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Elevator ride comfort monitoring and evaluation using smartphones

Yang Zhang [a], Xiaowei Sun [b], Xuefeng Zhao [a,*], Wensheng Su [b]

[a] *School of Civil Engineering, Dalian University of Technology, 116024 Dalian, China*
[b] *Jiangsu Province Special Equipment Safety Supervision Inspection Institute. Branch of Wuxi, 214174 Wuxi, China*

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ABSTRACT

With rapid urbanization, the demand for elevators is increasing, and their level of safety and ride comfort under vibrating conditions has also aroused interest. It is therefore essential to monitor the ride comfort level of elevators. The traditional method for such monitoring depends significantly on regular professional inspections, and requires expensive equipment and professional skill. With this regard, a new method for elevator ride comfort monitoring using a smartphone is demonstrated herein in detail. A variety of high-precision sensors are installed in a smartphone with strong data processing and telecommunication capabilities. A series of validation tests were designed and completed, and the international organization for standardization ISO2631-1997 was applied to evaluate the level of elevator ride comfort. Experimental results indicate that the proposed method is stable and reliable, its precision meets the engineering requirements, and the elevator ride comfort level can be accurately monitored under various situations. The method is very economical and convenient, and provides the possibility for the public to participate in elevator ride comfort monitoring. In addition, the method can both provide a wide range of data support and eliminate data errors to a certain extent.

1. Introduction

Along with the growth in urban development, the elevator has been rapidly developing as the main upright traffic conveyance system in high-rise buildings. As people enjoy the convenience brought about by elevators, their levels of safety and ride comfort can also be put to public consideration [1,2]. Vibrations are one of the most important factors affecting elevator ride comfort. They not only hinder the normal operation of an elevator, they are also the cause of serious accidents. Elevator vibrations mainly include vertical and horizontal vibrations. When an elevator is operating under the action of a traction machine, vibrations in the vertical direction are quite obvious [3–5], and people may feel significantly lighter or heavier because of the presence of acceleration, which can affect them physiologically and psychologically. Because the influence of horizontal vibrations is relatively small in a low-speed elevator, they are not always monitored or analyzed. However, with the increase in number of the high-rise buildings, a large number of high-speed elevators have been adopted. For example, the operating speed of the elevator in the Taiwan 101 Building can reach up to 60.6 km/h [6]. The horizontal vibrations, which are typically many times greater than those of a low-speed elevator, have become even more severe, seriously affecting the elevator ride comfort, which has begun drawing the attention of the public. Thus, a monitoring method of

* Corresponding author.
E-mail address: zhaoxf@dlut.edu.cn (X. Zhao).

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acceleration in three directions has been chosen to ensure a higher level of elevator ride comfort [7,8]. Traditionally, vibration testing of an elevator relies on the use of a regular accelerometer, and the corresponding test method is unable to successfully monitor the state of the elevator. To address the issues of real-time monitoring, many researchers have combined the Internet and elevators to put forward a remote elevator monitoring system [9–11] that enables monitoring the safety level of an elevator in real time, and optimizes its operating efficiency using a dispatch system to shorten the wait time of the passengers as much as possible [12,13]. Combining the monitoring system with a network is an important direction for the development of health monitoring.

With the rapid development of smartphones in recent years, their quality and quantity have both grown in leaps and bounds, achieving strong data processing and telecommunication capabilities. In addition, several types of high-precision sensors are embedded in current smartphones. A smartphone is an integrated system consisting of data acquisition module, transmission module, display module, and calculation module. Because of the strong capability of smartphones, they have been widely used in human health monitoring [14,15], telemedicine services [16], traffic information acquisition [17], vehicle location [18], and even physics experiments [19,20]. Zhao et al. [21–25] studied the application of smartphones in the field of structural health monitoring (SHM), which invokes the sensors embedded in a phone to monitor the status of different structures. Their experiment results show that a smartphone-based method is stable and reliable in meeting the different engineering demands. Such applications combine monitoring and smartphones together, and thus, users can participate in the monitoring. This method makes it possible to achieve public participation in testing at a large scale, comprehensively supply measurement data, and conveniently share information.

In this paper, a method for monitoring elevator ride comfort level using a smartphone is proposed, in which the smartphone's built-in acceleration sensor is used to monitor the vibrations of the vertical and horizontal directions of the elevator, the elevator ride comfort level is evaluated based on the collected data, and the assessment results are uploaded to an SHM site. First, a smartphone application was designed and developed. The application invokes the sensors which are embedded in smartphones to monitor the ride comfort of an elevator. Compared with an acceleration measurement, the results show that this particular method is stable and reliable, and its precision meets the engineering requirements. Second, the international evaluation system standard ISO2631-1997 is considered. Third, an elevator ride comfort validation test was carried out under different running modes and loads. The experiment results show that this method can be used to monitor the elevator ride comfort level under various situations; in addition, the monitoring data are in accordance with the elevator running mechanism, and the ride comfort evaluation results are consistent with the subjective feelings of the human body. Finally, the method was applied to the monitoring of elevator ride comfort in three different buildings. The results indicate that the method can be applied to various types of elevators, and can meet the various demands of engineers. The method integrates monitoring by the public, and provides technical support for the establishment of a regional monitoring database of elevator comfort.

2. The software of elevator ride comfort monitorimng

2.1. Interface of monitoring software

To monitor the elevator ride comfort using the sensors embedded in a smartphone, smartphone software, Orion CC, was designed and developed by our team. The main interfaces of the software are shown in Fig. 1. This software provides local account services, and the collected data are uploaded to an SHM site. "Current location" is for obtaining the location infor-

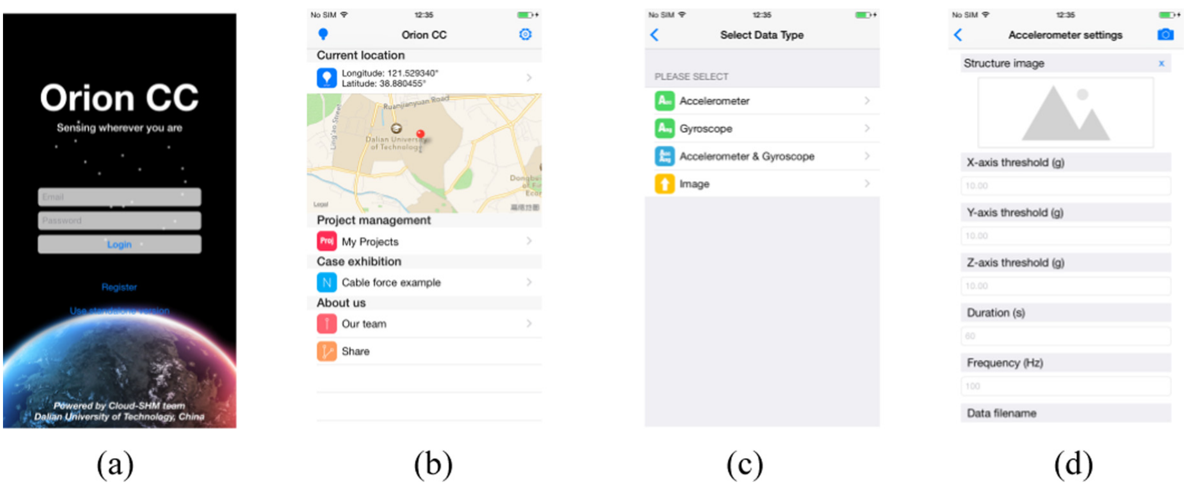

Fig. 1. Interface of monitoring software.