ECE 5555 Final Project Proposal: Vision-based Position and Velocity Estimation for Automatic Bee Tagging Application

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***Abstract*—The problem addressed in this proposal is an estimation algorithm that predicts the future position of a bee for the purpose of automatically tagging it using a robotic delta arm as they enter or leave their hive through a tube, while minimizing the impact on the bees' natural behavior and ensuring their safety. The delta robot employs a smooth motion control strategy that allows it to make small, continuous adjustments while aiming for precise tag placement. A significant penalty needs to be introduced for incorrect tag positioning to ensure the safety and well-being of the bees.**

I am proposing a vision-based approach to estimate the position and velocity of the bees in real-time using as input a camera that observes their movement through the tube. The estimation algorithm needs to account for the inherent limitations of the delta robot, such as its inability to make large corrections or instantaneous movements, and the need to maintain a safe distance from the bees for as long as possible to avoid disturbing them. The approach presented will demonstrate how this estimation algorithm can enable effective positioning of a delta robot for accurate bee tagging with minimal interference in their natural motion, in order to facilitate more effective bee research and conservation efforts.

I. INTRODUCTION

Bees are essential pollinators and play a critical role in the maintenance of ecosystems. In recent years, it has become increasingly important to study their behavior for the purpose of conservation. One method for studying bee behavior involves tagging individual bees to monitor their movement patterns, interactions, and general behaviours. Traditional tagging methods involve capturing bees using a vacuum, placing them in a freezer to temporary immobilize them, and then manually applying glue and a tag to their backs. Often, this process is carried out in the field, rather than in a controlled laboratory environment, making it even more labor-intensive. These manual methods are time-consuming, prone to human error, and may negatively impact bee welfare. To improve the efficiency, accuracy, and safety of the tagging process, there is a growing interest in and strong use case for automating this procedure using robotics.

In order to facilitate automated tagging, an experimental setup has been developed in which bees navigate through tubes when entering or exiting their hives. This controlled environment facilitates the positioning of a camera facing the bees, enabling tracking of their movements as they cross the tube and the use of a delta robot to tag them in Fig.I. The camera operates at a speed of 50 ms per frame, capturing the bees as they traverse the tube at speeds of up to 20 mm/s. The bees pass through a rectangular tube, which provides both a constrained space for observation and a means to ensure that the bees remain within the robot's workspace.

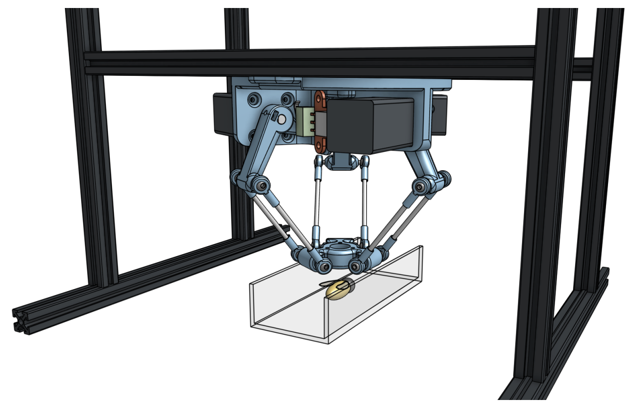

Fig. 1. Delta robot tagging mechanism

The robotic arm used for tagging is a rotary delta robot, commonly employed in pick-and-place operations. This type of robot has inherent physical limitations, derived from the maximum speed and acceleration of the stepper motors, the kinematics, its size, and effector weight. Consequently, it is essential to develop an estimation algorithm that takes these constraints into account to ensure smooth and precise tag placement. On each bee, the tag needs to be placed between the two wings so as to not interfere with the bees flight. From the size profile, this means placing it ahead of the the middle legs and behind the head. This position is slightly offset from the center of mass of the bee and will depend on the bee's size.

