International Journal of Hybrid Information Technology
Vol.8, No.1 (2015), pp.317-324
http://dx.doi.org/10.14257/ijhit.2015.8.1.28

Research on Operational Intention Identification of Quayside Container Crane Driver

Wei Yan, Yuwei Zhao and Houjun Lu

Engineering Research Center of Container Supply Chain Technology, Ministry of Education, Shanghai Maritime University, Shanghai 201306, China
zhaoywtracy@gmail.com

Abstract

To study intelligent auxiliary drive system of port machinery, it needs to identify operational intention of quayside container crane driver. With the background of loading and unloading process of quayside container crane, upon Hidden Markov Model, double HMM model is established. The algorithm of revised Forward-Backward is applied to calculate each likelihood of HMM in operation layer, the model of the largest likelihood is selected to be the identify result of operation behavior. After combining them to constitute the observation sequence bunch, it will be sent to the intention layer of HMM to conduct the identification of operation intention of crane driver. Finally, HMM is realized by Matlab. By means of field statistics, the basic data can be determined and effectiveness is also verified. It turns out that this model can accurately identify the operational intention of quayside container crane driver, which is of great significance for studying intelligent auxiliary drive system of port machinery.

Keywords: *Crane driver, operational intention identification, operational behavior identification, HMM*

1. Introduction

Security incidents during the port production are on rise year by year, the safety of the workers has received great attention and experts start to study intelligent auxiliary drive system of port machinery. The intelligent auxiliary drive system of port machinery can execute auxiliary loading and unloading operation by identifying operational intention of crane driver. A cognitive architecture of the driver model (Bi *et al.*, 2013) is proposed based on the queuing network to speculate the intention of lane-changing drivers. Through such a driver model which was on the basis of queuing network, operational behavior relative to the probable operational intention can be simulated and driver intention can also be inferred by means of comparison between the real data and the simulation result. Wang *et al.* (2013) utilized mathematical statistics and neural network to establish the membership function and rules of the fuzzy logic inference system, and fuzzy logic inference system was used to achieve the purpose of identifying operational intention. Up till now, there is little study on the identification of operational intention and most of the study is built upon the car drivers (Zhu *et al.*, 2014). The study of operational intention identification on the quayside container crane driver has not been found.

Based on Hidden Markov Model, double-layer HMM on quayside container crane driver is established. Double HMM is divided into operational layer and intention layer, which are used to identify loading and unloading behavior (Niu *et al.*, 2013) and operational intention (Jin *et al.*, 2013; Zong *et al.*, 2009) Revised Forward-Backward is applied to calculate each likelihood of HMM and the model of the largest likelihood is selected to be the identification result of operation behavior. Sequence bunch will be sent to the intention layer to calculate likelihood in

ISSN: 1738-9968 IJHIT

intention layer and finally conduct the identification of operation intention of crane driver.

2. Description of Hidden Markov Model

2.1. Markov Chain

Markov chain is the discrete-time random processes with Markov property. During this process, the future state of the certain thing is only connected with the current state and the future state cannot be speculated by the previous one, that is to say, the past has nothing to do with the future state.

2.2. Hidden Markov Model

Hidden Markov Model is a typical form in Markov chain, where its state cannot be directly observed, so it is called invisible state and it need to be observed with the help of other observation sequences. Each invisible state leads to corresponding observation sequences through corresponding probability density distribution, and each observation sequence transform through certain probability density distribution. Therefore, Hidden Markov Model belongs to a double stochastic process.

