Real-time Monitoring of Ready-Mixed Concrete Delivery with an Integrated Navigation System

Ming Lu, Xuesong Shen, Hoi-Ching Lam

Dept. of Civil & Structural Engineering, CSE
Hong Kong Polytechnic University, HKSAR, P.R.China

Wu Chen

Dept. of Land Surveying and Geo-informatics, LSGI
Hong Kong Polytechnic University, HKSAR, P.R.China

Abstract. The escalating scale and growing complexity of ready-mixed concrete (RMC) delivery operations have challenged current methods for monitoring RMC delivery and dispatching truckmixers by two-way radio voice-based communication and experience-driven management. This paper describes an integrated navigation system, based on Global Positioning System (GPS)/Dead Reckoning (DR)/Bluetooth Beacon (BB) and Global System for Mobile Communication (GSM) technologies. The application of the integrated navigation system in tracking RMC truckmixers on and off Hong Kong construction sites is presented. The system performance in terms of positioning precision in tracking RMC truckmixers is analyzed. In addition, the readily available data of event times resulting from tracking RMC truckmixers is found conducive to high-end simulation modeling for productivity analysis and improvement in construction.

Keywords. Integrated Navigation, Concrete, Monitoring, Wireless Communication.

1 Introduction

Steady growth in urban infrastructure developments and commercial and residential developments will sustain the heavy demand and usage of Ready-Mixed Concrete (RMC) in major cities in the years to come. The quality control and monitoring of concreting construction is drawing increasing attention by specialist managers in construction and the general public. Meanwhile metropolitan areas typically adopt the one-plant-multisite RMC production and supply system, according to a study

benchmarking the performance of concrete placing in buildings of Hong Kong, Beijing, U.K, and Germany (Lu et al., 2003). Hence, more systematic and advanced technologies for real-time tracking of truckmixer operations and monitoring RMC delivery are required, to improve the status quo of managing RMC delivery logistics.

The research is to develop a real-time monitoring platform of RMC delivery based on automated and reliable methods so as to realize: (1) real-time locating the RMC truckmixer on the move between a batch plant and construction sites; (2) collecting the event times of the RMC deliveries automatically for keeping quality control records and for further modeling analysis leading up to optimized management strategies; (3) enhancing the reliability and convenience of the communication between the truckmixer drivers and the control center via the vehicle-borne positioning and communication units.

To facilitate the monitoring of vehicles, materials and labor in construction, many previous research applied quantitative methods to perform orbital tracking and data collection. Jaselskis et al. (1995) described potential applications of the radio frequency identification tags (RFID) technology in the construction industry. For instance, RFID allows the identification of construction vehicles along with the materials being carried as they pass through electronic check points. Navon and Goldschmidt (2002) proposed a conceptual model based on the Ground-based Radio Frequency stations, using the same principles as GPS, to locate and monitor labor activities in a building site. Limited works can be found in literature about the monitoring of RMC, even though the importance of RMC quality and status monitoring during delivery has been widely recognized. In order to meet the practical requirements, and to validate the usefulness of emerging technologies for monitoring RMC

delivery an integrated navigation system, based on Global Positioning System (GPS)/Dead Reckoning (DR)/Bluetooth Beacon (BB) and Global System for Mobile Communication (GSM) technologies, is developed and its applications described in this paper.

The present paper first overviews the monitoring system design with respect to (1) integrated navigation technology, (2) event time collection and (3) wireless data communication, followed by a case study conducted in Hong Kong for analyzing the performance of the system, especially for demonstrating the positioning precision in tracking RMC truckmixers on and off a construction site and ready availability of event times resulting from tracking truckmixers. Such data is conducive to high end simulation modeling for productivity analysis and improvement. Finally, conclusions are given on this research and recommendations for future work made.

2 Development of RMC Transport Monitoring System

Because of the time-sensitive nature of RMC material, overdue RMC deliveries (unexpected extension of the RMC delivery time) may compromise concrete quality, resulting in concrete joints, water leakage, and potential structural hazards. Concrete starts to set after being mixed and is unsuitable for placing once the time between the start of loading at plant and the finish of unloading on site is over 105 minutes according to Hong Kong's practice. However, unlike monitoring other construction resources (materials or labors), whose orbit can be tracked by attaching positioning sensors to individual resource units, such as RFID tags, RMC could not be discretely supervised due to its continuous near-liquid state. Therefore, it's proposed in this research to track the truckmixer, the carrier of RMC, for obtaining and analyzing important event times associated with RMC

delivery. And an integrated positioning and navigation unit on board the truckmixer was developed and field tested. Real-time location and status of the truckmixer in the cyclic RMC delivery process alongside event times could be transmitted to the Control Center of a RMC batch plant) through wireless data communication channels.