Automating the process of bee tagging is an area with relatively limited research. However, there are a few examples that highlight the potential of such methods. Gernat et al. created an automated system to track individual honeybee motion and interactions in real-time in [2], studying five colonies each with around 1,200 manually barcoded bees. They discovered honeybees exhibit bursty interaction patterns, with alternating

Fig. 2. Captured Frames of Bee Entering Hive

short periods of high frequency interactions and longer periods of low frequency. The system provided insights into honeybee social behavior and transmission dynamics, and demonstrate a potential use cases for automating tagging bees.

II. Proposed Models and Algorithms

The proposed algorithm for estimating the position and velocity of bees in real-time is an Extended Kalman Filter (EKF). The input of the EKF will be based on one of two approaches: the position of the center of mass of the bee or the amount of the bee visible in the x and y dimensions. The center of mass approach will employ a deep neural network (DNN), while the visibility approach will utilize contours and moments. The output of the EKF will be either the estimated bee position and velocity at a given time in the future along with a covariance value representing the confidence in the estimation.

A. Data Sets

For testing the proposed model, a dataset consisting of tens of thousands of bee frames will be used. These frames will be sorted and grouped per bee that passes in front of the camera. For each bee, I will store information that will be used in the experiments for the estimation algorithm.

For the DNN-based center of mass approach, each bee dataset will be labeled by identifying the frame that shows the entire bee, such as the bottom middle frame in Fig.II. From this frame, the center of mass of the bee with respect to the center of the image will be calculated, and the frame will be divided into 20 vertical regions. Each of these sections will be added to either the training or validation sets and matched with the center location of the bee.

For the visibility approach, each frame in the bee dataset will be labeled with the size of the bee visible thus far in the x and y dimensions. This method will provide an alternative representation of the bee's position, which can be used to compare the performance of the two estimation approaches.

B. Problem Approach

I will implement an EKF to estimate the speed and position of a bee based. The motivation for this is that the functionality needed is that of a Kalman Filter but with nonlinear systems.

In [1], the authors propose a method for modeling animal movements through a new class of random diffusion models. These models involve different states for an animal and rules for movement within those states. In the standard random diffusion model, the random fluctuations that influence the motion of particles are assumed to be Gaussian in nature. The assumption of Gaussian noise is not always valid for all physical or biological systems, but it simplifies the problem and allows for the use of statistical methods, such as the calculation of the variance and covariance of the bees' motion, to better understand the behavior of the system. This is a common assumption in many physical and biological estimations. For this problem I will assume that the random fluctuations in the speed of the bee are normally distributed and have a zero-mean.

For each camera frame, starting from when the bee enters the frame, the following steps will be repeated:

1) EKF predicts the state of the system based on the previous state
2) DNN/Visibility approaches measure their estimates of the bees center of mass/visible area
3) EKF updates the predicted state and reduces the uncertainty in the state estimate
4) Program takes the state and calculates the kinematic commands needed to move the delta robot

C. Evaluation Criteria and Experiments

The two proposed approaches will be compared in terms of computation time, required traversal distance of the delta robot, and prediction accuracy. The ultimate goal will be to find a feasible-optimal method of determining where and when the bee will be at a position early enough that the delta robot can tag it while also creating a trajectory as direct as possible to the final location.

Experiments will include simulations using varying sizes and speeds of bees and show the output trajectory, its length, and whether the bee was successfully tagged in the correct location with a reasonable downward force.

III. Expected Results

I expect that both experiments will have similar estimations due to the EKF, but that potentially the DNN input will result in a more optimal solution to this problem because with a shorter final trajectory. I am hopeful that the overall experiments will demonstrate the feasibility of this problem in real life utilizing an EKF.

References

[1] P.G. Blackwell. Random diffusion models for animal movement. *Ecological Modelling*, 100(1):87–102, 1997.

[2] Tim Gernat, Vikyath Rao, Martin Middendorf, Harry Dankowicz, Nigel Goldenfeld, and Gene Robinson. Automated monitoring of behavior reveals bursty interaction patterns and rapid spreading dynamics in honeybee social networks. *Proceedings of the National Academy of Sciences*, 115:201713568, 01 2018.