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Evaluating Keyless Data Acquisition Technology for Construction Site Applications

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ABSTRACT

This paper describes a group of technology for automatic data acquisition in construction, which is refereed as Keyless Data Acquisition (KDA) technology, including bar coding, magnetic stripe, optical character recognition, radio frequency identification and voice recognition. First, past literature related to this area is reviewed and briefly discussed. Then a KDA implementation scheme is presented, detailing the considerations and logical steps involved in this issue. The make this concept better understood, a brief KDA implementation example in material control with special emphasis on warehousing is depicted. Finally, concluding remarks and future research directions are given. The experience gained from field tests reveals that the group of KDA technology in combination gives excellent solutions to field data collection/entry problem, whereas a standalone technology, such as bar coding, is insufficient for practical use.

INTRODUCTION

The manual process of data collection and data entry often results in the bottleneck of information management in construction. One of the most encountered problems relates to the data feedback on site. Since most site data are first collected in forms or reports and then entered into to computer, prompt data process and feedback to management level is inapt to achieve. Also, the repeated treatment of raw site data by manual recording and entry reveals waste of human resources. Furthermore, erroneous entry/re-entry are inevitable which impede the effectiveness and increase the cost of information management. A average error rate of 0.33% is indicated by Burke [5].

In the past, a number of researchers have addressed these problems by arguing that keyless data acquisition (KDA) technology, sometimes referred as automatic identification technology, is the key to resolve problems cited previously. Stukhart and Chang [11] suggest that bar coding can be used for receiving, storing, picking, sorting, and checkout of materials on site. Stukhart and Pearce [12] argue bar coding can enhance productivity in the industrial construction by eliminating human error and greatly speeding up the data entry process. Bell and McCullouch [2] who were involved in the CII bar code research report that the benefits of implementing the bar code technology include the reduction in time associated with improved data entry and inventory operations. Rasdorf and Herbert [10] develop a construction management information system which uses bar coding for jobsite resource identification and activity identification for enhanced project control. The two researchers further compare the system performance of automatic identification technologies including bar coding, optical character recognition, magnetic stripe and radio frequency for construction environment [9]. Liou [7] extends the discussion to a variety of KDA technology and indicates that data capture and data entry are critical to the success of a project management information system, and that efficiency and accuracy can be gained from this group of technology.

Although great interest was shown in these research efforts, few practical applications have so far been reported with extended field implementation. Through field testing, it was found bar coding technology has its limitations for practical construction use, including its low information density and vulnerability to harsh site conditions. As more KDA technologies are being applied in other industries, it is essential to introduce this group of technology and to set the base for its implementation in the construction industry. This paper first summarizes the characteristics of KDA technologies and compares their strength and weakness. Then, the strategy and procedures of implementing KDA technology in construction are discussed. Site material control is used as an example to illustrate this concept. In the final portion, concluding remarks and future research areas are presented.

KDA TECHNOLOGY REVIEW

KDA technology is a form of automatic data entry method by means other than a keyboard. Currently, KDA technologies which have been applied or experimented in other industries include bar coding, magnetic stripe, optical character recognition, radio frequency identification, and voice recognition. Among them, bar coding is the most popular. Brief introduction of each technology is given below. The comparison of their strength and weakness can be seen in Table 1.

1. Bar Coding

A bar coding system consists of a bar code symbology, a code printing device, a bar code scanner, a host computing unit and application programs to manipulate data. A bar code represents binary logic with a pattern of dark and light bars, usually called a cipher.

2. Magnetic Stripe

A magnetic stripe stores data in an encoded form via magnetic media. The encoded data resides onto the surface of a magnetic stripe by locations of positive and negative polarity which can be viewed as the dark and light bars in a the bar coding representation.

3. Optical Character Recognition

Patter recognition is the base technology for optical character recognition systems. Printed characters are each divided into pixels. These pixels are then illuminated by light from a scanning device. By combining the varying reflected light intensity of each pixel, a character can then be defined by pre-set templates of characters.

4. Radio Frequency Identification

A radio frequency identification system is consisted of a transponder to receive and send radio frequency signals, an antenna, a computing unit, and a frequency signal reader which decodes and transmits the signal to the computing unit. Since the reader can be substituted by a transponder which can both send and receive signals, it is possible to adopt such systems for dynamic information exchange, in that the reader can response to the transponder with new information, once data is received.