2.3. Forward-Backward Algorithm

On the premise of HMM parameter λ, forward variable $\alpha_t(i)$ is defined, $\alpha_t(i)$ expresses that t moment satisfy state S_i and meet the probability of given observation sequence(O1,O2,…Ot)before t moment(including t moment).Backward variable $\beta_t(i)$ is defined similarly, indicating that S_i appears at the moment t and the observation sequences after t moment satisfy the probability(O_{t+1},O_{t+2},…O_T). For constituting HMM of crane driver, specific equation of $\alpha_t(i)$ and $\beta_t(i)$ are shown below.

$$\alpha_{t+1}(j) = [\sum_{i=1}^{N} \alpha_t(i) a_{ij}] \prod_{l=1}^{4} b_j(O2_{t+1}(l)) \quad (1)$$

$$\beta_t(i) = [\sum_{j=1}^{N} \alpha_{ij} \beta_{t+1}(j)] \prod_{l=1}^{4} b_j(O2_{t+1}(l)) \quad (2)$$

In the equation, a_{ij} is defined as the probability for transferring from state s_i to s_j, while $b_i(O2_t(l))$ is defined as the probability to meet $O2_t(l)$ in four corresponding observation values on the premise that they are under the state of s_i at t moment. It is assumed that *l*=1 represents operating state of trolley, *l*=2 represents lifting state of spreader, *l*=3 represents on and off state of lock, and l=4 represents up and down state of guide plate. For instance, $O2_1(1)$ means the observation sequences of trolley when t equals one.

3. Construction of Double-layer HMM

3.1. Loading and Unloading Operation of Crane Driver

Loading and unloading operation of crane driver is a continuous and complicated process. In the closed-loop man-machine system, driver needs to operate and control the quayside container crane to accomplish port operation in accordance with the operation conditions and own operational intention and habits. Based on different loading and unloading environment, the reaction of crane drivers must be connected with their psychological states. The operation procedure is complex and various, but crane driver usually have the specific operation regulation under the similar loading and unloading environment. For hoisting and discharging in compound working conditions, some regulations are determined as below. With regard to the hoisting, the procedure will be as follows. Firstly, trolley accelerates forward, decelerates, brakes and lays the spreader down accelerately. Secondly, the spreader decelerates, brakes and lays the guide plate down. Thirdly, the spreader goes down slowly to match with the hole of container and lock. Finally, the spreader goes up accelerately and decelerates. The operation for discharging is relative. So it can be identified for operational intention according to the general regulation of operational behavior of crane drivers.

On account of the characters of HMM, we construct double-layer HMM for the quayside container crane driver. The operational layer of HMM(under layer)contain four models, which correspond to trolley operation, spreader lifting, on and off state of lock and up and down state of guide plate. Apply observation sequences of different operational behavior to train four trolley operations HMM, four spreader lifting HMM, on and off state of lock HMM and up and down state of guide plate HMM. After the piecewise process of a long observation sequence, it will be input into each HMM groups and identification sequence bunch will be got piecemeal for four single working conditions. Then it will be processed as the observation sequences of intention layer (upper layer) in accordance with the loading and unloading operational regulation of container. The observation sequences correspond to four HMM of regularly hoisting, regularly discharging, irregularly hoisting and irregularly discharging in the intention layer (upper layer). The double-layer HMM structure is shown in Figure 1. Based on such a model structure, each model can independent complete identification. Operational efficiency has been improved under the structure and it can directly identify the operational behavior and operational intention in real time.