2.1 Integrated Positioning & Navigation

At present, an array of technological tools is available to deal with land vehicle positioning and navigation. These include Global Positioning System, Dead Reckoning, Radio Beacon and so on. The integrative use of data from GPS, dead reckoning and Bluetooth Beacon is considered a cost-effective solution to RMC truckmixer positioning and tracking.

(1) Global Positioning System. GPS has been widely used in vehicle navigation due to its high accuracy and cost-efficiency. Accuracy of the order of 10-20 m is now possible after the US Government removed Selective Availability (SA) restrictions on 1 May 2000 (Ochieng et al., 2002). To obtain the positioning information of a fix, signals from at least four satellites are required. To achieve accurate positioning of truckmixers with GPS alone in the highly dense urban areas and harsh construction sites is difficult due to satellite masking and serious multipath errors from high-rise buildings and the enclosed environment of a building site under construction. (so-called urban canyons areas). A recent study to characterize the performance of GPS in a typical urban area of Hong Kong Island showed that only around 50% of the test area is receptive of GPS signals (Lu et al., 2002). Moreover, for those accessible control points, the positioning error with GPS is found to be significantly large, over 40% of points greater than 20 m and 9% of points greater than 100 m.
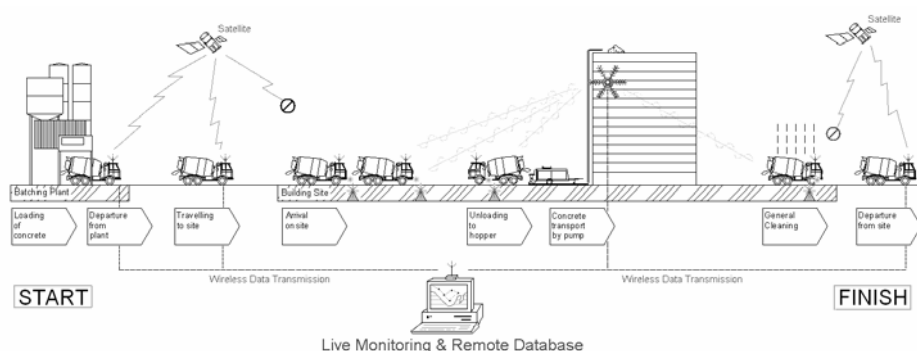

Fig. 1 Process of RMC delivery with truckmixers

(2) Dead Reckoning. DR is a positioning technique based on the integration of an estimated or measured distance

vector. The system is derived from two or more sensors that measure the heading and displacement of a vehicle.

Usually, gyroscopes are used to measure the heading rate and the odometer is used to measure distance. In contrast to GPS, DR systems are self-contained and require no external motion information for positioning. On the downside, data from inertial sensors drift with time. Additionally, any small constant error increases without bound. Therefore, inertial sensors are unsuitable for accurate positioning over an extended period of time.

(3) Bluetooth Beacon. The Bluetooth wireless technologies is an emerging technology originally designed as a short-range wireless connectivity solution for personal, portable, and handheld electronic devices (Hallberg et al., 2003). Bluetooth radio can be classified into three power classes, according to the transmission power. The working range of Bluetooth varies from 10m to 100m, depending on the power class of the device. The present research has drawn on the Bluetooth technology developed for navigating the vehicle through urban canyons areas (Xiong et al., 2002). The technology is also potentially applicable to on-site construction resource positioning by spacing Bluetooth Beacon in the key locations of the construction sites.

In the integrated scheme, optimal Kalman filter is adopted to integrate GPS/DR information following the concept of loose coupling, which means the system could calibrate DR errors in real-time when GPS functions well, and where GPS is unavailable, impermanency DR could sustain positioning independently. In the mean time, in case that GPS is unavailable for relatively long time, errors of DR drift with time severely degrade the system performance, Then the Bluetooth Beacons spaced along the vehicle travel route on and off construction sites supplement in performing accurate point positioning, which are actually used to calibrate errors as an emergent positioning assistant to GPS/DR.