Table 1 The Strength and Weakness of KDA Technologies

KDA Technology	Strength	Weakness
Bar Coding	1. Easy to be reproduced 2. Inexpensive to install 3. Non-restricted format 4. Word processing capability 5. Non-restricted wanding 6. Full character set	1. Low information density 2. Easy to be polluted 3. Coding itself can not be understood
Magnetic Stripe	1. Low error rate 2. Read-write capability 3. Non-restricted wanding 4. Full character set 5. Inexpensive to read 6. High storage density 7. Robust to environment	1. Restricted data format 2. Coding is not visible and readable to humans 3. Difficult to be reproduced 4. Difficult to be modified 5. Sensitive to magnetic fields and high temperatures 6. Unsure data integrity
Optical Character Recognition	1. Human readable 2. Full character set 3. Read-write capability 4. Word processing capability 5. Image storage 6. Able to read long texts	1. High installation cost 2. Low recognition speed 3. High reading cost 4. Restriction on read orientation 5. Low precision tolerance
Voice Recognition	1. Hand free 2. Easy to be reproduced	1. Low information density 2. Sensitive to noise 3. High installation cost 4. Prone to human errors
Radio Frequency Identification	1. Low error rate 2. Read-write capability 3. Robust to environment 4. Non-restricted format 5. High information density 6. Dynamic information exchange 7. Hand free 8. No physical connections	1. Expensive to install 2. Incompatibility to same frequency 3. Unreliability of data transmission 4. Limitation on transmittal distance 5. Restricted usage by regulations

5. Voice Recognition

The basic principle in voice recognition is that each unique sound can be represented as a unique set of data in a digitized form. Each command can be represented as a (or a series of) unique sound. Once a sound is made it can be converted to a digitized form and recognized with a pre-set template, the corresponding command can be activated. In the same manner, site data can be collected by site management and "spoken" directly into a computer.

IMPLEMENTATION OF KDA TECHNOLOGY

Past experience of using bar coding technology in construction has been largely unsatisfactory, primarily due to the fact that this technology alone can not resolve data processing needs from a comprehensive perspective. In fact, a justification should be made to examine the combined use of individual KDA technologies. Therefore, it is meaningful to investigate how to benefit from this group of technology in a systematic approach. An implementation scheme is presented in this section to illustrate this concept, as follows:

1. Constructing Activity Procedure

The activity procedure described here refers to that of construction management functions, such as material control and quality inspection. This step requires formal description, either graphical or textual, of daily management procedures practiced by site personnel.

2. Identification of Data Flow

By examining each activity procedure, it is possible to infer data flows and data items usually unexpressed in the procedure. One may accomplish this by studying forms or reports related to the procedure in consideration, when available.

3. Data Categorization

From all data flows previously identified, six characteristics of each data item need to be noted with care according to site practice: (a) frequency of each data item being treated in all data flows, (b) data type, i.e., numeric or charters, (c) data width in terms of digits, (d) nature of data treatment, such as collection, entry/re-entry and update of data, (e) present method of data treatment, and (f) environment in which data treatment is performed.

4. Technology Mapping

From comprehensive understanding of data to be treated as well as the procedures involved, KDA technology can be now compared with data treatment requirements to enumerate the possible areas of applications. Four aspects of each KDA technology need to be compared with the data characteristics discussed in the previous step: (a) amiable area of application from past experience, (b) favorable data type to be processed,

(c) maximum data width to be processed, and (d) suitable environment for implementation.

5. Technology Selection

The result of technology mapping shows where each KDA technology exhibits high potential for application. However, the selection of KDA technology takes great effort in balancing the preference of site management personnel and achievable benefits. In a practical sense, the configuration of KDA technology for site application should both increase the efficiency of site management functions and provide flexibility and ease of use.

KDA APPLICATIONS AND EXAMPLE ILLUSTRATION

The application of KDA technology in construction can be viewed from three perspectives. In the corporate level, this application refers to part of office automation in construction firms and does not distinguish itself much from that in other industries. In the project level, the main application concentrates on activities related to schedule and cost control. One obvious example is the tracking of all project expenses that belong to a single cost account. Indeed, the most prominent area of application resides in the site management level. The general area includes the identification and tracking of labor, material, drawings, documents, equipment and tools. However, past research has reported these application opportunities mostly based on bar coding technology. As automatic identification technology progresses, a more extended analysis is justifiable.

