Multiple-object Tracking and Its Application to Fly Behavior Analysis

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論 文 内 容 の 要 旨

Chapter 1 Introduction

The use of computer has been applied to many fields in our daily life. From a small scale like personal use to a larger scale like industry, computer is used to perform a specific task to make life easier and even used for the task that is beyond human ability. Using computer to process visual data that may be in form of digital image or video, computer vision comes to take action and makes the thing possible. Multiple-object tracking is one of the most important tasks in computer vision and dealing with multiple objects that present in a scene is the main focus in this study. Computer vision techniques used in multi-object tracking are simply sequential uses of single object tracking. In single object tracking, variety of algorithms are used such as SIFT (Scale Invariant Feature Transform), HOG (Histogram of Oriented Gradients), Lucas-Kanade, and ESM (Efficient Second-order Minimization). Human tracking is one of the most popular research that have been done by many researchers. In a scene of many people, each person is tracked by using features e.g. color and shape. However, tracking with multiple-object that have few features is more challenging since the algorithms used for human tracking cannot be used in this task. Tracking of *Drosophila Melanogaster*, a popular model organism known as fruit fly, is considered to be the task since they have the same appearance and they can perform sudden moves. We have developed fly tracking programs that can track multiple moving fly in a closed arena. Moreover, the program is used in real biological experiments to determine the average velocity of flies and to count the number of jumping flies.

Chapter 2 Control of distributed sensors

In this chapter, we focus on controlling of mobile multiple sensor nodes to collect data from a lake. The reason of choosing lake is that besides river and ocean, dynamic of lake is smaller comparing with those two resources and this simplifies the simulation. Since the sensor nodes need to use energy from the batteries attached with them, limitation of energy for mobile monitoring unit has been a problem for the monitoring system. Therefore, if the energy consumption for the sensor nodes distribution can be reduced, there will be more energy left in the limited battery that will allow the monitoring system to last longer, which result in higher monitoring system efficiency. Since there exists water flow in the lake, the idea of utilizing the flow to assist the movement of each sensor node can be the answer to the power consumption problem. In this research, a water monitoring distribution system is developed under the point of low power consumption of sensors distribution.

Lake simulation using Navier-Stoke equations is carried out. Multiple-object in term of floating monitoring sensor nodes with linear motion model are distributed throughout the simulated lake with different controllers. The linear motion model in this chapter is used in multiple fly tracking in chapter 4 later. A controller introduced in this chapter was created by applying a forced damped harmonic oscillator to errors of centroid and variance of the object group. The controller can provide group distribution with low energy consumption compared with a method using simple position-velocity control. The distributions are performed in both uniform constant water flow field and complex steady flow field. Less energy consumption makes the lake monitoring sensors system be able to achieve long time monitoring of water resource. The lower in energy consumption for the monitoring sensors distribution saves the amount of limited energy inside the battery attached to each sensor node. Therefore, with low energy consumption, the monitoring system operating time will last longer and the system efficiency will be increased.

Chapter 3 Pair-wise assignment of identity

Drosophila Melanogaster, generally known as common fruit fly, is an important model organism in neurobiology. With *Drosophila*, many sophisticated genetic methods can be used to manipulate the activity of specific neurons in a targeted manner. This allows powerful experiments that examine the structure and function of the nervous system at the resolution of single neurons.

Machine vision systems have been worked for locomotion analysis of insects, such as bees, houseflies, and ants. This work uses machine vision system on *Drosophila*. In order to understand behavior of *Drosophila*, one of the important information that need to be measured is their movement. To make an observation of their movement in a controlled environment, a high performance measuring system is required. For a single fly, it is quite simple to observe its movement but it is not possible to provide some movement patterns that are related to interactive behavior among a group of multiple flies. Instead of a single fly, generally a group of fruit flies are studied together in an experiment. The reason for studying a group of flies is that it provides some behaviors of interaction between flies that cannot be seen from observing only a single fly, such as touching and chasing. Observing multiple flies concurrently makes it difficult and challenging to track each fly using human eyes and even by using computer vision system since their appearance are similar. This work introduces a system for detecting and tracking in order to solve the problem of multiple flies tracking. The captured video of flies is used for fly tracking and posture estimation.

In detection step, a region can be a noise, a singly fly, or merging of multiple flies. The program can distinguish these classes by calculating a likelihood of the region based on the bounding box's diagonal length and ellipse eccentricity. The merging of flies can be split by varying the threshold applies to the region. In tracking step, the program searches for the nearest position of each fly in the next frame to be the next position of the fly. The program can provide position and velocity of each fly in a pair of two frames. In addition, it was used in a sweet taste neurons block in water-sugar arena experiment.