2.2 Event Times Collection

The cyclic process of RMC delivery between the batch plant and construction sites (as shown in Fig. 1) consists of five activities: 1) loading concrete into the truckmixer at the batching plant; 2) the truckmixer traveling to a specified site; 3) waiting for unloading the truckmixer on site; 4) unloading using a particular placing method; and 5) the truckmixer returning to the plant. The key objective of truckmixer positioning research is to extract valuable event times, from which travel times along travel routes, on-site queuing times, and unloading times et al could be derived for (1) quality control record keeping, (2) analysis of logistical efficiency of RMC deliveries, and (3) support of further RMC production-delivery-placing operations simulation modeling and productivity improvement.

To collect the event times automatically entails application of two feasible data-capturing techniques. On one hand, with accurate positioning of the truckmixer, event times, such as reaching or leaving the plant and sites, could be extracted conveniently by matching real-time truckmixer's positions to specified locations of the plant or sites in a digital map (GIS). Status of the truckmixer thus could be updated as location-stamped events are updated with time. On the other hand, the location matching approach would fail given that more than one event of the truckmixer overlap in GIS, e.g. the on-site waiting event and the unloading event occur sequentially in time at the same location in a site. Therefore the research has resorted to additional signal collection techniques to record the unloading time point: the time-stamped signal can be collected as the result of pressing the unloading button near the dashboard of the truckmixer, or alternatively, from the locomotor sensor mounted in the vehicle.

2.3 Wireless data transmission

Real time data communication from the truckmixer and the Control Center is vital to monitoring the motion and status of the RMC truckmixer. Two-way radio based on voice communication has been widely used due to its low cost in operation and flexibility in system's configuration. However radio waves traverse only a limited range, which is inadequate for covering truckmixers' operations in a metropolitan area. Standard cellular phones communication based on GSM/GPRS (General Packed Radio service) network can overcome the range limitation of radio communication, also such text-based communication systems present many advantages over voice-based system, for example, the text message could be time stamped, queued, easily interpreted without error (Naresh et al, 1997). So in this research of RMC truckmixer tracking, the Short Message Servers (SMS) of GSM is utilized for wireless, real time data transmission (Fig. 2).
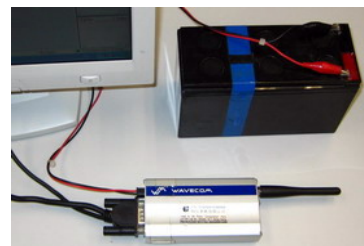

Fig. 2 Wireless data communication based on GSM/GPRS MODEM

One SMS contains up to 160 letters, which is enough to relay current location and status information of a truckmixer. The tracking SMS mainly comprises of time, position (latitudinal and longitudinal coordinates), heading, and also specifics of RMC (quantity, temperature, et al). In contrast with the data

communication means of GPRS, the frequency of sending SMS over GSM is set to be more than 30 seconds per message (usually 1 minute), which limited by the response of GSM network servers. Yet this frequency is considered adequate for the RMC truckmixer monitoring application.

3 Case Study

The real-time RMC monitoring system was developed under the framework of the GPS/DR/BB integrated navigation system. Two prototypes were mounted on one truckmixer owned by our industry collaborator −Heng Fai Ready-Mixed Concrete Corporation, Hong Kong− (Fig 3), and tested for 6 months in 2005. The objectives of the experiments are: (1) to confirm the positioning accuracy of the integrated navigation system under the practical constraints, as compared with the performance of GPS alone; (2) to validate the event times automatically collected, by checking against the manual records; and (3) to test the reliability of using GSM/GPRS SMS based communication for real time data transmission.

Fig. 3 Prototype of the RMC monitoring system and site trials on the truckmixer

Truckmixer tracking records with time and dynamic status stamped was sent to the Control Center and projected to a digital map, with the updating rate of one point per minute as demonstrated in Fig. 4. Details of the tracking records, such as time, position (latitudinal and longitudinal coordinates) et al, were also saved in a Microsoft Access database (Fig. 5).

Fig. 4 Tracking result to Site Tung Chung

Fig. 5 Record data format

In tracking a truckmixer traveling to different sites, the positioning accuracy of the GPS could suffer severely from blocking and multipath of satellite signals along specific routes, especially in highly dense metropolitan areas. Statistic analysis of truckmixer positioning data for three building sites in Hong Kong reveals the percentage of positioning with error less than 10 meters is only 48% by GPS in a site located in Causeway Bay, Hong Kong Island, and increases to 82% by applying the integrated solution. While the accurate positioning percentages (10m) also increase significantly to 90% and 93% as of the integrated system, from 72% and 80% as of GPS for a Mong Kok site and a site on HK PolyU campus, both of which are situated in Kowloon, Hong Kong, which is a less dense district in comparison with Causeway Bay (Fig. 6)..
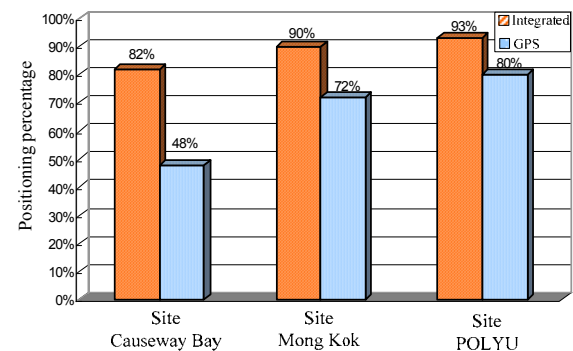