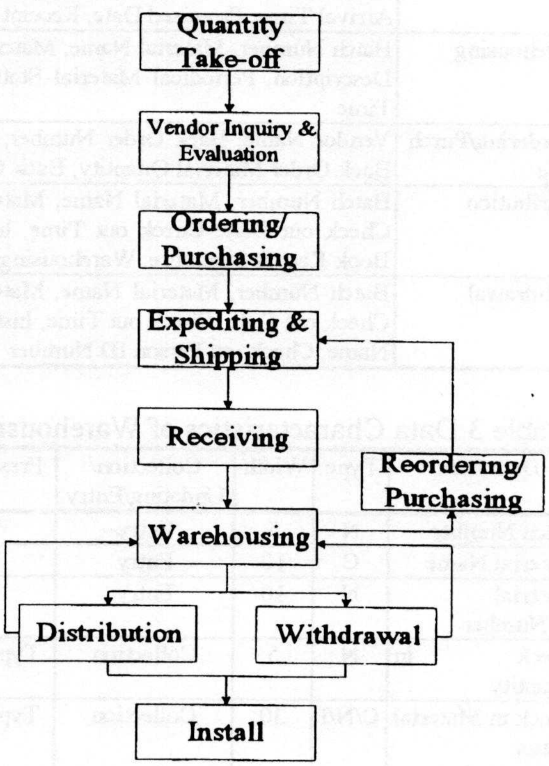

Fig. 1 Work Flow of Material Control

Although most conclusions drawn from past research delivered a strong message that KDA technology is needed in construction, one critical issue which also deserves attention concerns the approach for implementation, especially from the perspective of a hybrid system. A field implementation example is presented in this section to illustrate this concept.

This example considers the application of KDA technology in material control,

Table 2 Data Item for Material Control Function

Operation	Data Item
Quantity Take-off	Project Name, Drawing Number, Material Name, Material Specification, Material ID Number, Material Description, Material Quality, Unit, Suggested Unit Price, Predicted Need Date
Vendor Inquiry and Evaluation	Dollar Value of Material Committed, Dollar Value Received, Vendor Name, Number of Partial Deliveries, Number of Late Deliveries, Evaluator Remark, Evaluator Signature
Ordering/Purchasing	Project Name, Purchase Order Number, Purchase Date, Item Stock Number, Drawing Number, Material Name, Material ID Number, Material Spec., Material Description, Material Order Quantity, Material Order Quality, Unit of Measure, Unit Price, Total Price, Need Date, Promised Date, Purchaser Signature
Expediting and Shipping	Delivery Date, Work Load, Morale, Material Name, Material ID Number, Material Description, Material Order Quantity, Material Order Quality, Need Date, Vendor Name, Vendor Contact, Promised Date, Expediter Signature, Expediter Remark
Receiving	Project Name, Purchase Order Number, Item Stock Number, Batch Number, Material Name, Material ID Number, Material Quantity Received, Material Quantity Received, Material Order Quantity, Material Order Quality, Material Specification, Material Description, Arrival Date, Arrival Time, Promised Date, Receipt Number, Receiver Signature, Deliverer Signature
Warehousing	Batch Number, Material Name, Material ID Number, Check in Quantity, Check in Material Status Description, Periodical Material Status Description, Storage Location, Check in Date, Check in Time
Reordering/Purchasing	Vendor Name, Back Order Number, Back Order Material Name, Back Order Material Number, Back Order Material Quantity, Back Order Material Quality, Back Order Material Spec.
Distribution	Batch Number, Material Name, Material ID Number, Check out Quantity, Material Description, Check out Date, Check out Time, Install Area, Book Keeper Name, Book Keeper ID Number, Book Keeper Signature, Warehousing Manager Signature, Warehousing Manager Remark
Withdrawal	Batch Number, Material Name, Material ID Number, Check out Quantity, Material Description, Check out Date, Check out Time, Install Area, Warehousing Manager Signature, Check out Person Name, Check out Person ID Number

Table 3 Data Characteristics of Warehousing

Data Item	Type	Width	Collection/ Updating/Entry	Present Method	Environment	Frequency	KDA selected
Batch Number	N	5	Entry	Type II	Indoor/Outdoor	Low	B
Material Name	C	10	Entry	Type II	Indoor/Outdoor	High	B/M/R
Material ID Number	N	10	Entry	Type II	Indoor/Outdoor	High	B/M/R
Check in Quantity	N	5	Collection	Type I, Type II	Indoor/Outdoor	High	B
Check in Material Status Description	C/N/I	30	Collection	Type I, Type II	Indoor/Outdoor	High	H/O
Periodical Material Status Description	C/N/I	30	Collection	Type I, Type II	Indoor/Outdoor	Medium	H/O
Storage Location	C	10	Collection	Type I, Type II	Indoor/Outdoor	High	B/M/R
Check in Date	D	8	Collection	Type I, Type III	Indoor/Outdoor	Low	PC
Check in Time	T	6	Collection	Type I, Type III	Indoor/Outdoor	Low	PC

