

## 論文の内容の要旨

### 論文題目

Three-dimensional Odour Source Localisation: Tracking and Biosensing Algorithms for UAVs (三次元匂い源探索：無人航空機のための探索と生体を用いた匂いセンシングアルゴリズムの開発)

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This research aims to introduce methods for enhancing odour tracking performance, including the study of tracking algorithms and biosensors. Odour sensing is an extraordinary ability for living creatures. Animals, including insects, can utilise this for finding water, exploring foods and localising mates. By utilising olfactory information, a gas-sensing robot can realise odour source localisation just like an animal. The technique can be applied and employed in various circumstances, such as monitoring air conditions, finding earthquake victims underground and exploring an unknown planet. Furthermore, a drug-sniffing robot can replace sniffer dogs and not only free them from labour works but also save the long grooming time.

Although the mechanism of animal odour sensing cannot be explained well, gas sensors have already been developed for monitoring systems. Nevertheless, this kind of robots cannot compete with living creatures currently due to the slow reaction in this field, which may be caused by underpowered sensing and tracking abilities. To improve the efficiency of the robot, the thesis introduces utilising a flying robot as a platform for overcoming the limitation of terrains, which enable it to complete searching tasks with a faster speed. Nevertheless, it also increases the complexity since an additional dimension needs to be considered. Furthermore, due to the limited payload and battery life, a UAV cannot carry many sensors as a land robot. Thus, how to take advantages of limited information is a challenge.

The thesis starts with introducing two common two-dimension (2-D) flying strategies, the gas

distribution mapping (GDM) and the zigzag (bio-inspired). Since these methods are designed for realising planar searching, they can be applied to not only land robots but also flying robots. The former method is frequently utilised after the gas spreads and stabilises in the environment. On the other hand, the later can be employed anytime but requires an airflow for implementing upwind searching to relocate a lost pheromone plume.

In a GDM approach, a robot will scan a specific target area for acquiring odour concentrations. After finish the process, the data can be utilised to generate an odour distribution map so that the robot can estimate the location of the odour source by pointing out the highest concentration point. However, the distribution maps may be changed by a flying vehicle due to strong airflows created by propellers. Additionally, the final result can be changed if a different flying direction was chosen. The thesis points out the blemish of this method and demonstrates a novel flying pattern which minimises the phenomenon effectively.

The zigzag, a reactive plume tracking method which can be seen on insects very often, can localise the source by following an odour plume. By using this method, a robot will turn at a specific angle to the direction of the wind and moves forward until it lost the odour. Previous studies have shown that with a greater angle, the success rate can be increased. However, this also leads to long tracking time. To shorten the process, the thesis introduces the idea of binary search to alter the upwind angle during searching. According to the result, though the accuracy is slightly lower than the original strategy, it can cut the tracking progress in half.

Furthermore, the thesis reveals one critical factor in 3-D tracking by studying three different insect flying patterns. From the experimental results, it is found that the importance of vertical movement is higher than the lateral one. By utilising this, a unique 3-D tracking algorithm, the Vertical-Horizontal Approaching (V-H Approaching) was built. Since 3-D tracking is a complex task, the thesis turns it into a two-two-dimensional problem so that previous 2-D algorithms can be applied to 3-D space. Unlike previous studies, it does not directly utilise 3-D olfactory information but focusing on one single plane at a time. By switching between two planar workspaces, the complexity of tracking task can be reduced.

Another critical issue for tracking an odour plume is the reaction speed. Although metal oxide gas sensors are easy to get and can be applied to a mobile robot without any specific expertise, the temporal resolution is too low, which cannot settle provisional changing olfactory information. On the other hand, an insect antenna can resolve odour pulses 20 times faster than an artificial sensor. Therefore, instead of utilising a conventional sensor, the thesis purposes employing an insect antenna as a biosensor for boosting sensitivity and response time.

The mechanism of EAG, a unique technique for measuring the potential of an insect antenna, has not been fully revealed. Although previous studies have purposed two types of electrical models for an antenna, it cannot explain why the potential changes when a stimulus occurs. Hence, after measuring the impedance of an antenna of silk moth (*Bombyx mori*) under different frequencies, the thesis introduces a new model that can reveal the mystery behind. The study provides a clue for not only improving the measurement method but also benefiting the research of olfactory biosensors in the future.

Previous studies show the application of EAG on a mobile robot. However, this has not been applied to flying robots yet. Due to the low tolerance of EAG, it cannot be utilised under noisy environment. The wind created by propellers of a UAV makes the odour-evoked response cannot be recognised by a robot. To overcome enhance its signal-to-ratio (SNR), the thesis proposes a novel antenna holder for protecting it from airflow turbulence. Compared to traditional setup methods, the new design has the advantage of not only ease of use but also provides a barrier for wind protection, which makes the SNR increase significantly. Furthermore, by studying the power spectrum density (PSD) of the signal, the thesis purposes utilising low sampling rate for bypassing the high-frequency noise, which can still keep the odour-evoked responses and ignore unnecessary noise.

To recognise whether an antenna senses an odour plume, setting a fixed threshold is the simplest method. Once the sensor signal gives a higher value than the prescribed threshold, it reflects that the sensor was triggered by odourants. However, due to the drifting bias, this algorithm may cause an error when the signal is not stable. In the thesis, the first two detection algorithms for EAGs, Dropping Counter (D-Counter) and Partial Integration, are introduced. Compared to traditional methods, these two novel algorithms show higher accuracies when facing drifting DC bias.

The significance of this study is that it demonstrates innovative methods for enhancing the performance of three-dimensional odour localisation with a flying robot. It introduces several methods for boosting the efficiency of tracking and sensitivity of sensors. The results indicate that compared to traditional methods, there is a superbly stronger improvement in efficiency and accuracy.