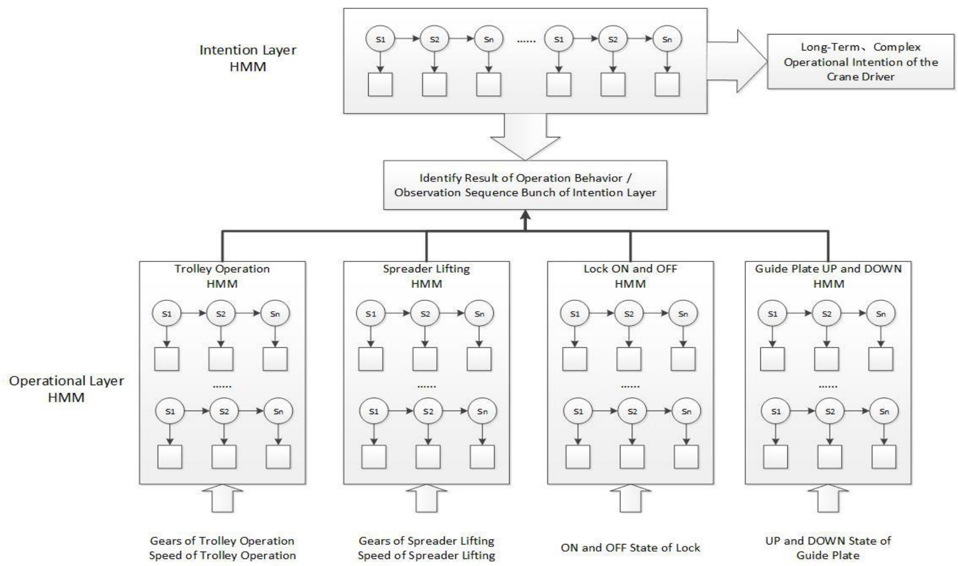

Figure 1. Double HMM Structure for Intention Identification of Crane Driver

3.2. HMM Operational Layer

For trolley operation, the operational behavior of crane driver includes normal acceleration of trolley, urgent acceleration of trolley, normal deceleration of trolley and urgent deceleration of trolley. Sensor data for operation of crane driver, including gears of trolley operation, speed of trolley operation should be collected to establish four HMM for trolley to identify operational behavior of trolley in a short period of time. Observation sequences of HMM groups can be described as the multidimensional vector form as follows.

$$O_1(t) = \{a(t), b(t)\} \quad (3)$$

In the equation, $O_1(t)$ represents HMM group of trolley operation, $a(t), b(t)$ respectively stand for gears of trolley operation and speed of trolley operation. The algorithm of revised Forward-Backward is applied to calculate each likelihood of HMM for operational data set of trolley in MATLAB environment. The model of the largest likelihood is selected to be the identify result of operation behavior.

The multidimensional vector form of spreader lifting is analogous as above.

For the on and off state of lock, two HMM has been established for locking and unlocking. Its observation sequences can be described as below.

$$O_2(t) = \{e(t)\} \quad (4)$$

$O_2(t)$ represents HMM group of the lock, while $e(t)$ represents the state of lock.

For up and down state of guide plate, HMM is also divided into two models, the multidimensional vector form of which is similar with the lock state as below.

3.3. HMM Intention Layer

Operational intention includes regularly hoisting, regularly discharging, irregularly hoisting and irregularly discharging for loading and unloading operational process of crane driver. Three dimensional identify result bunch of operational layer will be divided according to the loading and unloading operational intention under the certain complicated working condition and it will also viewed as the observation bunch in the HMM intention layer to calculate the likelihood of each HMM in intention layer. The observation sequence can be expressed as the following vector form.

$$O_3(t) = \{x(t), y(t), u(t), v(t)\} \quad (5)$$

In the equation, $x(t), y(t), u(t), v(t)$ individually represent the identification result of trolley operation, spreader lifting, on and off state of lock and up and down state of plate guide in operation layer.

After combining the operational behavior of crane driver under the single working condition to constitute the observation sequence bunch, it will be sent to the intention layer of HMM to calculate likelihood of each HMM and conduct the identification of operation intention of crane driver.

4. Parameter Determination of Double-layer HMM

4.1. Operational Layer HMM (under layer)

Input data of operational layer HMM include gears of trolley operation, speed of trolley operation, gears of spreader lifting, speed of spreader lifting, on and off state of lock and up and down state of guide plate, those of which are observation sequences in the operational layer HMM and they are used to identify operational behavior of crane driver. Behavior of crane drivers can be divided into different types for normal or urgent acceleration of trolley and spreader, normal or urgent deceleration of trolley and spreader, on or off of lock, up or down of the guide plate. According to loading and unloading operation of crane drivers, it can be assumed that in the following state-transition matrix, element x_{ij} means the probability that corresponding state transfer from the i-row to j-column, and the row represents the state at time t, while the column represents the state at time t+1.

