CONCEPTUAL DESIGN OF AN AUTOMATED REAL-TIME DATA COLLECTION SYSTEM FOR LABOR-INTENSIVE CONSTRUCTION ACTIVITIES

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OBJECTIVES

The objective of this paper is to describe a conceptual model of a real-time automated data acquisition system for monitoring labor-intensive construction activities. This system is in the very early stages of development. System requirements and Phase 1 development plans are outlined.

Prior to discussion of the proposed system, it is important to recognize the authors' perspective in this paper. The content is primarily directed toward the types of data necessary for evaluating labor-intensive construction activities. The focus is on potential technological solutions that may address the process of gathering data related to these information needs. Specific apparatus and operations are not included in the discussion.

BACKGROUND

Since the early 1980's, there has been considerable research interest in automating the design-construction process. This interest has been the greatest in the areas of robotics and artificial intelligence. In 1986, the National Science Foundation (NSF) sponsored four research projects related to construction robotics. In 1987, NSF plans to support a similar number of projects that focus on information flow across the design-construction interface. To date, much of the emphasis in construction automation has been on the macro level with special attention on the use of computer aided drafting/design systems and on the development of computer interface protocols and similar concerns.

At the project level, most of the attention has been on robotic applications and expert systems. Very little attention has been paid to the gathering of data needed by the large computerized integrated design systems that are being developed. Simulation and forecasting algorithms and expert system programs also must rely on project data. How these data will be efficiently and accurately collected is of great concern to the authors. It appears that the need for real-time feedback for project control purposes has largely been ignored as a focal point of research interest.

Labor-intensive construction activities on commercial building projects are the authors principle areas of interest. Aside from the initial work done by O'Brien at the University of New South Wales, Kinsington, N.S.W., Australia, little attention has been directed towards monitoring labor-intensive activities. Yet these activities are the most difficult to control and represent the area of highest risk to the contractor. Also, they represent a large part of the cost of a commercial project. Thus, worthwhile developments in this area can lead to significant improvements in cost, time, and quality.

Why automate the construction site data collection process? Previous research by the authors has demonstrated the lack of substantive research into cause-effect relationships at the site level. Such research requires micro-level performance studies. While some studies have attempted to quantify the effects on performance caused by overtime, weather, remobilization, manning level, repetition in the design of components, degree of management control, constructability, delays and disruptions, and congestion, the construction industry continues to suffer from the lack of reliable data bases. The databases used in the above-mentioned studies are generally very small. The quality of the data is questionable because most projects were either very small or very large, and little is known about the data collection methodologies. Without quantifiable cause-effect relationships that have been developed using statistically rigorous data collection and analysis procedures, the effectiveness of the various design, planning, and control strategies cannot be adequately assessed.

Clearly from the research perspective there is a need to collect considerable data from a large number of projects constructed under a variety of conditions. For project control purposes, it is necessary to provide real-time feedback. Data collection using current methodologies is highly labor-intensive itself. Automating the data collection process will greatly enhance the project control and communication aspect of construction projects.

INFORMATION NEEDS

Project control, performance control, and forecasting involves the assimilation of information in the areas of production, manpower utilization, material resource allocation, and quality control. In each of these areas, there are specific information needs that are required before effective project control can take place. The following represent the key data sources related to labor-intensive information needs:

1. Production Information
2. Manpower Utilization
3. Material Assignments
4. Quality of the Work

These are detailed more completely in Tables 1 - 4. Certain information needs are important for some activities and irrelevant for others. As inference structures are developed around the information needs criteria, additional sources of information may be identified. Therefore the needs and expressed in Table 1 - 4 should be viewed as preliminary and further refinement is expected.

Table 1. Information Needs to Characterize Production (Output)

Area of Need	Criteria	Data Collected
Production Information	completion status	quantities installed measurements (dimensions)
	rate of placement	timed measurements
	interruptions in placement	timed measurements
	origin of interruption	crew location material availability tool availability

Table 2. Information Needs to Characterize Manpower Utilization (Input)

Area of Need	Criteria	Data Collected
Manpower Utilization	type of activity	work related, support related, or delay
	activity locations	spatial coordinates travel distances
	internal vs. external delays	idle time
	equipment location	equipment availability
	material location	stockpile location travel distances

Table 3. Information Needs to Characterize Material Allocation

Area of Need	Criteria	Data Collected
Material Allocation	material location	spatial coordinates and amount
	installation location	spatial coordinates
	waste/yield	measured amount
	site layout	laydown locations, distances
	equipment location	location relative to material stockpiles equipment movements

Table 4. Information Needs to Characterize Quality Control

Area of Need	Criteria	Data Collected
Quality Control	alignment (3-D)	spatial location
	conformance to plans	geometric shapes and sizes component identification
	conformance to specification	test results component identification rework

SYSTEM REQUIREMENTS

System requirements are considered to be those attributes necessary for effective implementation of an automated data collection system. The proposed system is a research prototype and has a different set of operational criteria than an applications package. The research system will eventually be developed into an applications system. The anticipated users, e.g., field personnel, will need a system that is significantly less operator oriented than the system proposed herein. This paper concentrates on the initial set of criteria for development of a research prototype system for automated data collection on labor-intensive construction activities.

