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A labor consumption measurement system based on real-time tracking technology for dam construction site

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ABSTRACT

The aim of the study presented in this paper is the development of a labor consumption measurement system based on real-time tracking technology for use on a dam construction site. Such technology includes Global Positioning System (GPS), and Geographic Information System (GIS). The system is three-layered and aims to solve several labor computational and usability challenges. The software for processing the collected data, presenting real-time site state visualization, and the accurate analysis of on-site labor consumption is run by smart phones with GPS devices, on-site private wireless base stations, and servers. The benefits of this quantitative labor consumption measurement approach for hydropower projects include the provision, for each dam monolith, of precise information regarding both the number and category of laborers together with their respective working hours. Such knowledge provides adequate quality management information for the owner and the supervisor and importantly aids payment negotiations with contractors. The proposed system was firstly applied to the world's third largest hydropower project. On-site tests successfully demonstrated the feasibility and effectiveness of the whole system. The results achieved show that the system is able to log entire on-site trajectories of laborers, and calculate the accurate labor consumption of each dam monolith.

1. Introduction

Despite the rapid development of China's construction industry which reached about 2,200 billion dollars in 2012, many problems still exist, especially as regards cost and quality management [1]. Because of the fiercely competitive environment of China's construction industry, contractors generally win tenders at the minimum profit level. It is hoped that any loss will be recovered at the final payment phase [2,3]. In the light of this "minimum profit level" practice, the number of construction claims and disputes has been gradually increasing to the point of being a burden to the construction industry [2,4]. Labor costs are one of the greatest risks in cost management and such costs, are often the biggest part of the overall variable cost in many civil construction projects, and as such present the largest single area of overrun [5]. The payment for contractors in hydropower projects is based on bills of quantities. Unit rates including the labor cost for different work items are fixed in contracts. However, in practice, as implied above, there are still work items that do not have pre-determined unit rates, such as extra work, day-works, and claims. These items make up a significant part of construction cost and obviously are the main reason for overruns. The additional labor consumption and increased labor rates involved are considerable components of extra work, day-works, and claims. The labor force is also an important factor in quality management, and thus a shortage in this area is likely to lead to quality problems [6].

Project management systems on large dam construction sites currently have weaknesses in labor force management. Firstly, the assignment of man hours to tasks is both normally managed and therefore known only at foreman level. The owner and the supervisor generally have no precise knowledge of the number of laborers and corresponding working hours involved. Secondly, because the specification of a project is not always completely defined, it is not possible to exactly pre-determine the number of man hours required. Thus the field foreman has room to arbitrarily assign and report those man hours actually used. Thirdly, the labor force is both large and dynamic making working hours difficult to measure [7]. Thus without a reliable labor consumption measurement and data gathering system on site, this arbitrary practice has significant disadvantages to owners and supervisors both financially and otherwise. During the construction period, variation orders and subsequent time extensions also provide chances to recover those losses resulting from low profit tendering and as stated above, it is believed that inflated information is given to owners by some foremen and contractors, with the objective of limiting losses caused by the deliberate tender underestimation costs. Money is also often clawed back during fixed-rate works as some contractors may use a smaller labor force on site than that recorded in the Work Breakdown Structure

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(WBS) previously checked and accepted by the owner and the supervisor. As strongly stated above, at the actual construction stage, the owner and the supervisor have no effective way of knowing the true labor consumption and therefore whether what is reported is accurate. Bogus reports and asymmetric information of labor consumption contribute to what is in essence almost an enforced blind acceptance, by the owner, of the contractors' claims and the related dispute payment negotiations [8,9].

A hydropower construction site, the test case used in this study, is highly complicated, usually involving thousands of separate pieces of work. If a claim is involved, the representatives of different parties generally hold different beliefs about the same facts [8,10]. In order to reach an agreement regarding settling a claim, a detailed examination is necessary. Traditional claim examinations involve establishing legal and factual grounds on which the claim is to be based. Such issues are likely to be investigated by resident supervisors of the project. The primary sources for claim examinations are such as project files, memos, and video footage. These are used to provide proof of the cost elements of the claim [11]. These sources do not reveal the number of laborers and their time spent, the latter being essential parts of the claim cost. Because the information is role-dependent and incomplete, as indicated above, it is common for contractors to inflate the labor consumption and labor rate to maximize any financial benefit during the claim negotiation. Meanwhile the owner does not have any technical basis upon which to counteract or adjust the contractors' demands [12,13]. Such a basis could only be founded on information presented by a substantial number of supervisors who were continuously present on site during the operations and who had the means to carry out uninterrupted and unremitting counting of laborers and hours worked. It is unlikely that such a performance would be possible or economically viable. Quality management undergoes similar problems as in these cases there are the same opportunities for incorrect inflation of time and cost. Hence it appears increasingly likely that an accurate count of labor numbers and the quantity of working hours can only be achieved by using reliable and user friendly automated tracking technology.

