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IFAC PapersOnLine 50-1 (2017) 4582–4587

Behavioral Analysis in Nursing and Caregiving Services Using Switched Linear Regression Models

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Abstract: In order to improve quality of nursing and caregiving services, it is important to analyze behaviors of service providers. Then, it is hard to directly analyze time series data. It is appropriate to find changing points and patterns of behaviors. In this paper, we propose a method for behavioral analysis using a switched linear regression model. First, an ICT-based system for nursing and caregiving services, which is developing by the authors, is summarized. Next, in order to analyze actual data obtained from this system, a switched linear regression model is introduced. An identification method of this model using mixed integer programming is proposed. Using this identification method, both the changing points of behaviors and the trend of the behavior between changing points can be obtained. Finally, the proposed method is applied to actual data in nursing and caregiving services.

Keywords: behavioral analysis, mixed integer programming, nursing and caregiving services, switched linear regression models.

1. INTRODUCTION

Modeling, analysis, and control of complex systems are an important problem in systems and control theory. Especially, modeling of complex systems with human behaviors is one of the challenging topics. In modeling of human behaviors, discrete event systems and hybrid systems are frequently used. In the field of discrete event systems, a Petri net has been used (see, e.g., Hiraishi et al. (2012); Pizzio et al. (2014); Rauterberg et al. (1997)). In the field of hybrid systems, a piecewise affine model has been applied to analysis of human behaviors in an automobile (see, e.g., Okuda et al. (2009, 2013)). It is difficult to consider a unified model for human behaviors. Hence, it is desirable to consider different models depending on applications.

On the other hand, *service science* is developing as a new research field. Service science is an interdisciplinary approach to the study, design, and implementation of service systems (see, e.g., Daskin (2011)). Needless to say, modeling and analysis of human behaviors (e.g., service providers) are important in service science. In this sense, service science and control theory are closely related.

For nursing and caregiving services, the authors have developed the ICT-based system called the Smart Voice Messaging (SVM) system (Uchihira et al. (2013)). The SVM system can assist carestaff in mutual communication and recording important information (see Section 2 for further details). Furthermore, using various information collected by the SVM system, we can analyze behaviors of service providers.

In this paper, we propose a method to analyze human behaviors based on actual data. Here, we focus on finding the changing points of behaviors. In addition, we also focus on the behavior between changing points. To analyze these points, we introduce a switched linear regression model (see also, e.g., Bako et al. (2011); Ohlsson and Ljung (2013); Vidal (2008)). In this model, the time interval is decomposed to some time intervals. For each time interval, a linear regression model is derived. The identification problem of this model is formulated as follows: Find both coefficients of linear regression model and time intervals minimizing the error between actual data and estimated data. By solving this problem, we can see both the changing points of behaviors and the trend of the behavior between changing points. This problem can be reduced to a

10.1016/j.ifacol.2017.08.1001

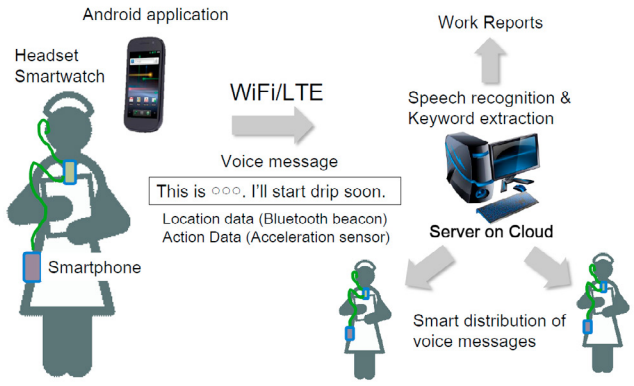

Fig. 1. Overview of the smart voice messaging system.

mixed integer linear programming problem. In this paper, the switched linear regression model is applied to analysis of position information of one service provider in nursing and caregiving services. The proposed method provides us a new method in model-based analysis/design of human behaviors.