The following criteria are presented as a partial listing of those important to the development of the prototype system:

1. Real Time Operation
2. Upgradable
3. Portable
4. Non-intrusive Measurement
5. Sociologically Acceptable
6. Rule Learning Capabilities

The following discussion develops these concepts in greater detail.

Perhaps the single most important requirement is that the data be processed in real time. Although the process time is related to the complexity of the system components and computational requirements, simply having data processed in the same time frame as the activity prosecution will enable the researchers to evaluate impacts and develop forecasting models. These forecasting models can be tracked against the remainder of the activity for validation. Data extracted from the real-time model can also be stored for comparison and evaluation of the many empirical and theoretical models that exist, but have never been validated as reliable models of the construction process. Real-time processing of data will be very beneficial to the daily progress of the work.

The technologies employed must be capable of being transferred from the one project to the next without reconfiguration. The compactness of the equipment is, therefore, a criteria for the selection of primary hardware. The portability of the system software will require careful consideration. Since each project is somewhat unique in configuration, the system should be able to orient itself on the project site. This can possibly be achieved through interfacing the system to spatial models of the project generated in the design process or through those created specifically for the data acquisition system.

The diverse sources of data will need to be combined through an expert knowledge based rule system. The variability of the project environments will require that the system be capable of learning additional knowledge rules and automatically modify the inference structure in accordance with the new rules. The new knowledge should be checked for conflicts with existing rules prior to implementation.

An important acceptance test for the system will be the sociological impacts of having worker activity monitored by a remote system. The intention, at the research stage, is to make data collection as non-intrusive as possible. A system that requires identification tags on workers, special pattern hard hats or any other symbol for machine recognition will not be acceptable. Non-intrusive data capture will also require that few, if any, hard-wired sensors can be utilized. This disadvantage can potentially be addressed by utilizing distributed collection devices that can transmit data to the central processing unit using radio signals. Mobile equipment are potentially the best application of the distributed data collection system. Applications are envisioned for monitoring isolated work activity that may impact the specific activity being evaluated, e.g., concrete batch facility monitoring during concrete placement at the project site.

Finally, a system criteria that will be important in both the initial research stage as well as the final implementation model is the capability to adapt to new technologies as easily as possible. As is usually recognized, new equipment is not necessarily compatible with old equipment. An early effort is necessary to configure the system in as flexible a configuration as possible without sacrificing the quality of the data received.

SYSTEM CONFIGURATION

The primary components of the system are detailed in Figure 1. The hardware technology for the major components is available and the authors are currently experimenting with several elements of the system. Since much of the system is still conceptual, no attempt will be made in this paper to specifically identify component capabilities.

The system consists of three interrelated elements: hardware, processing software, and the expert system inference structure. These will be discussed in conjunction with specific areas of application.

The vision portion of the system has the greatest potential for gathering data. It also has the largest number of potential problems associated with a hostile environment. The typical industrial application of vision equipment usually requires a substantial time investment for investigating lighting arrangements. The method of lighting in industrial applications can be accomplished with several methods, while on a construction project, natural light is the most abundant. Artificially lighting a construction activity would certainly be a major task. Artificial lighting may, however, be accomplished without interfering with the progress of the work. Another problem associated with the vision system is the distance that the camera may be positioned from the subjects. Industrial applications have some constraints, but in general, the application location could be considered at the micro level. Construction covers a larger field of view and will necessitate a camera location at a greater distance from the subject. Although there are some anticipated difficulties utilizing vision systems in the construction environment, none are considered to be limiting to initiating the research effort. The vision data collected can provide a great deal of information. Personnel working on

