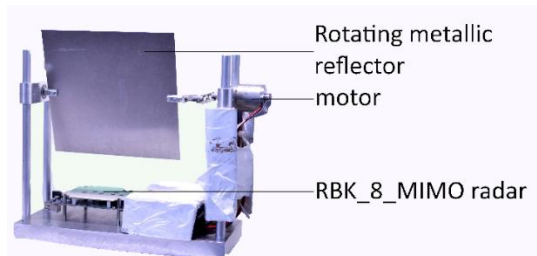


Figure 1: The beamscanning FMCW MIMO radar operating at 77.5 GHz used to track the 3D trajectories of untagged flying insects.

We applied the MUSIC-based algorithm reported in [8] to two-dimensional radar images for deriving both the range and the azimuth angle of the flying insects. The target elevation angle was estimated from the angle formed by the rotating reflector

surface and radar antenna patch surface, when the radar echo of the target reached its highest magnitude. To estimate the measurement resolution and precision of the millimetre-wave beamscanning radar, we used a metallic sphere of about 2.5 mm in radius. We derived (not shown here) that the radar cross section at 77.5 GHz (namely, -47 dBsm) of such sphere was close to that of a bumblebee worker (*Bombus terrestris*) at this frequency. The direction of arrival of electromagnetic field backscattered by the sphere was estimated for an azimuth angle ranging from -25° ($\cong -\theta_A/2$) to 25° ($\cong \theta_A/2$), and for an elevation angle ranging from 65° to 115° . The maximum detection range was up to 2 m . This range may be significantly larger with a harmonic radar, but at the expense of high transmitted power (25 KW is required for reaching about 900 m at $9 - 18\text{ GHz}$ [4]).

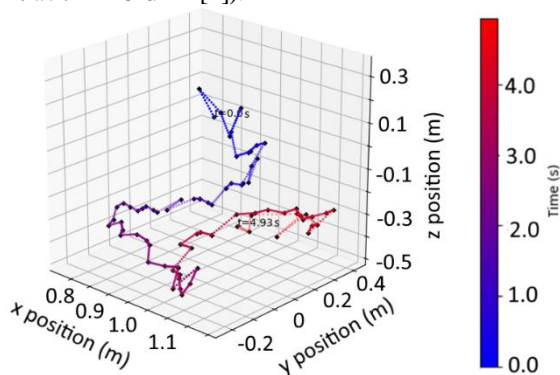


Figure 2: Estimated 3D trajectory of a small-sized (2.5 mm in radius) moving metallic sphere from the millimetre-wave beamscanning radar (the radar cross section of this sphere is close to that of a bumblebee). Black dots indicate the detected positions of the sphere. Successive positions in time are connected by a straight line, whose colour depends on time (see colour scale). The detection starts at $t = 0\text{ s}$ and ends at $t = 4.93\text{ s}$.

The obtained 3D trajectory of the metallic sphere is shown in Figure 2. The range resolution, i.e. the smallest radial distance to be distinguished from the radar data between two targets, was found to be of 15 cm by using two metallic spheres of 2.5 mm in radius. The range precision, i.e. the statistical variability (or root mean square) of measured target-to-radar distances for the same true distance, did not exceed 3 cm in the overall radar detection volume. With a metallic sphere of 2.5 mm in radius, the measurement precision for azimuth and elevation angles were found to be of 0.9° and 4° , respectively (the higher incertitude of the elevation position is due to the difference between mechanical and digital beamforming). Therefore, the measurement precision of azimuth angle was equivalent to that achieved by a harmonic radar, but the range precision was much better due to larger radar bandwidth (3 cm with FMCW radar vs 1.5 m for harmonic radar).

III. 3D TRAJECTORY OF UNTAGGED FLYING INSECTS

The millimetre-wave beamscanning FMCW MIMO radar was then used for estimating the flight trajectories of two untagged bumblebee workers (*B. terrestris*). Bumblebees were observed during their learning flights, i.e. flight patterns used by the insects to acquire visual memories of their nest surroundings upon their first departure from the colony [9]). Observations

were made in an outside flight cage ($10\text{ m} \times 20\text{ m}$) during a warm dry day with blue sky. The obtained 3D trajectories are displayed in Figure 3. In this example, the two bumblebees were far enough to connect without ambiguity their respective positions. However, if more than about 10 bumblebees are present in the scene, the extraction of individual trajectories became very challenging due to the radar range resolution of 15 cm .

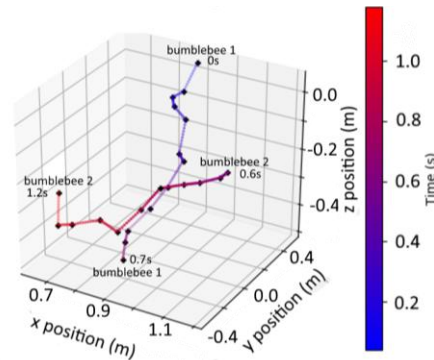


Figure 3: 3D fight trajectories of two bumblebees during 1.2 s derived from millimetre-wave beamscanning radar data. A straight line, whose colour depends on time, connects successive detected positions (every 62.5 ms) of each bumblebee (see colour scale). The detection starts at time $t = 0\text{ s}$.

IV. CONCLUSION

We report a new radar technique for determining the 3D flight trajectories of multiple untagged flying insects. Investigation are in progress to increase the detection range, determine the maximum number of detectable individual trajectories, and to accurately estimate the velocity of the flying insects. This novel application holds considerable promises for future studies of insect behavior in natural conditions, in regards to existing techniques.

REFERENCES

- [1] J. M. Mola and N. M. Williams, 'A review of methods for the study of bumble bee movement', *Apidologie*, vol. 50, no. 4, pp. 497–514, 2019.
- [2] P. J. Kennedy, et al., "Searching for nests of the invasive Asian homet (*Vespa velutina*) using radio-telemetry," *Comm.Biology*, vol. 1, Issue 1, 2018.
- [3] J.L. Woodgate, et al., "Continuous Radar Tracking Illustrates the Development of Multi-destination Routes of Bumblebees," *Scientific reports*, vol 7, Issue 1:17323, Dec. 2017.
- [4] J.R. Riley, et al., "Tracking bees with harmonic radar," *Nature* 379, pp. 29–30, Jan. 1996.
- [5] M.Hagern, et al., 'Space Use of Bumblebees (*Bombus* spp.) Revealed by Radio-Tracking'. [Online]. Available: <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0019997>
- [6] M. Lihoreau, et al., "Radar tracking and motion sensitive cameras on flowers reveal the development of pollinator multi-destination routes over large spatial scales," *PLoS Biology*, 10, e1001392, 2012.
- [7] "INRAS Products – Radarbook", [Online] Available: www.inras.at/en/products/radarbook.html
- [8] F. Belfiori, et al., "Application of 2D MUSIC algorithm to range-azimuth FMCW radar data," *European Radar Conference*, Amsterdam, The Netherlands, 29 Oct – 2 nov. 2012, pp. 242–245.
- [9] A. Philippides, et al., 'Bumblebee calligraphy: the design and control of flight motifs in the learning and return flights of *Bombus terrestris*', *Journal of Experimental Biology*, vol. 216, no. 6, pp. 1093–1104, Mar. 2013.