Informatics Research Proposal: Bio-Inspired Controller for Flying Drones

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April 2018

1 Introduction

In recent years, a lot of researchers have taken advantages of biological structure and generated some fantastic robotics designs, like the famous BigDog Quadruped Robot from Boston Dynamics [7] and swarm intelligence optimization algorithms introduced in [1]. Biology usually provides researchers with reasonable solutions for developing intelligent and robust robotics system as it's a truth that most creatures in the world are able to response to fast-changing environment quickly and stably. For example, many insects like bees and ants have incredible ability to return their nest straightforward even after they have been moved hundreds meters away. This kind of behaviour is known as path integration: the animal keep tracking their positions and direction during movement and have the ability to return nest expeditiously even there is no sufficient landmarks [9].

In this project, we will take advantages of a bio-inspired model, central-complex(CX) model, which is proposed by *Stone et al* [10] to control a flying drone so that it can perform similar homing behaviour as bees. The implementation of CX model is inspired by a common region in many insect's brain called Central Complex, which play an important role in navigation ([6]). This model have already been applied in a wheeled robot successfully. However, compared with the movement of Bees, a wheeled robot is less flexible (can only move in two directions) and is limited in 2 dimensions. Is is deserved to explore whether this model is still working when it comes to 3 dimensional case. The main objective of the project is ,by successfully applying the model to control a drone, we will be able to provide a novel solution for autonomous robotics navigation system as well as strong evidences of the correctness of the neuron model. In addition, if the model works well, we will further explore other applications like recording multiple food positions during foraging process.

In the following sections of this proposal, some biological background will be introduced and discussed. And then, the technical methodologies will be illustrated in details in section 3. And finally, section 5 shows the work plan using Gantt chart and discusses some possible risks for this project.

2 Background

The amazing path integration behaviour among animals, especially among insects, has already been pointed out for decades. Biologists have found that honeybee can travel away from its nest up to 10 km without losing its way [11]. What's more, Cataglyphis fortis (a king of desert ants), was found to be able keep track of their positions during foraging trip even after moving hundred meters away [5]. In recent years, some researchers have already taken the navigation ideas behind and implemented some effective algorithms for path integration. However, there's no related works implementing CX neuron model for path integration.

2.1 Path integration of Bees

Fig. 1 illustrates the 3d structure of Central complex, which is found to be internal compass for bee [10]. The protocerebral bridge (PB) contains TB1 neurons, Noduli tangential neurons (TN neurons) responded strongly to translational optic flow. lower division of the central body(CBL)

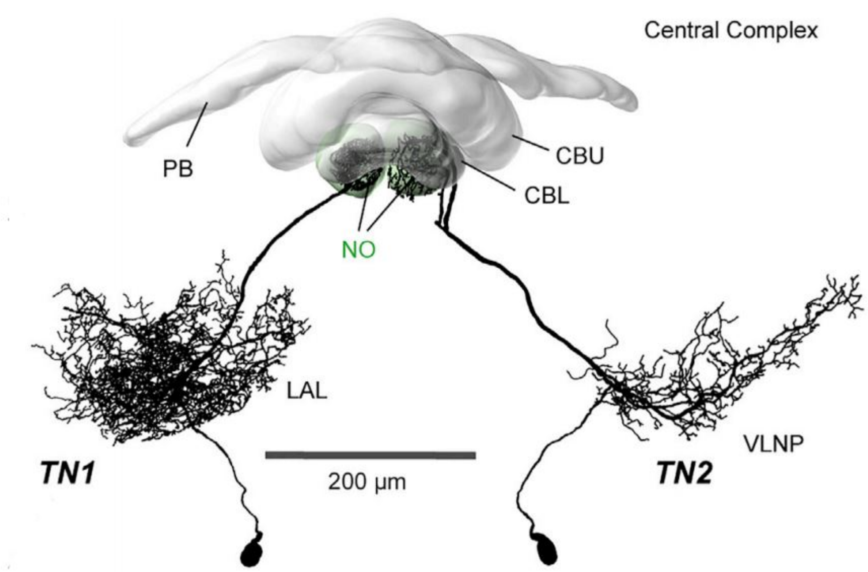


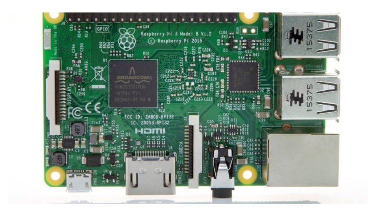
Figure 1: The 3d structure of the sweat bee *Megalopta genalis*, taken from [10].

3 Methodology

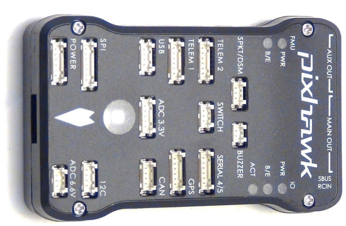
3.1 System Setup

The hardware we are going to use is a flame wheel f450 drone, a Raspberry Pi 3, a Pixhawk fight controller and the Vicon system (for motion capture). For the software, Robot Operation System (ROS), an open-source robotics control system, will be used as the control system. ROS is commonly used in robotics researches as it provides convenient and fast solutions to develop robotics system. What's more, it is developed in Linux, and provides a vibrant community which enables you to solve majority of questions quickly.

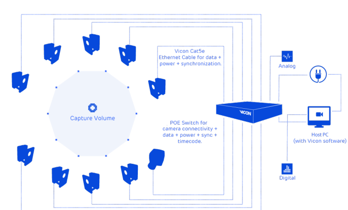
(a) f450 quadcopter.



