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主 論 文 の 要 旨

論文題目 Robust Recognition of Human Behavior Based on Stochastic Switched System Model （確率的切り替えを伴うシステムモデルに基づく人間行動のロバスト認識）

氏 名 張 大鵬

論 文 内 容 の 要 旨

Recently, modeling of human behavior attracts much attention from many researchers in psychology, engineering, and computer sciences. Human behavior is considered as a combination of human motions accompanied with human-environment interactions. One of the most important applications of the human behavior analysis is human identification; The second prospective application of the human behavior modeling is the design of human machine interaction; The third application concerned is human motion tracking which is very similar with object tracking.

1 Overview of Previous Approaches and The Proposed Model

There are two kinds of approaches of promoting the performance and robustness of recognition system based on stochastic modeling: (1) design a robust model/estimator which can automatically reduce the influence of undesirable features and make the system have the ability to reject the undesirable samples; (2) pre-processing the raw data to extract desirable features which can aid the robustness of the system. The former model-based approach is emphasized in this dissertation.

The simplest way to model the underlying human behavior from raw signals may be linear Auto-Regressive (AR) model. But it is not possible to use the simple AR model to get high performance on identifying the intrinsic signal sources. Linear models, deterministic nonlinear models are not sophisticated enough in complex human behavior analysis. Though the number of primitive features may be finite, the total number of combinations of primitive features and statistical features are infinite. Conventional expert systems without stochastic modeling strategy are also unable to be used in tasks with large amount of multidimensional data, especially when it adopted an ‘top-down’ modeling strategy. Expert systems often adopted deterministic methods to represent the human knowledge. But the

stochastic processes and unknown features of human behavior can not be easily integrated into them. Hybrid system often encountered with computational problem when there are many singularities in the parameter updating processes. Transfer Belief Model can only be effective in limited number of cases which fulfill its assumptions.

In order to solve these problems and promote the recognition rate, the autoregressive model and the HMM are combined together to serve the goal for constructing proto-type model for robust recognition. Thus Markov chain model is chosen as the base of the proposed stochastic switched system model because it is convenient to model a system with switching regime. The proposed stochastic switched system model can not only function as a statistical method modeling the observable output sequence, but also can be used as a tractable behavior model letting us learn the underlying motion phases which are the basic constructive units for behavior modeling.

2 Goal of Research and Our Approach

Our goal is to provide an integrated, versatile robust recognition approach which can be utilized in many cases related to human behavior analysis. At first, a universal model proto-type is necessary. The proto-type model should have enough robustness to adapt the requirements of various tasks and be molded into high-precision, task-dependent model.

The basic idea is storing the outliers in the 'heavy-tail' of statistical model and setting an appropriate weighted parameter for the heavy tail. The robustness of most recognition system can be explained in an important research field of statistics: robust statistics. Its characteristic is its robustness against errors caused by 'outliers', and deviations from assumptions (e.g., assume that the residual error is normally distributed but in fact it is non-normal distribution).

The motivation for practical application of the proposed model are depicted step by step in the following paragraphs.In Chapter 3, special state are defined as 'pen-up' state by computing the related state-transition parameter algebraically. So two kinds of states can be distinguished out like nominal distribution and contaminated distribution in ϵ-contaminated Gaussian mixtures. In Chapter 4, two kinds of states become distinguishable by adding equal constraints on the parameter matrix of the states of the same class. The results of the emphasized class of states and insignificant class of states. In Chapter 5, the work of emphasizing desirable states and downweighting heavy-tailed states is done by an innovative parameter estimation algorithm called Constrained ECM algorithm.

In particular, the proposed task-independent stochastic switched system model functions as the "father class" of the stochastic models necessary for various applications in Human-Robot Interaction system or public security systems. The stochastic switched system model can represent switching/underlying dynamics not only in the engineering field like control systems, but also in real-world phenomenas like bio-mechanical system.

2.1 Signature Verification

It is our first try to integrate the feature space analysis with the configuration of the classifier (HMM). A signature verification is approached with a new and effective learning method for HMM introducing the essential feature of physical phenomena. The feature is defined from input space by analyzing the pressure profile (pen-tip pressure). And then it is found that to discuss features together with the associated properties of the classifier is much convenient and fruitful in promoting the whole system's performance.

Segmented HMM was proposed and verified as an extension of conventional HMM. By inserting several special states (which are called pen-up states in signature verification) whose state-transition parameter is calculated by explicit knowledge get from the input signals, one long left-to-right HMM with large number of states, could be segmented into several sub-models. By analyzing the Baum-Welch algorithm (based on EM algorithm), it is found that the sub-models are almost independent from each other except state-transition events between the sub-models. So the parameter estimation algorithm could also be performed independently, and then the computational load could be reduced to one fifth of that of the conventional method. This characteristic could also be used to changing the modeling strategy for complex human behavior analysis. At first, the sub-models could be modeled. E.g., each sub-model represents each stroke of the motion. Then secondly, connect necessary sub-models into a large left-to-right HMM which function as the recognition model. Combined with several interesting edit distance of sequences, this new modeling strategy will be powerful in case of modeling complex motions/behaviors with lots of stroke.

2.2 Gait Recognition

The objective of this work is to recognize human identities when their walking speeds are varying in certain range. The gait recognition model chose stochastic switched model as the pattern classifier. Stochastic switched model is a kind of hybrid model which modeling the discrete switched events of several dynamical systems.

