Automated Data Acquisition for On-Site Control

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Abstract: The purpose of this paper is to highlight the need for automated real-time project control, as well as to present a model for such control, based on Automated Data Acquisition (ADA). The idea behind the present development is to determine if measuring the location of workers, or other mobile agents on-site, at constant time intervals, using remote sensing, provides the required control data. The ideas developed here can also be implemented for navigating and controlling construction robots.

1. INTRODUCTION

Real-time control of on-site construction is essential to identify discrepancies between the plan and the actual performance, in order to take immediate corrective measures and to reduce to a minimum the damages caused by the deviations. The later the deviations are discovered, the more serious the potential damage is, and the more complex and costly the corrective measures must be. High quality data is needed not only for real-time control of current projects, but also to update historic databases. Such an update will enable better planning of future projects in terms of costs, schedules, manpower allocation, etc.

Based on today's practice, in order to collect control data in a building project accurately and in a timely manner, one needs to employ controllers to measure the time it takes to construct each element, record the number of workers in each crew, and calculate the respective quantities. The inputs can then be calculated on the basis of this data. For the control, one must compare the measured (actual) inputs to the planned ones and check their effects on the cost estimate, on the schedule, on the work methods, etc. Because such data collection is very expensive and time consuming, many construction companies do not perform much control and even less so in real-time. At best they use crude control methods which are normally based on accounting data. These methods are only capable of giving data quite some time after the controlled events took place. Consequently, they do not permit an analysis of the causes for deviation, nor do they enable corrective measures to be taken for the current project to reduce the damage. Sometimes project managers and/or foremen do perform some control on-site, but this is normally not done systematically, it is done at very long time intervals and, in many cases, it is based on intuitive data.

Construction has no theory of process control [1]. Most of the control efforts to date have been made to develop cost control models [e.g. 6]. These models do not take advantage of the emerging new technologies, such as project modeling and Automated Data Acquisition (ADA). Very limited work has been published relating to using the latter in construction [14]. The present paper demonstrates the potential of the new technologies for real-time on-site control.

2. OBJECTIVES AND METHODOLOGY

The main objective of the present research is to develop a model for on-site control based on ADA. As this is a new idea, this research attempts to check its feasibility; determine the needs for information flow among the pertinent construction management functions; identify enabling technologies for ADA needed to support the real-time nature of the model; develop an ADA model, which is capable of capturing and feeding the control model with the needed data in real-time; develop a model for real-time control; and try it in a construction project.

The research methodology consists of two major activities. The first involves the understanding of concepts and principles relevant to the model and its enabling technologies. The second involves the development of the models and their implementation. The research methodology involves the following steps:

1. A literature review, pertaining to control methods, and to ADA technologies.
2. Determination of the operating environment of the model.
3. Development of a conceptual control model, including the following steps:

Identification of potential technologies for ADA.

Determination of the data flow.

Determination of the data types and structures.

Determination of the decision-making hierarchy.

Development of algorithms.

Investigation of user interface aspects.

4. Implementing the model by computerizing it.
5. Testing, evaluating and verifying the model, including the following steps:

Field data collection from a real project.

Calculation of the actual work in that project.

Testing the computerized model using the data collected in the field.

Comparison of the results with the actual work inputs.

3. PRINCIPLES OF PROJECT CONTROL

Project control can be defined as *identification of deviations between the desirable and the actual performance.* The performance is evaluated for this purpose by measuring *project indicators*, such as cost, time, quality, resource utilization, etc. The control is done to enable the project management to take corrective measures, and to update historical records in order to improve future planning. The problem with the above definition is that it is very difficult to determine the *desirable performance* of project indicators. This is due to the diverse nature of construction projects -- even *identical* projects are normally built under different conditions. Consequently, the tendency is to equate the *desirable* performance with the *planned* one. This approach is adopted in the present paper.

Project control is, therefore, done by *measuring* the *actual* performance of the controlled indicator and comparing it with the *planned* one. Manual detailed measurement of some of the project indicators is time consuming and labor intensive, which is probably why those indicators are not controlled in detail and even less so in real-time. Infrequent, non-detailed control does not enable corrective measures to be taken.

On-site construction can be viewed as a process, which transforms resources into the final product. The inputs of those resources are some of the indicators to be controlled. Project control has three elements: (1) data collection, which measures the actual performance; (2) comparison of the collected data to the planned performance; and (3) an action. If there is no deviation between the planned and the actual performance, the process continues as planned. On the other hand, when a deviation is detected, the action depends on the source of the deviation. If the cause for deviation is the performance (i.e. the performance is different from the plan), the project manager analyzes the reasons for it and takes immediate corrective measures. Otherwise, it can be assumed that incorrect inputs were used for planning, which means that the plan itself has to be changed. At the same time the historical records can be updated.

