Mechanical Systems and Signal Processing ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Model-based approach for elevator performance estimation

E. Esteban [a], O. Salgado [a,*], A. Iturrospe [b], I. Isasa [c]

[a] Mechanical Engineering, IK4-Ikerlan, J.M. Arizmendiarrieta 2, 20500 Mondragon, Spain
[b] Department of Electronics and Computer Sciences, Mondragon Unibertsitatea, Loramendi 4, 20500 Mondragon, Spain
[c] Mechanical Engineering, Orona EIC S. Coop., Pol. Lastaola s/n, 20120 Hernani, Spain

ARTICLE INFO

Article history:
Received 7 July 2014
Received in revised form
29 June 2015
Accepted 8 July 2015

Keywords:
Elevator
Dynamic modeling
State space models
Kalman filters
State estimation

ABSTRACT

In this paper, a dynamic model for an elevator installation is presented in the state space domain. The model comprises both the mechanical and the electrical subsystems, including the electrical machine and a closed-loop field oriented control. The proposed model is employed for monitoring the condition of the elevator installation. The adopted model-based approach for monitoring employs the Kalman filter as an observer. A Kalman observer estimates the elevator car acceleration, which determines the elevator ride quality, based solely on the machine control signature and the encoder signal. Finally, five elevator key performance indicators are calculated based on the estimated car acceleration. The proposed procedure is experimentally evaluated, by comparing the key performance indicators calculated based on the estimated car acceleration and the values obtained from actual acceleration measurements in a test bench. Finally, the proposed procedure is compared with the sliding mode observer.

1. Introduction

Maintenance and modernization services account for more than a 46% of the total revenue in some elevator leading companies [1]. Maintenance and modernization services are expected to continue to grow, although with significant variation between countries and a pricing market environment characterized by very intense competition.

Actually, elevator maintenance services involve periodical *in situ* inspections in order to evaluate the elevator performance and its ride quality. In order to reduce variability in the results of elevator ride quality measurements, the standard ISO 18738-1:2012 [2] encourages industry-wide uniformity in the definition, measurement, processing and expression of vibration and noise signals defining several key performance indicators [3]. These key performance indicators are now part of specifications for most elevator installations. Most of the performance indicators established by the standard ISO 18738-1:2012 are calculated by processing the elevator car acceleration signal in the vertical direction.

Currently, periodical *in situ* inspections are generally conducted employing commercial equipment designed specifically to evaluate the performance of an elevator installation. The use of these commercial equipment involves installing additional sensors in order to measure the required magnitudes. The EVA-625 [4] and the Lift PC [5] system are widely employed portable systems that evaluate the elevator installation according to the ISO 18738-1:2012. Both evaluation systems require accelerometers placed on the elevator car floor. However, permanently installing sensors involve additional costs, and installed sensors are also prone to malfunction. Therefore, it is desirable to employ already existing signals from

* Corresponding author.
E-mail address: osalgado@ikerlan.es (O. Salgado).

http://dx.doi.org/10.1016/j.ymssp.2015.07.005
0888-3270/

the regulator in order to evaluate the elevator performance. Using regulator signals also opens up the way to provide remote monitoring services for continuously evaluating the elevator condition.

The Kone Corp. has developed the portable ESiteSurvey™ system [6], for evaluating the condition of elevator installations. The functionality of the ESiteSurvey™ system goes beyond a mere implementation of the ISO 18738-1:2012 procedures. The ESiteSurvey™ provides a comprehensive set of elevator system parameters, readily after round-trip test run. The ESiteSurvey™ acquires the electrical power consumed by the machine by means of current probes fixed to the terminals of the electrical machine. It also measures the acceleration of the elevator car by means of accelerometers. Using the acquired signals it estimates different parameters, such as car and counterweight masses, guide friction loses, as well as machine efficiency. These estimations are based on a power balance model approach. The parameters of interest are estimated by minimizing the deviation between the expected power needed to move the elevator by the model and the measured consumed power.