Type: N/Numeric, C/Character, I/Image, D/Date, T/Time
Present Method: Type I/Hand Written Type II/Typed and Computerized
Type III/Type and not Computerized
KDA selected:B/Bar Code, M/Magnetic Stripe, R/RF/ID, H/Handwriting Recognition, O/OCR
PC:Personal Computer

with special attention on warehousing, in construction jobsite. A generic activity procedure of site material control is given in Figure 1. In Table 2, the data related to this control activity is presented (characteristics of these data are ignored due to length limitation). The data related to warehousing is each examined as follows (Table 3):

1. Batch Number
   This data item is first shown in "Receiving" and is seen as an entry.
2. Material Name
   This data item is first shown in "Quantity Take-off" and is seen as a re-entry from "receiving" of Type II.
3. Material Identification Number
   Same as "Material Name".
4. Check-in Quantity
   This data item is originated in "Warehousing" and is first shown in either form of Type I or Type II.
5. Check-in Material Status Description
   Same as "Check-in Quantity".
6. Periodical Material Status Description
   This data item is updated periodically. Each update is seen as data collection of either Type I or Type II.
7. Storage Location
   Same as "Check-in Quantity".
8. Check-in Date/Time
   This data item is existed in either writing or the form of computer hard copy at the time of data entry; therefore, it is seen as Type I or Type II.

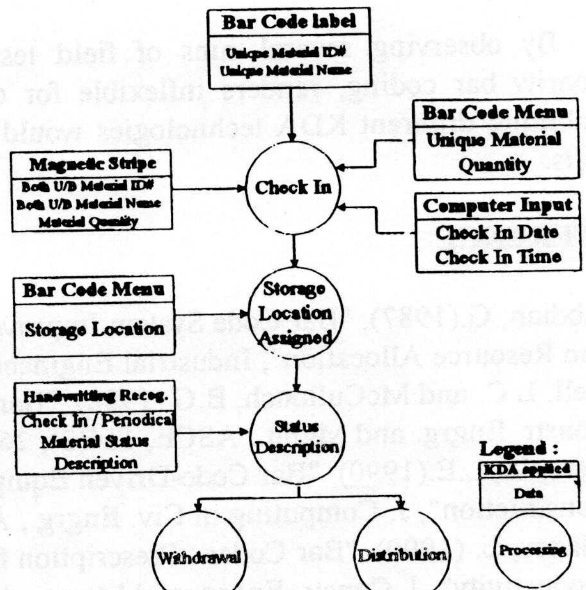

Fig. 2 Operation Flow of Warehousing

From the above analysis, a field implementation example in warehousing is depicted in Figure 2. To accomplish this implementation, the introduction of a bar code menu for warehousing is required. A simplified example is presented in Figure 3.

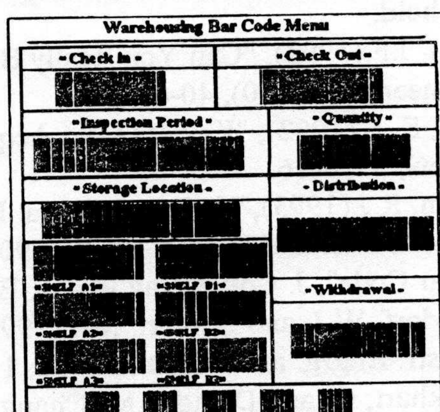

Fig. 3 Sample Bar Code Menu

CONCLUSION

This paper has reviewed past research related to the automatic acquisition technology of construction data and introduced the concept of KDA technology with particular emphasis on how to implement and benefit from this group of technology. The implementation scheme is accompanied with a demonstration example for detail of illustration. However, due to length limitation, only a small portion of the entire field prototype is given. It is hoped that, with the above discussion, the KDA technology can be used more widely as part of the construction automation effort. Some issues, however, remain to be further investigated: (a) The strategy of combining different KDA technologies to maximize the overall system functionality with minimal cost; (b) A thorough examination of KDA technologies in other areas of application including corporate, project and site level; and (c) A comprehensive procedures and technology standards for full scale implementation in construction.

By observing several runs of field test, it is seen that a standalone system, primarily bar coding, renders inflexible for changing data processing needs on site. Combining different KDA technologies would produce more practical and satisfactory results.

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