4. PROJECT MODELING

The control model is an integral part of a comprehensive approach to the automation of the construction process called Computer Integrated Construction (CIC). It is described in numerous publications [e.g. 3, 8, 9, 15]. In CIC all the activities are carried out with the aid of computers, starting with design, through construction planning, to the actual on-site construction. The latter is supported with various construction management software tools and is performed by robots.

The CIC approach is based on the concept of a project model, which includes a physical description of the building and a description of the activities needed to construct it. The project model evolves with the project itself, being able to supply the needed data at each development stage to all the participants of the process. Thus, hard copy production is not needed for communication within the process itself, but might be produced for other purposes.

Numerous research efforts to develop project models have been made [e.g. 4, 12, 13]. The object oriented (OO) project model enables one to generate, store, process, and transfer all the data relating to the project at all stages of the construction process. It includes information relating to the physical description of the building, construction planning information, and resource-inputs data. The project's OO database is initiated at the beginning of the process, while defining the owner's requirements, and accompanies the process up to the delivery stage. The as-made project model is used later during the building's life for maintenance and remodeling purposes.

The present work assumes that a project model is available. Consequently it makes use of the potential advantages and relates to them as given.

5. THE CONTROL MODEL

The present model (schematically described in [5]), pertains to one of the more challenging issues of project control, namely the control of inputs on-site. A number of assumptions are made for the development of the model, the most important of them are:

- Knowing the ~~worker~~ mobile unit's location enables one to determine the activity it is engaged in. Algorithms that determine these activities, based on the unit's location, are currently under development. A detailed description of these algorithms will be given in the presentation.
- Design and planning of the controlled project are carried out according to the project modeling approach as presented in Section 4 above. This enables the assumption that data relating to the physical facility (geometry, topology, locations, etc.) and to the plans (schedule, planned inputs, etc.) can be extracted automatically from the project model database, as described in detail in [11,8 and 9].

Detailed scheduling data is available from the project model database. The detailing level of the control model depends on the detailing level of the schedule. If a "work section" for a typical crew is defined as an apartment, or the entire floor, the control output will pertain exactly to the same work section. In order to give enough time to analyze the causes for deviations and to take corrective measures, these work sections must be small enough, yet not too small, to make the planning too tedious. It is suggested, therefore, that a work section be defined as the *portion of a project where one, and only one, crew is performing at any given time.*

The model is designed to generate output in real-time, which means that it can report about actual manpower-inputs of an activity no later than 1 - 2 days after it has been completed. This can be done at a reasonable cost only if data, needed for the control model, is collected automatically. To calculate the actual manpower-inputs the model needs to determine the physical quantity of work for the given work section (e.g. m^2 of painted wall) and the time the crew spent performing that work. The physical quantity can be