$$A = \begin{pmatrix} a_{11} & \cdots & a_{17} \\ \vdots & \ddots & \vdots \\ a_{71} & \cdots & a_{77} \end{pmatrix}$$

Gears of trolley operation will fall into seven classes, the first three class are used for forward acceleration, class 5 to 7 are used for backward acceleration and class 4 is used for braking. In the matrix, the row represents the state of a_t, on behalf of class one to seven from top to bottom, and similarly the column represents the state of a_{t+1}.The state-transition matrix for the speed of trolley operation, gears of spreader lifting, speed of spreader lifting, on and off state of lock and up and down state of guide plate are analogical as mentioned.

4.2. Intention Layer HMM (upper layer)

Three-dimensional observation sequence bunch of operational layer will be divided according to the loading and unloading operational intention under certain working condition and the sequence bunch will be determined as the observation sequence in intention layer HMM to identify operational intention, including regularly and irregularly hoisting, regularly discharging and irregularly discharging. In the confusion matrix, the column represents four operational intention, while y_{ij} stands for the probability that the i-row operational behavior corresponds to the j-column operational intention.

Row stands for the operational behavior of the trolley in the confusion matrix, it expresses normal acceleration of trolley, urgent acceleration of trolley, normal deceleration of trolley, urgent deceleration of trolley from top to bottom. The confusion matrixes of others are similar.

5. Case Study

Revised Forward-Backward algorithm is applied to calculate the likelihood of each HMM and the largest likelihood is selected to be the identify result, which is shown in Table 1. In the Table, gears of trolley operation fall into seven classes. Gears operation directly controls the state of acceleration, braking and deceleration. The speed of operation is classified in accordance with normally and urgently pushing operation. Gears and speed control of spreader lifting are analogous. One stands for unlocking of the lock and putting away guide plates, while two means locking and letting down guide plates. Operational intentions are classified as regularly and irregularly hoisting, regularly discharging and irregularly discharging. Referring to practical port loading and unloading operation regulation, gears of trolley and spreader, on and off lock and state of guide plates should be input into the established double HMM to identify. Identification results are shown in Table 1.

Table 1. Double HMM Identification Results

Gears for operating trolley	Pulling Speed of trolley	Gears for operating spreader	Pulling Speed of spreader	on and off state of lock	State of guide plates	Operational intention
1	1	2	1	2	2	2
1	2	2	1	1	2	1

1	2	4	1	1	2	3
1	2	6	1	2	2	2
4	1	4	1	2	2	2
4	1	6	1	1	2	1
4	2	6	1	1	2	1
4	2	6	1	2	2	2
7	1	2	1	1	2	1
7	1	4	1	2	2	2
7	2	2	1	2	2	4
7	2	6	1	2	2	2
…	……	…	……	…	…	……

After comparison between identification result and practical operational intention of crane driver, the conclusion is achieved that the model can accurately identify operational intention of quayside container crane driver.

6. Conclusion

With the foundation of loading and unloading operational regulation of crane driver, double HMM has been established. After analyzing of the model identification result, it turns out that the model can accurately identify operational intention of crane driver under complicated conditions. So the model can be used to study intelligent auxiliary drive system of port machinery, in order to reduce the security incidents during the port production and to improve the effectiveness of port efficiency.

Acknowledgements

This work sponsored by Shanghai Maritime University Research Project (20120065), Shanghai Top Academic Discipline Project- management science & engineering, National Natural Science Foundation project (71101090), Doctoral Fund of the Ministry of Education (20133121110001), Shanghai Municipal Education Commission Project (12ZZ148, 13YZ080, 14YZ112), Ministry of Transport Research Projects (2012-329-810-180).

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Authors

Wei Yan, he is a PhD, Professor, and Ph.D. Supervisor. Research Fields include logistics and supply chain management, knowledge engineering and expert system. (E-mail)weiyan@shmtu.edu.cn