And the main concern is to promote the classifier's discriminative power and robustness. The model's topology will be changed according to the average velocity range in specific task. The inspiration is originated from Gait pathology. There are many properties of gait are examined and considered in this area, like stride length, cadence and gait phases (single-standing gait phase, double-standing gait phase). The strategy to integrate knowledge gained in gait pathology in this work is to tuning the classifier, not the techniques related to preprocessing step.

The key technique is a new equal constraint introduced between a pair of discrete states (which are denoted as a pair of reciprocal states in gait recognition. It is assumed that the dynamics of these 2 states are similar. They share a common set of parameters which only differ on the permutation orders. The difference is which foot is the stance foot. A multi-state gait model may contain more than one pair of reciprocal states.

2.3 Driver Identification

The task of this work is identify drivers in order to provide personal assist in corner-curving. Thus it is natural to extract the driving features of different individuals in order to get the knowledge on how to assist the driver better. In addition, the successful representation of driving features by the driver models will promote their identification rates. Rigidly speaking, driving should be considered as an "behavior" rather than an motion, but the behavior is also an combination of motions. Though the conventional method like collecting joint trajectories does not work here, the multi-sensor signals could be treated as "trajectories" of several joints. This idea helped a lot to solve the main challenge which is to recognize the driving patterns from the multi-dimensional data collected by various sensors of vehicle-mounted system. As mentioned before, the driving behavior analysis is not like the conventional human movement analysis, so besides the feature and signal analysis, much efforts were made to invent new learning algorithms corresponding to the language of high-level human behavior. The objective is to overcome the difficulty of parameter initialization of complex stochastic switched model and to promote the numerical stability of parameter estimation algorithm.

At last, we proposed a new Constrained ECM algorithm which can estimate parameters selectively with constraints representing pre-knowledge of human. The algorithm adopted combinatorial theory and modified conventional ECM algorithm by changing the grouping and ordering of CM-steps.The conventional ECM algorithm (short for Expectation Conditional-Maximization algorithm) is an extension of Expectation Maximization algorithm. The keyword 'partition' in ECM algorithm should be highlighted, because referring to the three aspects in human behavior modeling: model, algorithm, and data, each of them need to be partitioned to disclose its underlying structure. The partitions in ECM is referring to the part of parameters each Conditional-Maximization step (CM step) dealing with. The idea of the proposed algorithm is by changing the orderings and groupings of CM-steps to generate new updating directions in the parameter space. The transition from the input space to the feature space is introduced by feature analysis method in Chapter 3; The equal constraints between states are introduced in Chapter 4. And the constrained ECM algorithms are designed in order to delineate its flexibility to be incorporated with the former two methods.

3 Conclusion and Future Work

We have presented a new modeling strategy for robust recognition of human behavior. The strategy was adopted and verified through the dissertation consisting of the three main works: signature verification, gait recognition and driver identification. A stochastic switched model was designed and functions as the proto-type for two practical systems (gait recognition, driver identification). We also provided three integrated human identification system and verified them by real-world experiments:

1. A segmented HMM particularly useful for the verification of the oriental characters has been proposed and analyzed. The segmented HMM is composed of many sub-models each of which corresponds to an individual stroke. In addition, the 'pen-up' state which represents the movement between strokes is explicitly introduced. Thanks to its segmented structure, the segmented HMM drastically reduce the computational load for the parameter re-estimation compared with the conventional model. In addition, the segmented HMM shows better discriminative performance, in particular for the data set which contains many skilled forgery.

2. A new gait recognition system synthesizing dynamics model of parametric human body and statistical model is proprosed and verified. By the thorough study of linear AR model and functional modeling strategy using different configurations of two pairs of reciprocal states, it provides a new perspective for human behavior modeling especially for temporal motions containing many distinct phases like walking and writing. By configuring the reciprocal states asymmetrically the highest recognition rate 93%, and robustness at low velocity can be achieved. Comparison study of several stochastic switched models and conventional HMMs showed that the computational load of the proposed model is quite low.

3. The driver identification system which is designed from the proto-type model for robust recognition of human behavior shows its robust characteristics towards individuals with different driving habits. By choosing proper dimensions of driving signals and several practical constraints on the regression coefficients and variances, the average recognition rate 78.7% was acquired in a cornering experiment with simple route.

The empirical success of robust recognition for human behavior analysis in these three applications are also presented by detailed explanations step by step. The key techniques are the optimum state sequence analysis by Viterbi algorithm. The validity of our modeling strategy in spite of the difference of the human behavior analysis tasks are proved, although some manual tuning is required to implement these ideas.

Through the research on sequences of motion primitives, we plan to implement this idea into the operation assistance system of nursing robot (RIBA) cooperated with nurses and patients. So sub-models related to classes of different operations are desirable. The statistical property of the proposed Constrained ECM algorithm should be verified under strict experimental studies using classical and new data corpus. The data collected in above project (operation assistance system of nursing robot) may be used as another real-world validation experiment for the algorithm.

We believe that the ideas presented in this dissertation may have wider applications to such areas as human-machine interaction, human-centered robotics, and non-intrusive surveillance systems. In order to achieve optimum models with respect to the requirements of different tasks, we can integrate pre-knowledge of multiple disciplines into the proposed human behavior proto-type model.