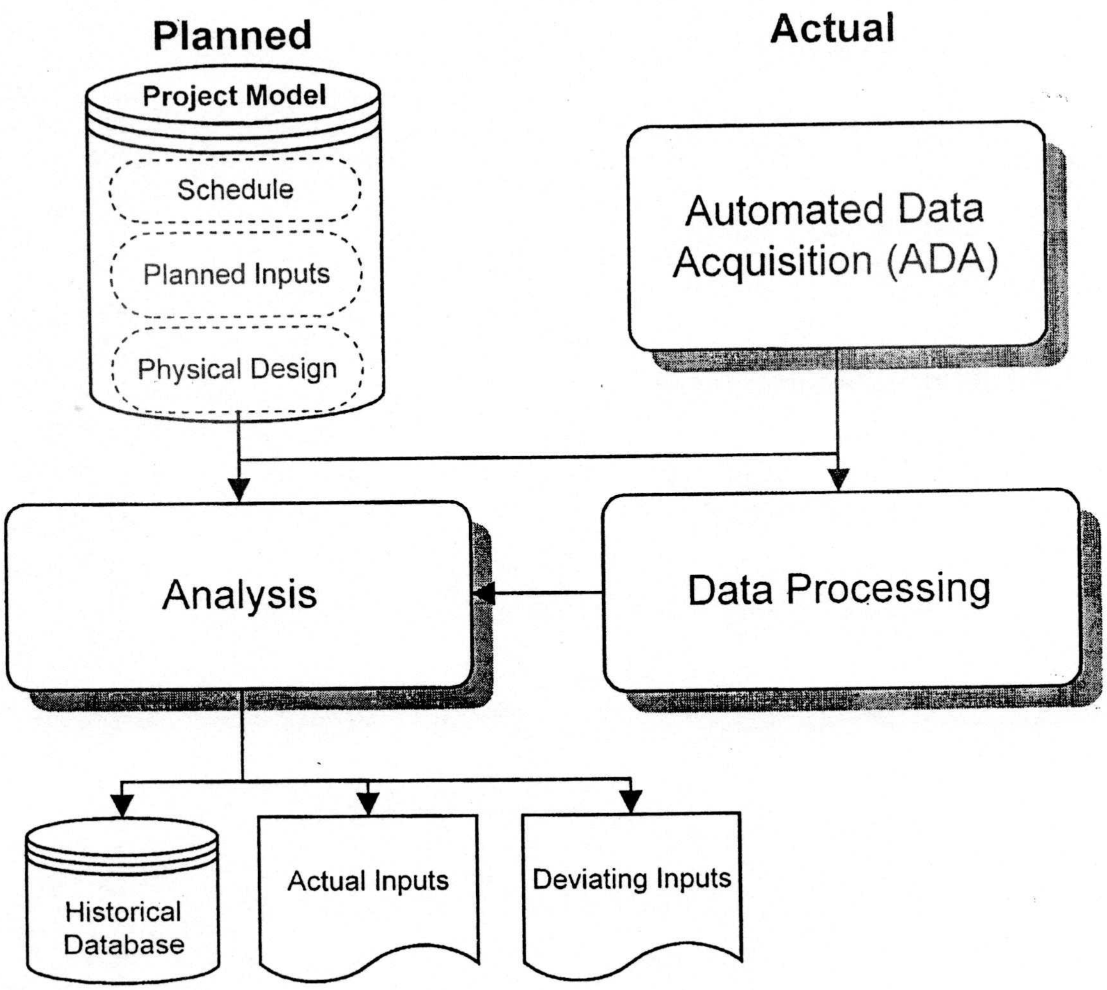

FIGURE. 1. A conceptual description of the control model.

automatically extracted from the project model. The present model extracts from the project model the following information:

- The planned schedule, which is updated periodically by the project manager.
- Location, orientation, topological, and geometrical information regarding the various building elements.
- Planned inputs for the project.

The idea behind the development of the present model is to use the data acquired automatically about the **location** of the crew members to determine the **time** it took to perform the activity. This is done by associating the location of the workers, at constant time intervals, to a physical element. The present model is designed to be fully automatic – a different approach, using Radio Frequency Identification (RFID) technology was presented by [7]. According to the schematic model presented there, the worker's arrival to the site, and movement between tasks, are recorded automatically, but s/he has to record the cost code of the various activities s/he was engaged in using a hand-held computer. The British Research Establishment has presented another approach to manpower-inputs measurement, using a full time observer(s) and a hand-held computer [2]. This measurement technique uses a human observer(s) who tours the site at regular intervals and records the tasks being undertaken.

The model (depicted conceptually in Fig. 1) consists of three modules: (1) Automatic Data Acquisition (ADA) of the mobile unit's location as function of time, (2) Data Processing, and (3) Data Analysis. The ADA is performed in real-time, the data processing and analysis are performed at the end of each working day upon receiving the data from the ADA module.

5.1. Automated Data Acquisition

The ADA module uses remote sensing technology to measure the location of each mobile unit at constant time intervals. The data collected for each unit is: the time, its global location, and its identification. Records containing this data are transferred to the data processing module. It is assumed that the mobile unit's location at the time of measurement represents its location during the entire time between two measurements.

The remote sensing technology selected for the ADA is Ground Based Radio Frequency (RF). A typical system of this kind computes ground positions using stationary transmitters (reference stations) to compute the position of a mobile object using the trilateration principles. The proposed system includes three, or more, reference stations, installed in key locations on-site (Fig. 2). In addition the system includes mobile units, and a Central Control Unit (CCU).