Information management systems including real-time monitoring or tracking technologies have developed rapidly and been widely applied in the construction industry [14–18]. Most studies focus on Health and Safety (H&S) management [19–21]. Some also discuss labor productivity management applications [22–26], but few studies have developed a product-level monitoring system for actual construction sites. In China, bogus labor cost reports focusing on the work of contractors appear frequently. These reports deal with topics related to sustainable development in the construction industry, especially in the field of hydropower construction where most projects have a heavy monetary investment. A demand for an anti-fraud labor management system for cost control and also for quality control has recently been strongly requested by hydropower owners and supervisors.

Driven by the above demand, investigative work has commenced in this area. This paper presents the development of a labor consumption measurement system for large hydropower projects based on a real-time tracking technology, combining GPS, GIS, and 3rd Generation (3G) networks. Using this system, the owner and the supervisor are able to conveniently track all laborers on site in real time, via web sites, aided by the use of personal computers (PC), tablet computers, and smart phones. By setting the query criteria, managers can get the number of different types of laborers and their working hours over the period of a bid package or a claim. By having possession of such data, construction project owners and supervisors have sound knowledge of details of the labor consumption before any time and cost disputes arise. Likewise such information is available during negotiations with contractors.

The rest of this paper is organized as follows: Section 2 gives a review of the most relevant technological background, while in Section 3, the system architecture, including hardware, software, and the core algorithm, is reported. Section 4 describes a demonstration to test the validity and stability of the whole system, and to estimate the precision of the labor consumption measurement method. A discussion of the studied topic plus suggestions for future work in this field are given in Section 5. Conclusions are given in Section 6.

2. State of the art

2.1. Tracking techniques

In recent years, many researchers have carried out substantial work on investigating tracking technologies and their applications which cater for various needs in the construction industry. As indicated above, owners and supervisors of construction projects have been positive about the need for the utilization of such technologies on construction sites. It is noted that their use would contribute to higher work performance and encourage better safety control and management [21] both remotely and in real time. To date, several tracking technologies have been demonstrated and are cited as follows: Radio Frequency Identification Device (RFID), Global Positioning System (GPS), Wireless Local Area Networks (WLAN or Wi-Fi) [27], Ultra-Wide Band (UWB), Zigbee, and Indoor GPS. These technologies have the ability to cover a wide range of activities and give relatively accurate results [28].

The RFID method has been found to be unsuitable for ubiquitous real-time tracking on large construction sites because of its limited communication range [29]. Most RFID research based applications focus on small range indoor positioning in supermarkets and hospitals [30,31]. WLAN and Zigbee based methods provide an accuracy of 1–3 m and communication ranges of no more than 100 m. For accurate tracking and data uploading, a certain quantity of access points (AP) and base stations are necessary [20,32]. This naturally raises potential problems regarding installation in the complex area of a construction site. UWB technology achieves accuracy which fluctuates between 0.1 m and 0.5 m [21]. Indoor GPS performs better as its mean bias is between 0.01 m and 0.02 m [28]. The disadvantage of UWB and indoor GPS is that these two technologies have a high cost and no mini device or daily-necessity-embedded tool exists for the implementation. The civilian GPS (defined as the GPS services with relatively low accuracy available for civilians) provides an accuracy which fluctuates between 5 m (adopting a dedicated correction system) and 15 m (without correction) [33]. The GPS technology coverage area is almost the whole surface of the earth and except for a portable receiver, no additional facility needs to be installed on site. Another GPS advantage is that it has become a standard and embedded component of a smart phone. With the popularity of smart phones [34], the application of GPS technology is easier to assign to laborers on site.

Over the past few years, many studies have focused on improving the accuracy and stability of civilian GPS. For example, an Inertial Navigation System (INS) or other motion measurement systems have been used together with GPS [35] in order to provide a complete service when the necessary satellites are not visible. In other research studies, vision features extracted from a laser scanner or a digital camera are fused with digital maps and GPS/INS localization measurements to achieve better accuracy [36]. Assisted Global Positioning System (AGPS) or in other words a GPS with the assistance of the omnipresent mobile network resources is an efficient method to improve the accuracy and reduce the time for the initial GPS establishment [37].

It is well known that GPS will work independently (defined as a device that does not require any technological installation), and is therefore suitable for the complex environment of a construction site. GPS devices are affordable and have become standard smart phone accessories. Hence GPS technology is easy to combine with wireless networks to implement remote real-time monitoring. The location data provided by GPS are geographic coordinates which can be analyzed with relatively little computational effort. Its theoretically unlimited operational scope also makes it suitable for large construction sites. As AGPS is integrated in most smart phones, the location accuracy which