Combination of Annealing Particle Filter and Belief Propagation for 3D Upper Body Tracking

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Abstract. 3D upper body tracking and modeling is a topic greatly studied by the computer vision society because it is useful in a great number of applications such as human machine interface, companion robots animation or human activity analysis. However there is a challenging problem: the complexity of usual tracking algorithms, that exponentially increases with the dimension of the state vector, becomes too difficult to handle. To tackle this problem, we propose an approach that combines several annealing particle filters defined independently for each limb and belief propagation method to add geometrical constraints between individual filters. Experimental results on a real human gestures sequence will show that this combined approach leads to reliable results.

Keywords: Body tracking, particle filter, belief propagation.

1 Introduction

In the last years, the interaction between man and machines has become an important research topic, as it can generalize the use of robots from conventional robotics aspects to companion machines which interact with humans. The development of a robot companion poses several important challenges because the dynamics of the interactions with humans imply that a robot companion would have to exhibit cognitive capacities. Moreover, the communication between a human and an assistant robot must be as natural as possible. It is an evident fact that gestures are an important part of natural means that humans employ to communicate, especially when speech-based communication is not possible [1] or has to be completed by gesture (designating objects or locations for instance). So, one of the basic task of human-robot interaction deals with an accurate detection and real-time tracking of human body parts.

The previous problem can be stated as tracking articulated motion in images. This involves the localization and identification of a set of linked and articulated subparts in a three-dimensional space. Along with the difficulties of single object tracking, some additional problems appear for the tracking of articulated body due to the sizeable degrees of freedom of the target. In fact, a realistic articulated model of the human body is usually composed by at least 20 DoF, and as computational costs

M. Xie et al. (Eds.): ICIRA 2009, LNAI 5928, pp. 824–833, 2009.

increase exponentially with the number of DoF, the exploration of the configuration space has to be optimized.

One way to solve the tracking problem is to use a probabilistic approach. Indeed, the motion analysis can be expressed as a Bayesian inference problem, and as the body parts are dependant the probability of a given configuration is conditioned by the upper body topology. Among known Bayesian solvers, one is well adapted for our problem, namely the particle filter. The strategies supported by this method allow the representation of the posterior distribution by a set of samples (or particles) with associated weights [2]. This set is updated over time taking into account the measurements (image features in our case), a prior knowledge on the system dynamics, and observation models. Unfortunately, it is well known that

1 – the number of particles required raises exponentially with the dimensionality of the configuration space.

2 – to have an accurate and plausible solution, we need a maximum of particles.

To avoid these antagonist requirements, we considered different developed methods that have been investigated with the aim to reduce the particles number. Some techniques proposed the Annealed Particle Filter (APF), which performs a coarse-to-fine layered search [3]. This modified particle filter uses a continuation principle based on annealing, to introduce the influence of narrow peaks in the fitness function, gradually. This allows to reduce by a factor of 10 the number of particles and, as a consequence, to significantly decrease computation times.

To adapt the previous approach to our problem, we represent 3D human body as a graphical model, where individual limbs are characterized by nodes and relationships between body parts are represented by edges connecting nodes and encoded by conditional probability distributions. Additional edges can also be introduced to manage partial or fully occlusions. This graphical model allows to track each subpart individually, and then to add constraints between adjacent limbs. By doing so, it was possible for us to add the Belief Propagation (BP) inference algorithm [4-9]. In this way, the initial high dimensionality problem is expressed as several problems of lower dimension, and thus the complexity of the search task is linear rather than exponential according to the number of body parts.

This article presents the development of a markerless human motion capture system that works with a standard camera coupled with a PC and does not require additional equipments. The system is based on a 3D articulated upper human body model and combines the advantages of above mentioned approaches to decrease the algorithm complexity induced by the high dimensionality of the problem. Rather than track the whole articulated body, each limb is tracked independently thanks to several particles filters (one for each limb); then, a BP method on factor graphs is used to estimate the current marginal of each limb according to geometrical constraints between limbs. Indeed, since belief propagation messages are represented as sums of weighted samples, the belief of each limb is approximated by a collection of samples. So, the association of belief propagation and particles filters algorithms is quite natural. Rather than a simple particle filter, we propose to use the annealing particle filter in this context. This combination of APF and BP allows to decrease the number of particles required per limb (and thus computation times) without modifying the quality of results.