Fig. 6 Positioning percentage within 10m in three Hong Kong sites

Despite the minor variability of positioning accuracy in different areas (82-93%), the integrated navigation system is found reliable and accurate for collecting key event times of truckmixers in real time. The accuracy could be further upgraded by placing more Bluetooth Beacons in the control points of those special sites, such as entrance, unloading bay, washing bay, and exit. Table 1 shows a glimpse of one-day tracking results (three to five trips to deliver RMC to different sites), which were recorded accurately and proved to represent the actual operations of the truckmixer being tracked.

Table 1 Event time collection of RMC delivery

Truckmixer ID: NU0001						Date: 23 August, 2005
No.	Loading	Dispatch	Arrival		Unloading	Depart
			Site ID	Time		
1	9:08	9:15	001	10:00	10:08	10:20
2	11:42	11:48	001	12:20	12:32	12:50
3	13:50	13:57	002	14:46	14:57	15:20
4	16:00	16:11	003	16:45	17:02	17:22
5	18:05	18:15	004	18:24	18:37	18:58

As for the SMS-based wireless data communication applied in the system, frequency of one minute per message could satisfy the requirement for real-time monitoring and automated data collection. However, potential instability of data transmission such as communication blockage and time delay were experienced for a short period due to limited network bandwidth, especially during rush hours of data flow.

4 Conclusion

The present paper has proposed an innovative approach to monitor RMC delivery in the urban construction industry, based on the GPS/DR/BB integrated navigation system mounted in the truckmixer - common carrier of the RMC. Feasibility of automated event time collection and using GSM networks for wireless data communication under the practical application requirements were also explored. Experiment results from six months site trails has revealed positioning accuracy with the integrated navigation system on and off Hong Kong construction sites, ready availability of event time collection and reliability of text-based SMS data transmission. The integrated navigation system is found reliable and accurate for collecting key event times of truckmixers in real time, achieving 82-93% positioning accuracy within 10 m. Follow up research will address (1) increasing positioning accuracy of the system especially in sites located in urban canyons; (2) exploring more reliable data communication technologies, such as GPPS based on data flow; (3) extending RMC monitoring from on-route to on-site, which could significantly broaden the application value of the system in construction management.

Acknowledgement

References

Lu M., Anson M., Tang S.L., and Ying Y.C. (2003) ***HKCONSIM: A practical simulation solution to planning concrete plant operations in Hong Kong.*** J. Constr. Eng. Manage., ASCE, 129(5), 547-554.

Jaselskis E.J., Anderson M.J., Jahren C.T. and Rodriguez R. (1995) ***Radio-frequency identification applications in construction industry***. J. Constr. Eng. Manage., 121(2), 189-196.

Navon R. and Goldschmidt E. (2002) ***Monitoring labor inputs: automated-data-collection model and enabling technologies***. Automation in Constr., 12(2), 185-199.

Ochieng W.Y. and Sauer K. (2002) ***Urban road transport navigation performance of the global positioning system after selective availability***, Transportation Research Part C 10. 171-187

Lu M., Chen W. and Chan W.H. (2004) ***Discussion of 'Building Project Model Support for Automated Labor Monitoring' by R. Sacks, R. Navon, and E. Goldschmidt***, ASCE's J. of Computing in Civil Engineering, 18(4), pp 381-383.

Hallberg J., Nilsson M. and Synnes K. (2003) ***Positioning with Bluetooth***. ICT 2003: 10th International Conference on Telecommunications. Vol. 2, 954-958.

Xiong H., Liu J., Chen W. and Sun Y. (2002) ***Application of Bluetooth technology in vehicle navigation***. NAVITS 2002, Nanjing, China.

Naresh A.L. and Jahren C.T. (1997) ***Communications and Tracking for Construction Vehicles***. J. Constr. Eng. and Mgmt., 123(3), 261-268.