ERCIM "Alain Bensoussan" Fellowship Scientific report

Fellow: Jérôme Lapuyade-Lahorgue
Visited Location: DIKU/DANAIM, University of Copenhagen, Denmark
Duration of visit: 15/12/2008 - 15/09/2009

I - Scientific activity

During my fellowship, I was incorporated into the image group on the "Human Motion Imitation" (HUMIM) project. This project consists in proposing a human motion model implying different mathematical techniques. Consequently, this project implies different skills in computer science, human physiology, mechanics and physics, optimisation's problems, differential geometry and statistics, and requires a deep team effort. Among the different methods used in the human motion modeling, one can quote "inverse kinematics", "particle filters tracking and statistical learning" and "manifolds learning".

Inverse kinematics is the problem of estimating the position of joints of the human body from the pose of the end-effectors. End-effectors are the ending of the kinematic chains, so end-effectors can be, for instance, the hands and the feet. Inverse kinematics differ from forward kinematics which gives the position of each joint relative to the position of the corresponding parent joint, and for which we compute exactly the position of the end-effectors. In the inverse kinematics, the position of joints are estimated from the position of end-effectors, but the problem being in general ill-posed, the solution is not unique. Despite of this diffficulty, inverse kinematics were a revolution in computer graphic science. Indeed, for instance, in computer animation, using forward kinematics, we move all joints to get a new pose; with inverse kinematics, the new pose is estimated from the new position of each end-effector, and so it is enough to move only the end-effectors. Regarding the ill-posed character of inverse kinematics, it can be solved by adding prior knowledge about human configurations.

In the HUMIM project, we are particularly interested in the tracking of human motion and as a future application: physiotherapeutic reeducation. A tracking of motion consists in recognizing automatically a motion from a video. To achieve this, we have to give the relation between the motion that we aim to estimate (hidden states) and the observed video. This relation is a probabilistic relation represented mathematically by $p(I|s)$, where s is the hidden state that we want to estimate (representing the motion's parameter in our case) and I is the observation (the video sequence). As in the case of inverse kinematics, such a problem is an ill-posed problem. To solve it, we consider a prior knowledge on the hidden state represented by a probability model $p(s)$ called "prior distribution". Finally, the hidden states are estimated from the posterior distribution given by the Bayes' formula $p(s|I) = \frac{p(s)p(s|I)}{p(I)}$ and using an appropriate estimator. The estimator is choosen according to the desired loss in the estimation. Such a method is called "Bayesian inference". The difficulties behind this method is the difficulty of computing exactly the posterior distribution; consequently we approximate it using particle filters.

Regarding the manifolds learning, it is a method to learn the subspace for which the data belongs. Indeed, the coordinates of the human body don't evolve in time on a linear space, consequently one cannot model it by linear relation. Manifolds are extension of linear spaces, one can view a manifold as a deformed linear space. For example, the sphere S^2 is a two dimensional manifold as it is locally the deformation of a plane. The manifolds learning can be thought of a pre-treatment of our tracker. Once the manifold is known, one can propose an adapted prior distribution.

My main contribution in this project was to propose more realistic prior models $p(s)$. Firstly, I contributed to implement a classical tracker for which the hidden process $s = (s_t)$, s_t representing the pose at time t, is a Markov chain. In this first work, we estimate only the position of end-effectors and the full pose is then computed using inverse kinematics. It is a improvement of the classical approach where the full pose is estimated directly, which needs a big number of parameters and consequently a heavy computational burden. This new method of tracking has led to two papers presented to the conferences: EMMCVPR 2009 and VRIPHYS 2009. The second part of my fellowship was devoted to the improvement of the prediction part: proposing more adapted prior distribution $p(s)$. A first idea that I developed from May 2009 to June 2009 was the modeling of eventual periodicity of human motion. To achieve this, I proposed that $p(s)$ is not anymore a Markovian distribution but the distribution of a process for which the "derivative" is a "Gegenbauer process". These processes are linear long-dependent processes which behave pseudo-periodically. The first studies have been made in the case of linear manifolds (vectorial spaces), and is subject to a submission in a journal in the next weeks. A parallel idea that I develop is the extension of Gegenbauer processes and other stochastic processes on manifolds. In the same time, I was able to extend some classical definitions of differential geometry in the stochastic case. These works about stochastic differential geometry can lead to publication in journal or publication of a technical report. Moreover, it constitutes a common theoretical background between the two parts of my fellowship [1].

II - Publication(s) during your fellowship

Conference

[1] Søren Hauberg, Jérôme Lapuyade, Morten Engell-Nørregård, Kenny Erbelen and Kim Steenstrup Pedersen, *Three Dimensional Monocular Human Motion Analysis in End-Effector Space.* In Energy Minimization Methods in Computer Vision and Pattern Recognition, EMM-CVPR 2009, August 2009, Bonn, Germany.

Abstract
In this paper, we present a novel approach to three dimensional human motion estimation

[1]the second part is spent at VTT, Espoo, Finland.

from monocular video data. We employ a particle filter to perform the motion estimation. The novelty of the method lies in the choice of state space for the particle filter. Using a non-linear inverse kinematics solver allows us to perform the filtering in end-effector space. This effectively reduces the dimensionality of the state space while still allowing for the estimation of a large set of motions. Preliminary experiments with the strategy show good results compared to a full-pose tracker.

[2] Morten Engell-Nørregård, Søren Hauberg, Jérôme Lapuyade, Kenny Erbelen and Kim Steenstrup Pedersen, *Interactive Inverse Kinematics for Human Motion Estimation.* In Workshop on Virtual Reality Interaction and Physical Simulation, VRIPHYS 2009, November 2009, Karlsruhe, Germany.
Abstract
We present an application of a fast interactive inverse kinematics method as a dimensionality reduction for monocular human motion estimation. The inverse kinematics solver deals efficiently and robustly with box constraints and does not suffer from shaking artifacts. The presented motion estimation system uses a single camera to estimate the motion of a human. The results show that inverse kinematics can significantly speed up the estimation process, while retaining a quality comparable to a full pose motion estimation system. Our novelty lies primarily in the speedup factor of the resulting particle filtering. With our approach it is possible to construct a robust and computationally efficient system for human motion estimation.

Submissions in preparation:

[1] Jérôme Lapuyade-Lahorgue, Søren Hauberg, Morten Engell-Nørregård, Kenny Erleben, Kim Steenstrup Pedersen, *Modeling Pseudo-Periodicity in Human Motion Using Multivariate Gegenbauer Processes* (the title is subject to modifications)

[2] Jérôme Lapuyade-Lahorgue, Søren Hauberg, Morten Engell-Nørregård, Kenny Erleben, Kim Steenstrup Pedersen, *Brownian motions, Gegenbauer processes and stochastic processes on manifolds: an application to human motion tracking* (the title and list of authors subject to modifications).

III - Attended Seminars, Workshops, and Conferences

Workshops:

March 2009 The 2009 DIKU-LASMEA Workshop on Computer Vision, 24 March 2009, University of Copenhagen, Denmark.
May 2009 Visit of Professor Ruzena Bajcsy at DIKU, University of Copenhagen, Denmark, 4 May 2009.

Summer School:

August 2009 Summer School on Manifold Learning in Image and Signal Analysis, Ven, Sweden, August 17-21, 2009.