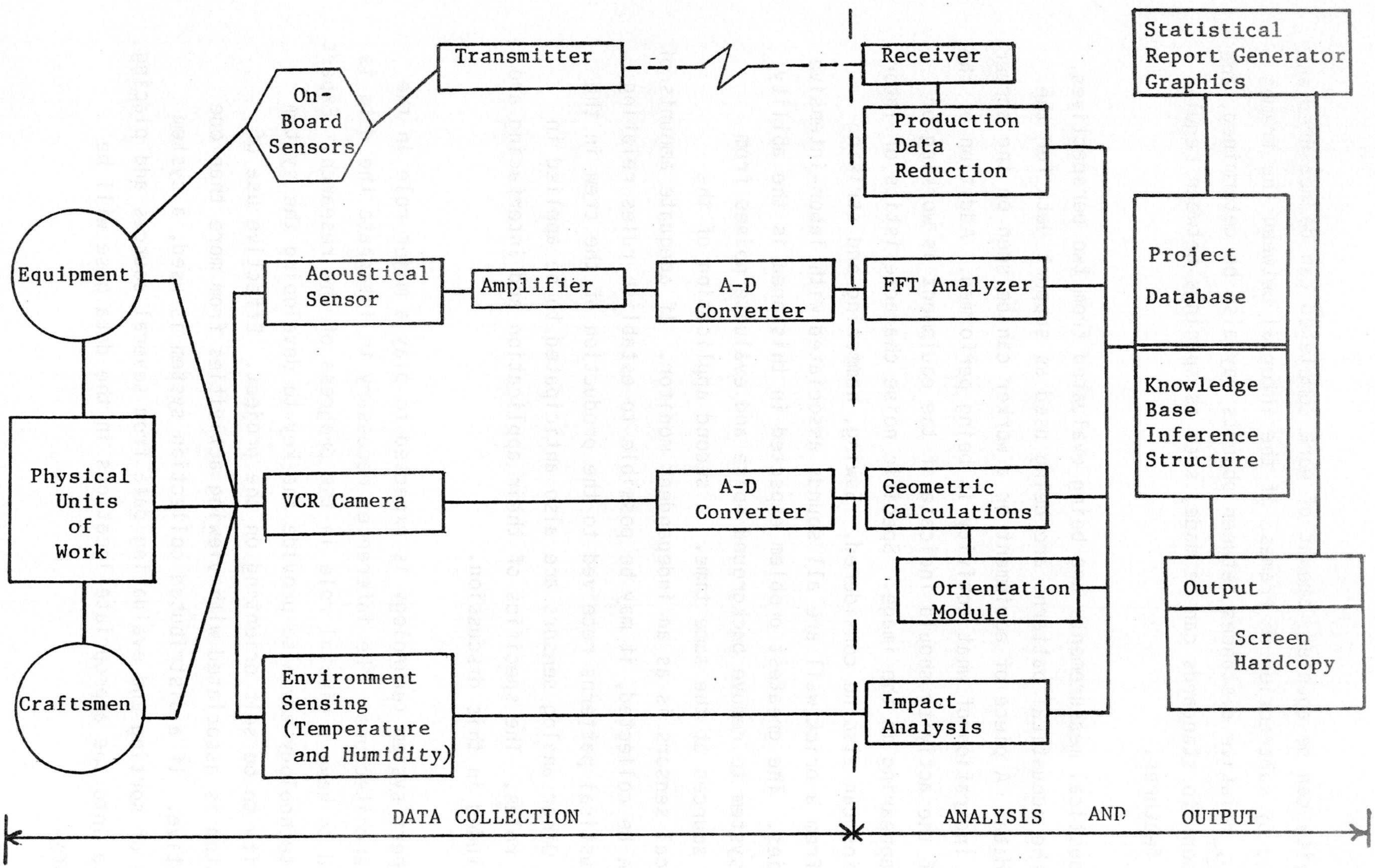

Figure 1. Schematic System Configuration

an activity can be counted, amount of work completed can be measured and evaluated by subtraction of frames, if the interval between the frames is known, relative distances between objects may also be determined, and comparisons to standards can be made, such as spacings between regular project features.

Acoustical measurements are being evaluated from two perspectives. First, the acoustical patterns are being used as support data for the vision data. A piece of equipment or a worker can be seen on the screen with no indication of what activity is being performed. Addition of the sound of the activity should indicate if the equipment is working or simply appearing in the image. Specific noise characteristics of labor activities can also be considered. Sawing, hammering and striking mortar from a brick wall are all sounds associated with labor-intensive activities. The greatest problem expected in this area is the ability of the system to remove background noise and evaluate noises from several sources at the same time. A second application of the acoustical sensors is as an independent monitor. If adequate amounts of data can be collected, it may be possible to establish rules relating the acoustical patterns received to the production of the crew in the field. Other analog sensors are also anticipated to be applied in various roles. The specifics of their application and interfacing are not included in this discussion.

