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Forecasting short-term subway passenger flow under special events scenarios using multiscale radial basis function networks

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A B S T R A C T

Reliable and accurate short-term subway passenger flow prediction is important for passengers, transit operators, and public agencies. Traditional studies focus on regular demand forecasting and have inherent disadvantages in predicting passenger flows under special events scenarios. These special events may have a disruptive impact on public transportation systems, and should thus be given more attention for proactive management and timely information dissemination. This study proposes a novel multiscale radial basis function (MSRBF) network for forecasting the irregular fluctuation of subway passenger flows. This model is simplified using a matching pursuit orthogonal least squares algorithm through the selection of significant model terms to produce a parsimonious MSRBF model. Combined with transit smart card data, this approach not only exhibits superior predictive performance over prevailing computational intelligence methods for non-regular demand forecasting at least 30 min prior, but also leverages network knowledge to enhance prediction capability and pinpoint vulnerable subway stations for crowd control measures. Three empirical studies with special events in Beijing demonstrate that the proposed algorithm can effectively predict the emergence of passenger flow bursts.

1. Introduction

Subway transportation systems are adopted worldwide as effective countermeasures to mitigate the adverse effects of rapid urbanization and traffic congestion (Ma et al., 2015). In the past decades, the construction of urban rail transits in both developed and developing countries has been increasing, and the expanding subway networks have stimulated a sharp rise in ridership (Zhang and Wang, 2014). Taking the Beijing subway system as an example, the average daily ridership in 2012 was 6.74 million passengers compared with the 1.19 million passengers in 2000 (Si et al., 2015). The ridership explosion has triggered a series of issues, such as crowdedness in trains and the insufficient capacity of subway facilities (Zhong et al., 2016). These phenomena became very common in metropolitan cities, including Beijing, Shanghai, and Tokyo (Ma et al., 2012). In particular, passengers in Beijing may not be able to board trains successfully due to overcrowdedness during peak hours. To alleviate the burden of high passenger demands, passengers are routinely restricted at certain subway stations and

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have to line up for boarding, or are even prohibited from entering the stations during peak hours. One possible solution to this issue is to provide proactive passenger flow forecasting information for passengers to adjust their travel paths, modes, and departure times. Reliable passenger flow estimation can also benefit transit operators in optimizing service schedules.

Existing literature on subway passenger flow prediction can generally be categorized into long-term and short-term predictions. Long-term passenger flow prediction essentially estimates future travel demands through the four-step transportation planning model or regression techniques (Horowitz, 1984). Regression models are required to establish a relationship between subway ridership and a series of influential factors, such as demographic, economic, and land-use information (Taylor et al., 2009; Chan and Miranda-Moreno, 2013). For short-term passenger flow prediction, statistical and computational intelligence-based models are extensively studied (Karlaftis and Vlahogianni, 2011; Ma et al., 2015; Vlahogianni et al., 2014). Generally, these models can be classified as time series (Ma et al., 2013; Xue et al., 2015), neural network (Tsai et al., 2009), support vector machine (Sun et al., 2015; Wang et al., 2015), and empirical mode decomposition (Jiang et al., 2014). Although these methods can capture the subtle and regular fluctuation of subway passenger flow to some extent, they are not designed to forecast non-regular demands due to special events (Pereira et al., 2015). These special events include concerts, sporting events, parades, and other public events that may attract a large group of people. When these events occur, a significant rise in passenger demand can be observed; such passenger flow irregularities are very difficult to forecast and manage because of poor information availability (Pereira et al., 2015). Determining the spatial and temporal distributions of passenger flows in advance is crucial for emergency response and stampede prevention (Zhong et al., 2015) and is considered a more effective countermeasure than reactive control and evacuation strategies. With reliable passenger flow information, transit operators can adopt several proactive measures to avoid overcrowding, such as bus feeder allocation, warning information dissemination, and temporary closure of stations. However, predicting irregular travel demands under special events is much more difficult than regular demand forecasting, because special events are nonrecurring and leave scant prior information for pattern recognition and machine learning models. Therefore, very limited effort has been made in this domain, with three exceptions. Kuppam et al. (2013) utilized the traditional four-step model to demonstrate the demand for special events. Pereira et al. (2015) developed a neural network algorithm to predict public transit arrivals for special events using social media and smart card data, as well as demonstrated the quality of transport predictions under special events. Ni et al. (2017) developed a hashtag-based event detection algorithm to detect high subway passenger flow based on social media data, and then proposed a parametric and convex optimization-based approach to forecast the passenger flow.

In the context of subway systems, predicting passenger flows under special events deserves more attention, especially in metropolitan cities where a large portion of the inhabitants take the subway for commuting (Zhou et al., 2014). Alternatively, a number of statistical and non-statistical model approaches have been developed, such as autoregressive moving average (ARMA), artificial neural networks (ANNs), support vector regression, linear regression, and radial basis functions (Pereira et al., 2015), to solve the short-term prediction of time series under special events. Among these methods, ANN has particularly gained greater attention due to its outstanding capabilities of capturing the potential nonlinear dynamical properties between input–output data. However, conventional ANNs utilized have issues with overtraining, local optima, and high computational burden (Zhang et al., 2014). The ARMA approach has also attracted substantial attention in forecasting time series to overcome these problems. Recently, some variants of ARMA models were developed to solve the issue of time series prediction, including simplified autoregressive, autoregressive integrated moving average (Khashei et al., 2012), and ARMA (Rojas et al., 2008). However, these models commonly require high model orders to accommodate stochastic variations of forecasting time series. In addition, these data sequence models are essentially linear. Thus, they may not adapt well in revealing the characteristics of the stochastic nature and uncertain nonlinear dynamics of time series data from special events, because most of the real applications are complex and nonlinear in nature (De Gooijer and Hyndman, 2006).

To tackle these problems, we proposed an identification approach for detecting and forecasting subway passenger flows under special events. This approach does not require any prior information regarding the events and only relies on limited observational subway passenger flow data. To achieve this objective, we proposed a novel class of *multiscale radial basis function* (MSRBF) networks to represent the underlying dynamics of the abnormal subway network. Generally, a conventional single scale or kernel width RBF network means that all basis functions have only a common single scale, or each basis function has a single individual scale. By contrast, the new RBF network in this work is employed as a number of multiscale basis functions, where each basis function contains multiple scale kernel widths. The detailed procedure of constructing an MSRBF network is as follows. First, in the MSRBF network, some unsupervised clustering algorithms, such as the fast fuzzy c-means clustering approach, are initially adopted to pre-cluster and determine the positions or centers of the basis functions. Second, for each selected center, the associated kernel widths (scales) are determined heuristically, and the selected centers and scales are then restricted to a fixed grid. Finally, an MSRBF network is converted into a model with linear parameters. An effective matching pursuit orthogonal least squares (MPOLS) algorithm (Billings and Wei, 2005), together with a generalized cross-validation (GCV) criterion (Li et al., 2011b, 2011a), is then applied to train the MSRBF network. A parsimonious model that only includes a relatively small number of regressor terms is likewise achieved and further used to predict the abnormal subway passenger flow at least 30 min ahead. Different from the majority of existing literature on passenger flow prediction, one of the advantages of the proposed algorithm is that it is capable of predicting station-level passenger flows by considering network knowledge and of ranking the relative contributions of other subway stations on prediction. Before the sudden rise of passenger flows at a certain station can be observed, there may be several other stations with high fluctuations of passenger flows. The irregularities of passenger flows for these stations are highly related to the occurrence of passenger flow