Chapter 4 Assignment of identity using head direction and moving prediction

The fly tracking program in chapter 3 is improved. This study introduces an approach to tackle identity swapping in a crossover scenario. It determines the heading direction by wing detection process, besides the detection of each fly's position. Wing position can be located by the fact that in the fly arena, the wings are brighter than the body and darker than the background. After wing position is obtained, the heading direction of the fly can be determined. Using both position and heading direction information together with a combination of two assignment methods, nearest neighbor search and Predict-Matching, the program can give a successful tracking result in the situation that has active or jumping flies. The improved fly tracking provides more information for the output, consistent identities throughout the video, and the processing time is also faster than the previous program.

Chapter 5 Behavior analysis of fruit fly

In this chapter, behavior analysis of fruit fly is discussed. The output data from improved fly tracking program from chapter 4 is used to classify simple behavior of fly such as stopping, walking, and jumping. All 1,184 frames of Video 1 in chapter 4 were chosen to be analyzed. Velocity in x and y direction are used as features to the random forest. Few frames were chosen to be the training data and this was done manually by the user. To show the efficiency of data provided by the tracking program, manual tracking and classification performed by human is used as a ground truth to compare with random forest classification of tracked data by the program. The random forest classification is one of the classifying techniques in machine learning tasks. The method consists of a number of decision trees that are constructed based on random data from a set of the training data. As a result, random forest together with data from the tracking program can classify simple behavior of fly like human do in the case of perfect identity assigned fly.

Chapter 6 Conclusions

According to the need of locomotion analysis for small model organism such as *Drosophila Melanogaster* or fruit fly, a machine vision system that can process data in form of video file and give correct tracking data is considered. In order to have a successful fly tracking program, many techniques such as fly detection, merging blob splitting, wing detection, identity assignment, and prediction of motion are the requirement of the program. In this work, a fly tracking system is introduced and discussed as multiple-object tracking problem with indistinguishable features. In addition, a system of controlling multiple lake monitoring sensor nodes is also discussed as multiple-object problem with distinguishable features. All the simulation methods are provided in each chapter and the tracking techniques of the fly tracking system are mentioned. The future works would be an improvement of the tracking program with ability to precisely detect fly's wings position. Furthermore, more complex behavior such as grooming will be the next task. By having precise wing position, better fly tracking system can be obtained and the complex behavior of a fly can be analyzed.

論文審査結果の要旨

データ科学の進展にともない, 生物行動の解析のために大量の個体を個別に追跡することが求められている。ショウジョウバエは遺伝子操作技術が確立されており, 遺伝子の違いによる行動変異を定量的に解析するのに適した生物である。見かけにおける違いがほとんどないため, 従来は自動追跡のために特殊なアリーナを用いたりショウジョウバエの羽根を切り落としたりして運動を制限していた。本論文は，運動を制限せずに多数のショウジョウバエを個別追跡する手訟を提案するものであり，個体のすれ違いや重畳，他個体との衝突による急な後退や飛行などが起こっても個体番号が入れ替わらない手法の開発を目指したものであり，全編 6 章からなる。

第 1 章は緒論であり，本研究の背景及び目的を述べている。

第 2 章は流れ場における複数センサの制御について述べている。湖中に浮かんだ分散型センサの軌道制御について研究しており，複数個体からなる群の統計処理の基礎となるものである。

第 3 章はショウジョウバエの速度推定プログラムについて述べている。糖活性化ニューロンブロックを施したショウジョウバエの水と砂糖の二つの領域内における実験において，このトラッキングプログラムが出力する水平速度および角速度による統計処理により，ニューロンブロックによる行動変異が定量的に解析されている。これは重要な成果である。

第 4 章は第 3 章で提案した手法を改良し，長時間の個別追跡を実現している。ショウジョウバエのハネを検出することで複数のハエが衝突している状況や交差している状況に対応する手法を開発している。さらに，前章のプログラムと比べて飛躍的に高速化されている。これは行動解析のために重要な成果である。

第 5 章は機械学習によるショウジョウバエの行動分類について述べている。人が数匹のハエの行動を分類した結果をコンピュータに学習させることによりランダムフォレストを構成し, 第 4 章のプログラムの出力をランダムフォレストに入力することで行動分類が可能となることを示している。人による網羅的な分類と同等の性能を示しており, これは有益な成果である。

第 6 章は結論である。

以上要するに本論文は, 自動追跡プログラムと機械学習分類が行動解析に有効であり, 遺伝学的行動解析においてコンピュータビジョンとビッグデータ解析が新たな生物学的知見を検出する実例を示すものであり, 情報科学およびシステム工学の発展に寄与することが少なくない。

よって, 本論文は博士（情報科学）の学位論文として合格と認める。