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# Mice and larvae tracking using a particle filter with an auto-adjustable observation model

Hemerson Pistori [a,d,*], Valguima Victoria Viana Aguiar Odakura [c], João Bosco Oliveira Monteiro [a], Wesley Nunes Gonçalves [b], Antonia Railda Roel [a], Jonathan de Andrade Silva [b], Bruno Brandoli Machado [b]

[a] Biotechnology Department, Dom Bosco Catholic University, Campo Grande, MS, Brazil
[b] São Paulo University, São Carlos, SP, Brazil
[c] Faculty of Exact Science and Technology, Federal University of Grande Dourados, Dourados, MS, Brazil
[d] Federal University of Mato Grosso do Sul, Campo Grande, MS, Brazil

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ABSTRACT

This paper proposes a novel way to combine different observation models in a particle filter framework. This, so called, auto-adjustable observation model, enhance the particle filter accuracy when the tracked objects overlap without infringing a great runtime penalty to the whole tracking system. The approach has been tested under two important real world situations related to animal behavior: mice and larvae tracking. The proposal was compared to some state-of-art approaches and the results show, under the datasets tested, that a good trade-off between accuracy and runtime can be achieved using an auto-adjustable observation model.



## 1. Introduction

Visual tracking of multiple objects is an essential task for many applications and has been successfully used in animal behavior analysis. Scientific experiments in laboratory with live animals need several hours or even days of constant observation by the researcher. The observation task for a long period of time by a human observer is a very boring and fatiguing work and most of the time the results obtained are not reliable or reproducible.

A variety of algorithms for tracking multiple objects has been proposed. Many of them are based on predictive filters, in order to achieve robustness to occlusion and real time performance. Predictive filters use a stochastic model of the tracked objects dynamics in order to propagate the state of the system, from frame to frame. The predicted state is combined with information derived from an observation model, to estimate the current state of the system (Funk, 2003).

This paper extends the work proposed in our previous work (Gonçalves et al., 2007a) with (1) an updated literature review, (2) a new set of experiments on another real-life problem (larvae tracking) and (3) an improved explanation and clarifications on the tracking approach proposed in our previous work.

The tracking approach proposed is based on particle filter augmented with an auto-adjustable observation model. This auto-adjustable observation model combines, dynamically, a connected component analysis and a $k$-means based model. In order to deal with situations where mice are in contact or under partial occlusions, the $k$-means algorithm (Har-Peled and Sadri, 2005; Malyszko and Wierzchon, 2007) is used. The $k$-means solve the problem of tracking with contact between objects, but with a relatively high processing time. Conversely, connected component analysis produces a faster tracker but can not handle situations where the objects are in contact. In order to obtain a balance between tracking precision and reduced runtime, in this paper it is proposed an observation model that can, automatically, change between $k$-means and connected component analysis. The dynamics model used in this paper is inspired in the random walk (Bartumeus et al., 2005) motion model, whose parameters have been set specifically for mice and larvae movements.

The tracker was analyzed using image shots in situations where the objects are both in contact or separated from each other. The particle filter performance was compared to that of human specialists, in the open-field experiment. This experiment proved to be an interesting way to compare tracking algorithms, as it provides ground truth data related to the objects spatial position over a observation section. Our proposal demonstrated to be correct

* Corresponding author. Address: Biotechnology Department, Dom Bosco Catholic University, 79022-040 Campo Grande, MS, Brazil. Tel.: +55 67 3312 3502; fax: +55 67 3312 3301.

*E-mail addresses:* pistori@ucdb.br (H. Pistori), valguimaodakura@ufgd.edu.br (V.V. Viana Aguiar Odakura), joaobmonteiro@gmail.com (J.B. Oliveira Monteiro), wnunesgoncalves@gmail.com (W.N. Gonçalves), arroel@ucdb.br (A.R. Roel), jonathannos@gmail.com (J. de Andrade Silva), brunobrandoli@gmail.com (B.B. Machado).

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when compared to ground truth data (collected by humans) and to be robust and efficient, when compared to other approaches (single observation model).

The paper is organized as follows. Section 2 describes the mice and larvae tracking problem. Section 3 presents related work on the application of computer vision to animal behavior identification and on particle filters. Section 4 briefly reviews particle filters and explains the auto-adjustable observation model. The experiments performed and the results of the proposed approach using the particle filter applied to mice and larvae tracking are described in the Section 5. Finally, the conclusions are presented and future works are discussed in Section 6.

## 2. Background

Computer vision has been increasingly used to automate scientific experiments in laboratory. Spink et al. (2001) describes how video-based tracking allows researchers to study the animal behavior in a reliable and consistent way for a long period of time to test new medicines on mice. The researcher is interested in how the behavior patterns change during exposure to pharmacological agents. In general, these activities are applied in large scale, using multiple doses and different animals, in order to ensure reliable statistics.