Expert system technology is expected to play a major role in the system architecture. The inferences necessary to integrate the data is expected to have a pivotal role in the progress of the research. Expert system technology may also provide the key to developing the system capability to be self orienting on the project. Effective use of the system is associated with viewing activities from more than one perspective. If a distributed collection system is used, a system capable of sorting and evaluating data from several sources and placing the data into the appropriate locations in the data base will be necessary.

RESEARCH PLAN

The development of a prototype system is clearly a long range goal and will require a number of technological developments in the area of sensor applications, interfaces and artificial intelligence. The time frame for developing an integrated prototype system is probably ten years. The elements described below represent Phase 1 plans which will probably take at least two years to accomplish.

Phase 1 involves the basic application of emerging technologies to the rudimentary analysis of construction activities. The goals are to assess the feasibility of the system and identify limitations where technological developments will be needed. The technologies to be applied include image processing, pattern recognition, acoustical processing and techniques for combining the data from these sensors. Three thrusts will be followed. These are: 1) geometric measurements, 2) evaluation of digitized images, and 3) development of identifiable acoustical signatures.

Geometric Measurements - The goal of this effort is to be able to automatically measure the areas and shapes of various construction components, e.g., walls, floors, etc. Irregular shapes are of particular interest. The initial approach will be to determine if components can be measured from the video image. The greatest potential technical problem will involve the lighting of the image and the available contrasts. This assumes of course that the digital conversion package and equipment are capable of high resolution and adequate numbers of grey levels. These must be evaluated prior to this effort. This initial effort will answer the questions: Is conventional lighting and equipment satisfactory? Is artificial lighting going to be required? Are image enhancement techniques satisfactory or do special routines function better? Which image enchancement technique works best given the project constraints? This part of the development process will involve measurements on masonry and reinforced concrete walls. Other activities and system components will be utilized as necessary. The second step in this process will be to develop scaling techniques for determination of areas and possibly volumes.

Vision Images - Using standard digitization techniques, various images will be examined to determine if they can be recognized under varying conditions. Image enhancement may be of some benefit to ensure adequate contrast. Edge enhancement may provide an adequate level of detail for plain geometric figures discussed above. Camera capabilities will be evaluated for their ability to adjust to existing lighting conditions.

Once it has been determined that objects (equipment and craftsmen) can be adequately identified, pattern recognition will be employed to identify like objects in different field conditions and orientations.

Once the mechanics of identification have been perfected, the element of time will be introduced to develop simple counting schemes. This effort will be done in two phases. In the first, the authors will count repetitions of a cyclic activity. Equipment operations are well suited for this type of activity. The system will need to be able to sort out the appropriate type of equipment from the fleet or other equipment that moves through the image. The extension is then to evaluate the same system of equipment operating in different orientations. The time concept is also important for the labor-intensive activities, but more easily developed and tested on cyclic activities.

Acoustical Signatures - The researchers will determine acoustical signatures of various construction equipment and of selected labor-intensive activities. Analysis will be performed by commercially available real-time algorithms. For the labor-intensive activities, the initial work will be done in a laboratory environment where external noise can be suppressed. Later, the analysis will be shifted to remote sites where the external noise is lower than on a typical commercial project site. Finally, the measurements will be evaluated on a commercial project in a noisy environment. In this way the researchers will be able to understand the problems associated with the measurements. Upon completion of this task the researchers will be able to catalogue common sounds associated with a construction site, and these will be correlated with the appropriate work activities.

FUTURE DEVELOPMENT NEEDS

Although the research effort is in the infancy stage, a close examination indicates that even limited success requires technological improvements in many areas. The interface problems between data sources, development of reliable inference patterns, and assimilation of information from multiple sensors are just several of the major obstacles to be faced. Within each of these problems there are many additional paths to be taken. The feedback from this effort will aid the developers of robotic applications and expert systems. The exercise of choosing appropriate sources of data will aid in the understanding of the decision making process and environment on a construction project. Data structures will improve along with our abilities to utilize the data.

The authors recognize that the system presented is far from being possible in the near future and encompasses many areas of expertise. It is hoped that more researchers join the investigation of new technologies interfacing at the site processes and decision environment. Specific areas that need to be developed before the system can be fully realized are cited below.

Parallel processing of data with retention of synchronized signals is seen as an important development. Separate processing and filtering of signals requires that they be coordinated in a time frame for the evaluation phase.

The extremely large volume of data being processed and potentially stored will require optimal processing technologies and high capacity storage facilities. These developments will greatly enhance the operational capabilities.

Development of intelligent sensor systems that are capable of seeking specific data requested by a central knowledge system will also advance the system development. Rather than a single direction for information flow, it will be important to have the system seek out data as necessary for evaluation of a particular problem on the project.