This paper is organized as follows. In Section 2, the outline of our ICT-based system for nursing and caregiving services is explained. In Section 3, a switched linear regression model is defined, and its identification method is proposed. In Section 4, a switched linear regression model is applied to analysis of human behaviors in nursing and caregiving services. In Section 5, we conclude this paper.

Notation: Let $\mathcal{R}$ denote the set of real numbers. Let $\{0,1\}$ denote the finite set consisting of 0 and 1. For the vector x, let $\|x\|_1$ denote 1-norm. For two integers k_1 and k_2 $(k_1 \leq k_2)$, let $[k_1 : k_2]$ denote the sequence of integers $k_1, k_1+1, \ldots, k_2$.

2. ICT-BASED SYSTEM FOR NURSING AND CAREGIVING SERVICES

Several ICT-based systems for nursing and caregiving services have been developed so far. In this section, as an example, we explain the Smart Voice Messaging (SVM) system developed by authors (Uchihira et al. (2013)).

Fig. 1 shows an overview of the SVM system. The main purpose of the system is to assist carestaff in mutual communication and recording important information that tends to be lost because of busyness of the work. The SVM system consists of smartphones with application software (SVM terminals), the server PC, and Bluetooth markers located in the field.

Once each person speaks a short message to the terminal, then the message is immediately sent to the server PC, and is distributed to other persons. Simultaneously, the voice message is transformed into text data by a speech recognition engine. Each person can browse past messages on the SVM terminal, and can read text or hear voice messages. Important keywords expressing the current situation are also extracted from the messages. Each voice message should be sent to only persons who need it. In order to realize such smart message distribution, various kinds of information are used, such as location data estimated by receiving signals from Bluetooth markers, acceleration sensor data that is used for estimating the current activity, and the keywords extracted from the messages. In addition, it is also possible to control the scope of receivers by explicitly speaking registered keywords.

Using various information collected by the SVM system, the following subjects were studied in order to discover new usage of the SVM system:

i) Agent simulation for complex nursing/caregiving processes (Hiraishi et al. (2012)),
ii) Behavior modeling of human activity and its application to anomaly detection (Hiraishi et al. (2014); Hiraishi and Kobayashi (2014)),
iii) Spatio-temporal situation recognition for a group of persons (Sato et al. (2015, 2016)).

Recently, the notion of information supervisory control has been proposed in Hiraishi et al. (2016). The aim of information supervisory control is to assist a group of persons in their work by providing appropriate information at appropriate timing. By implementation of this control method, the effectiveness of the SVM system will be enhanced.

In this paper, various information collected by the SVM system is used in offline analysis of behaviors of service providers. In particular, we focus on the following problems.

i) When is the changing point of behaviors?
ii) What is the property in the behavior between changing points?

These problems are important for analyzing several actions of service providers (e.g., cooperative actions of multiple providers). It is difficult to directly check various information collected by the SVM system. It is desirable to derive a mathematical model for expressing various information. In order to solve these problems, we propose an identification method of switched linear regression models.

3. SWITCHED LINEAR REGRESSION MODELS

In this section, first, a switched linear regression model is defined. Next, an identification method of this model is proposed based on mixed integer programming.

3.1 Definition

Consider a discrete-time dynamical system with the input $u(k) \in \mathcal{R}^m$ and the output $y(k) \in \mathcal{R}^p$. For simplicity of discussion, we assume $m = p$, but we can easily consider a general case. In order to model its behavior in the finite time interval $[0 : N]$, we utilize a switched linear regression model. This model is defined by

$$y(k) = \sum_{i=1}^{n_y} a_i(k) y(k-i) + \sum_{i=1}^{n_u} b_i(k) u(k-i) + c(k), \quad (1)$$
$$k \in [0 : N],$$

where coefficients $a_i(k), b_i(k), c(k)$, $k \in [0, N]$ are given by