Instead of a power balance model, more accurate models accounting coupled electrical dynamics, could explain better the whole elevator system dynamics, allowing a deeper understanding of the coupling between the mechanical and the electrical subsystems.

Condition monitoring comprises different monitoring techniques and their selection depend, among other factors, on the prior knowledge about the monitored system. An excellent survey of condition monitoring techniques can be found in [7] where model-based and data driven approaches are compared. Comparing the model-based and data-driven modeling approach, model-based approaches rely on the availability of a theoretical model of the monitored system, which can be derived using physical modeling principles [8]. The performance of a model-based method depends on a large extent of its accuracy when describing the system dynamics. Furthermore, a model-based approach should require a sufficiently generic model to address variations in the elevator configuration. However, model-based approaches have been successfully employed for both electromechanical systems monitoring and control applications [9,10]. Regarding to data-driven modeling approaches [8], monitoring systems have to be trained, so enough training data is needed, which is not the case for our application [11,12], as for other industrial applications [13].

Two of the most employed model based observer algorithms in industry are the Kalman filter (KF) and the sliding mode observer (SMO) [14–18]. Comparing the KF algorithm and the SMO algorithm, the SMO is simpler to implement but under noisy measurement conditions the KF algorithm performs better than the SMO algorithm [18–20]. Therefore, the approach proposed in this paper is based on a state space model and employs the KF as an observer; but it is also compared to the SMO.

Our approach, as shown schematically in Fig. 1, is based on a dynamic model for a 1:1 elevator installation, comprising both the mechanical and the electrical subsystems. Then, the Kalman filter (KF) algorithm is applied as an observer, estimating the elevator car acceleration. The input signal used for the KF algorithm is the regulator signature and the output signal is the machine encoder. Once the car acceleration is estimated, the five key performance indicators (KPI) are calculated as described by the ISO 18738–1:2012 in order to estimate the ride quality performance.

The rest the paper is organized as follows. In Section 2, both the dynamics of a 1:1 elevator installation and its model are described. In Section 3, the Kalman filter is applied for observing elevator car acceleration and five ride quality performance indicators are calculated. In Section 4 the proposed method is experimentally validated and compared and finally several conclusions are discussed in the last section.

2. Elevator model

An elevator installation comprehends both mechanical and electrical components as it is shown in Fig. 2. The elevator car carries the passengers or loads upwards and downwards. The mass of the elevator car is balanced by a counterweight in order to reduce the torque demanded to the machine. An electrical machine drives through a pulley onto the suspension ropes which interconnect the elevator car and the counterweight. Both the car and the counterweight move vertically constrained by a pair of rails each.

The installation modeled in this paper is driven by a permanent magnet synchronous machine (PMSM) [22] which is controlled using a field oriented control (FOC) regulator [23] and the velocity signature profile is dynamically calculated, depending on the starting car position and its final destination. The velocity loop obtains its feedback from the motor encoder.

The mechanical force imbalance between elevator car and counterweight exerts a mechanical torque in the rotor shaft that is actively balanced with the electromagnetic torque exerted by the machine. The mechanical subsystem and the

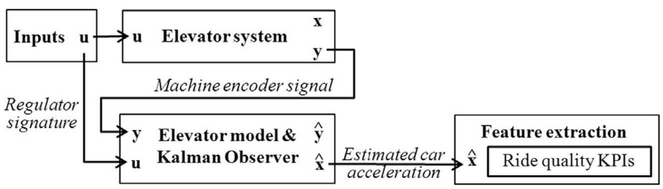

Fig. 1. Application of the model-based approach for the estimation of elevator performance indicator. Adapted from [21].

Please cite this article as: E. Esteban, et al., Model-based approach for elevator performance estimation, Mech. Syst. Signal Process. (2015), http://dx.doi.org/10.1016/j.ymssp.2015.07.005