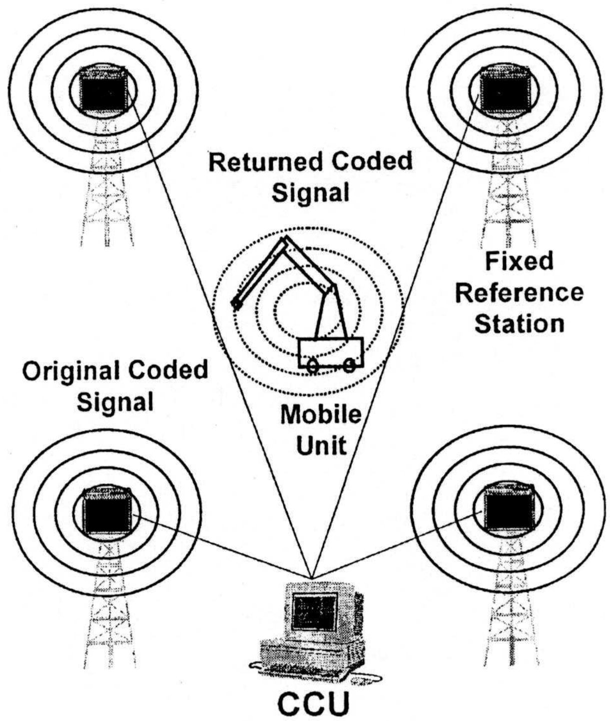

Figure 2. Ground based Radio Frequency Identification System

The CCU directly controls the fixed units (reference stations), indirectly controls the mobile ones, calculates the mobile units' locations, and stores the accumulated data, namely the mobile units' identifications, and their locations at all time intervals. The time interval (~ 5 - 30 minutes) will be determined by the required accuracy and its influence on the capacity of the system. At each time interval, the CCU initiates a measuring cycle by signaling all the fixed units, which, in turn, signal all the mobile units. After the returned signal is received, it is processed and stored in the CCU.

At each time interval, when signaled by the CCU, all the fixed units transmit a coded signal, which includes the station's identification. When these signals are received by the mobile units, they are decoded, the unit's identification code is added, they are coded again, and they are transmitted back immediately. When a fixed unit receives a returned signal, it records the time-of-flight (TOF). When the CCU identifies that a signal from a mobile unit was received by three, or more, fixed stations it calculates the unit's location according to the trilateration principles.

5.2. Data Processing

The objective of the data processing is to determine how much time every unit spends performing each activity. It is assumed that if a unit stays in the work envelope of a building element, it is performing an activity associated with that element. This assumption is currently verified by the field experiments and the results will be presented in the conference. A work envelope can be defined for this purpose as the *volume in the vicinity of the building element, where a mobile unit working on the element could be detected.* Every building element has a number of work envelopes, depending on the activity. For example, the work envelop of an activity 'painting' a building element 'wall', would be a prism of approximately the wall's planar measurements with a width of, say, ~1 m pointing towards the interior of the room. Consequently, in order to associate the units' locations to the activities, the work envelopes of all the building elements associated with the pending activities are calculated together with the quantity of work needed to complete each of those activities.

The last step of data processing is to calculate the time every mobile unit spends within the work envelope of each element (associated to the corresponding activities). This is done on the strength of data collected by the ADA Module, the time interval and the unit's identification, as well as the activity's work envelope. At this stage all the necessary data is available for the Analysis Module to determine which activities have been completed, to calculate the time it took to complete them and accordingly to compute the inputs.

5.3. Analysis

All the calculations are performed for activities that have been completed. Consequently this is the first decision made by the Analysis Module. Once the module identifies an activity that had just begun, it defines all its predecessors 'completed'. If an activity is not completed, the model continues to accumulate time for it. The *Actual Duration* is computed for each completed activity. The actual inputs are calculated based on these durations and the quantity of work needed to complete the activity. The actual inputs are then compared to the planned ones, taken from the Project Model. Detailed algorithms for the Data Processing and the Analysis modules will be given in the presentation.

5.4. Output

As mentioned above, the model is designed to give output in real-time. The output of the model is threefold:

1. Actual inputs, given in different sorting options.
2. A list of activities which deviated from the plan. The activities in this case are given for defined and controllable work sections of the building, such as an element, an apartment, the entire floor, etc.
3. Actual inputs for the update of the historical database.

6. CONCLUDING REMARKS

The purpose of this paper is to highlight an area in construction automation that needs to be addressed with more vigor. The paper suggests a schema for an Automated Data Acquisition System that can support real-time on-site control. Quite a lot of work still needs to be done for such a system to be fully operational, including further developments to project modeling and developments of detailed algorithms for the control model (this work is currently being carried out by the authors and the results will be highlighted in the presentation). Real-time control is imperative to incorporate robots in the on-site construction process, especially when a number of robots are employed together. Consequently, the ideas developed here can be implemented for navigating and controlling construction robots.

The approach to control presented here raises a question relating to what can be defined as 'the big brother syndrome', which is a potential obstacle because the workers may naturally resist being monitored. In the case of the Automated Data Acquisition presented here, there is no difference between this data being collected automatically or manually, as done by [2]. Additionally, the workers will have to realize that the purpose of monitoring is to provide the construction manager with information that will allow him/her to control inputs in order to identify problems and to take corrective measures. Examples of such problems may be: unsuitable work methods, missing equipment, tools or other resources, unclear instructions or drawings, etc. Clearly, the system **must not** be used for policing purposes, namely to identify workers who did not work honestly. A more comprehensive discussion regarding resistance to automation and ways to overcome it can be found in [10].

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