In particular, for measuring motion behavior (e.g. track length, velocity, acceleration), unusual movements that happen after long periods of inactivity and the ones that occur during many hours or days (daily behavior analysis, for example), video-based tracking is an interesting alternative to a human observer, who is unable to perform these tasks efficiently (Spink et al., 2001). In addition, automatic tracking does not suffer from fatigue or distraction and this approach eliminates the subjectivity when various observers classify the same action performed by the animal. This paper presents two different real world situations of animal behavior analysis: the mice and larvae tracking.

Tracking multiple mice is an interesting task because mice are deformable and, in some cases, indistinguishable objects. The animal behavior along these experiments may be recorded, automatically or semi-automatically, in video. During the experiment, the researcher observes the animal and records information about actions related to specific behavior of interest. Video-based tracking can aggregate automatic pattern recognition, applied to the captured images, to extract measurements from animal behavior.

Tracking multiple larvae has recently turned into a very important task for public health. In Brazil, Dengue causalities, according to the Ministry of Health, affected around 128.13 cases by 1,00,000 inhabitants. Dengue control has been limited to combating the vector using synthetic and biological insecticides. However, due to continuous use, the vector, *Aedes aegypti*, has become resistant to some chemical products. The ecological damage produced by synthetic insecticides has motivated scientific research towards finding active products of botanical origin, and a number of species have been investigated.

In order to access the efficacy of this products, bioassays are carried out as five replicates in a climate-controlled environment. Twenty third-instar larvae of *A. aegypti* are placed in a 25 ml test solution. Essays are conducted using the same number of larvae in a DMSO-distilled water solution. The larvae mortality after 24 h are recorded. Total absence of larval movement as well as dark body color and cephalic capsule are used as an indicative of death. A computer vision system is being devised to automate this process and will provide greater reliability, reproducibility and access to information not easily obtained by humans, as the precise time of death of each larva. As the larva is placed in a liquid solution, that is constantly moving due to the live larvae, the "absence of movement" can not be easily identified using simple standard computer vision techniques.

In both cases, mice and larvae, tracking multiple objects is required. Basically, tracking multiple objects consists in determining which and how many objects in the scene will be tracked and then locating each one of them in consecutive frames. This task receives a special attention in computer vision; however, it is still an open and challenging problem due to the variation in the conditions of lighting, presence of noise and potentially ambiguous conditions, such as occlusion of multiple similar objects. Some examples of applications of tracking multiple objects are tracking multiple animals to automate experiments with laboratory animals (Branson and Belongie, 2005), social insect interaction analysis (Zia Khan Balch and Dellaert, 2003; Morais et al., 2005), monitoring people for tracking players (Okuma et al., 2004), identification of 3-d human motion (Choo and Fleet, 2001).

## 3. Related work

There are many computer vision works approaching the problem of automatic animal behavior analysis and this section briefly report on some of these works. This section also presents some recent work related to the use of particle filters in tracking multiple objects in images.

### 3.1. Automatic animal identification and behavior analysis

Automation of animals identification and behavior analysis, both in controlled or in wildlife situations, is becoming a very important topic in Computer Vision. For instance, Burghardt and Campbell (2007) combined several computer vision techniques, like feature prediction trees and shape contexts in order to find and identify African penguins living in a colony. Using a new class of human psychology inspired structural descriptors, Chia et al. (2008) presented some promising results on the automatic identification of four-legged animals, including cows and horses. The identification of snakes attack behavior has been tackled, using a Hidden Markov Model framework, by Gonçalves et al. (2007b).

Haar-like features and AdaBoost classifiers, integrated with a low-level feature tracker, were used in (Burghardt and Calic, 2006) to detect and track lions on wildlife videos. Two recent works tackle the problem of insects identification and tracking using techniques based on invariant moments and concatenated histograms of local appearance features (Kumar et al., 2007; Larios et al., 2007). Other species whose automated monitoring are being pursued using computer vision techniques include fishes (Zhou and Clark, 2006; Morais et al., 2005), bears (Wawerla et al., 2009) and birds (Figueiredo et al., 2003; Tweed and Calway, 2002).

### 3.2. Particle filters

Particle filter has been extensively used in tracking multiple objects (Hue et al., 2001; Moreno-Noguer and Sanfeliu, 2005), employing visual (e.g. color, texture), geometric (e.g. contours, shape) and motion features (Moreno-Noguer and Sanfeliu, 2005; Okuma et al., 2004; Hue et al., 2001). In (Moreno-Noguer and Sanfeliu, 2005) a robust framework for tracking rigid and non-rigid objects was developed. The particle filter implementation was based on visual and geometric features. The framework was evaluated in two experiments, a book boundary tracking and a moving leave, in situations that other algorithms may fail.

Particle filter has been used to track objects in different domains. Chakravarty and Jarvis (2006) apply particle filter to track multiple persons using visual features and Vacek et al. (2007) use particle filter and lane detection to track road marking in an