(b) Raspberry Pi 3



(c) Pixhawk



(d) Vicon system

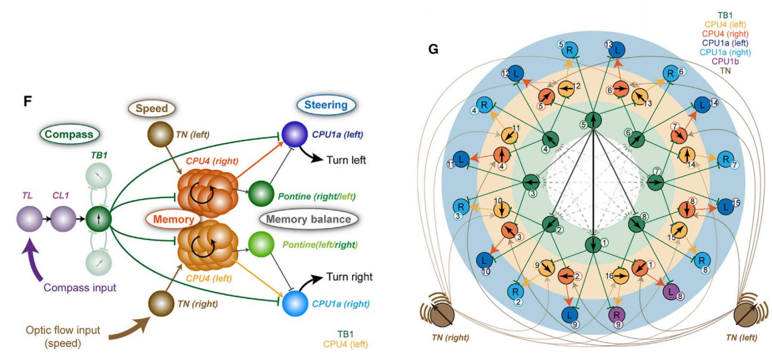
Figure 2: Hardware setup

3.2 Central-Complex Model

As introduced before, developed by [10], this model is inspired from bees' brain structure, central-complex in specification. Fig. 3 shows the graphic overview of the CX model. From the figure, we know that there are seven kinds of neurons. The TN cells are sensible to transnational optic flow, and thus responnsible for calculation speed. In this model, TN neurons take the agent's speed as input. In addition, TL (input) layers receive direction input from the agent. And as an output layer, CPU1 neurons is connected to the driving system. The layers list are shown below:

- Speed Layer 1 – TN-neurons
- Heading Layer 1 – TL-neurons
- Heading Layer 2 - CL1-neurons
- Heading Layer 3 – TB1-neurons
- Layer 4 - CPU4-neurons
- Layer 5 - Pontine neurons
- Layer 6 - CPU1-neurons

For more detailed explanation and algorithm implementation, please refer to the paper by *Stone et al* [10].



(a) Principal connections (b) Ring-like topology

Figure 3: Taken form [10], CX model

3.3 Optic Flow Computation

It has already been proven that honeybees and probably many other insects make use of optic flow to measure distances [8]. Optic flow is the pattern of apparent motion of objects, surfaces, and edges in a visual scene caused by the relative motion between an observer and a scene [3]. There many algorithms for computing optic flow, in this section, several famous and commonly-used algorithms are introduced.

The Horn-Schunck method Considering two image frame from time step t and time step t+1, we want to compute how every pixels in *I(t)* is transform into *I(t+1)* by a vector *(u,v)*. Horn-Shunck method is one of the possible algorithms for computing optic flow.

The basic concept is to minimize the error function equation below (derive form [4]):

$$E_{HS} = \sum_{(x,y)} \left(\frac{dI}{dx}\mu + \frac{dI}{dy}v + \frac{dI}{dt}\right)^2 + \lambda\left(\left(\frac{du}{dx}\right)^2 + \left(\frac{du}{dy}\right)^2 + \left(\frac{dv}{dx}\right)^2 + \left(\frac{dv}{dy}\right)^2\right) \quad (1)$$

The first component of the error function accounts for the image data which try to align the same pixels in two frames, while the second component of the function is used to improve smoothness.

The Lucas-Kanade method

$$E_{LK}(u,V) = \sum_{(x,y)} w(x,y)(I(x+u, y+v, t+1) - I(x,y,t))^2 \tag{2}$$

Lucas-Kanade combined Horn-Schunck

Horn-Schunck method is considered a global feature method as it taking the whole images into consideration while Lucas-Kanade is classified into local feature method [2].

$$E = E_{HS} + \lambda((\frac{du}{dx})^2 + (\frac{du}{dy})^2 + (\frac{dv}{dx})^2 + (\frac{dv}{dy})^2) \tag{3}$$

4 Evaluation and Outcomes

The way to evaluate this project is quiet straightforward: how close is the flying drone return to the starting position. As the position of the drone can be detected by the Vicon system, the evaluation criterion will be the distance between the staring and ending position of the flying drone. And the final result should have similar performance with that of wheeled robot experiment in theory. After we finished this project, the major outcome we will get is be a stable and novel drone controller. And if the whole process is extremely successful, some other alternative outcomes like a improved CX model for drone controller may be obtained as well.

5 Workplan and Risks Management

The detailed work plan is illustrated on the Gantt chart shown in Fig X. In the exam period from April 20th to May 20th, we will mainly focus on setting up all the hardware and software for the project.

Risks and management

- Computation capability limitation

  As introduced in section 3, Raspberry Pi 3 will be used as the 'brain' for the whole system. Considering flying drone is moving much faster than wheeled robot, we may need to increase the frames taken per seconds as most of the optic flow computation algorithm assume that 2 continuous frames should have small differences. Under this consideration, the computation capacity of Raspberry Pi may be insufficient. One possible solution for this issue can be using off-board computer to replace raspberry pi. Another solution can be limiting the moving speed of drone, so that we can take fewer frames in same period of time.

- Resulting in poor performance

  This problem can be caused by multiple issues, like computation capability limitation, limited camera horizon, noisy input data and so on. Actually, under my consideration, this issue will definitely exists during the experiment process. The solution can be really different depends on the detailed situation. So, we only discuss the worst situation here. If the performance is still far from satisfaction, the first thing we can do is implement a simple PI method as what *Lucas Scimeca* did in previous project. That will act as a benchmark to judge whether the CX model is getting reasonable results when only existing hardware is available. The last thing we may try is generating fake sensor data using Vicon system to get noisy-free input and see if we get better result.

- Hardware hazards

  Controlling flying drones could be dangerous sometimes especially when we are examining new control system. To avoid destroying the whole drone or even getting injury, some safe process should be done. For example, program the drone so that the drone can be shut down immediately by pressing a button.

Figure 4: Work plan

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