Automation and Robotics in Construction XII
E.Budny, A.McCrea, K.Szymanski (Editors)



# Construction quality control through pen-based computers

Machine Hsie[a], Luh-Maan Chang[b], and Ming-Teh Wang[c]

[a]Research Engineer, National Expressway Engineering Bureau, Taiwan.

[b]Associate Professor, School of Civil Engineering, Purdue University, U.S.A.

[c]Associate Professor, Department of Civil Engineering, National Taiwan University, Taiwan.

## ABSTRACT

This paper describes research results and the experience gained by applying pen-computers to the area of construction quality. A pen-based computer system has been developed to include the functions of signature, error detection, drawing capability, form navigation, user instruction, and decision making. The system eliminates the required effort to convert the inspection data from paper forms to computers input. Moreover, it contains statistical algorithms to automatically facilitate either accepting or rejecting the quality of a finished construction product.

A pen-based computer provides many benefits. This paper will begin with a brief review of the pen-based computer technology followed by detailed design of the pen-based computer system for quality inspection of steel bridge painting. Finally, conclusions and recommendations will be provided.

## 1. INTRODUCTION

Field engineers' primary responsibility is to maintain quality construction. However, processing inspection data at construction sites takes a considerable amount of time. First, they need to record many measurements on inspection forms. The daily inspection data can be many pages. After recording the data on paper, and brought back to the office, the data needs to be manually typed into computers for further processing. The double-data-entry requires additional work and cause many errors. On the other hand, if computers are not utilized, the paper inspection forms will accumulate around the office and the amount of paper will quickly become out of control. Many efforts have been made to efficiently collect and process inspection data of construction. The construction data processing is overwhelming field engineers.

To solve the above problems, inspection procedures on construction sites need to be computerized. The pen-based computer is proposed to break the barriers in transmitting computer technologies to construction sites. As a result, a **PEN**-based computer system for

steel **P**ainting **I**nspection (**PENPI**) has been developed. Currently, a menu-driven interface system for data capture and process has been built inside the PENPI system (Chang and Hsie 1992).

The purpose of this paper is to present the results and lessons learned in this research. This paper will begin with a brief review of the pen-based computer technology. Detailed design of the pen-based computer system will be given. Finally, conclusions and recommendations will be provided.

## 2. REVIEW OF PEN-COMPUTER TECHNOLOGY

The pen-based computer is one of the most recent developments in computer technology (Baran 1992). A pen-computer uses a pen as the input device for a portable computer. It features a handwriting recognition system that allows users to write directly on the screen. The system then converts the input to characters, just as if they had come from a keyboard (Miastkowski 1992). The handwriting recognition technologies applied included neural networks, probabilistic Markov modeling, fuzzy logic, dynamic programming and clustering algorithms (Quain 1993).

Currently, there are two types of Digitizer technologies used by the pen-based computers including Restrictive and Electro-Magnetic (EM) Digitizers.

- A Restrictive digitizer is overlaid onto the surface of Liquid Crystal Display (LCD). The pen mark directly contacts the LCD's surface. A conductive coating on the surface sends x and y pen coordinates by determining the voltage emitted by the screen.
- An Electro-Magnetic (EM) digitizer is embedded beneath the LCD. The EM digitizer has certain advantages over the resistive digitizer. For instance, some restrictive units lower the light transmitted by the LCD due to an extra coating of wires on the screen (Barr 1992).

## 3. ADVANTAGES OF USING PEN-BASED COMPUTERS

Pen-based computers are proposed for people who are away from their office but still want to utilize the power of computers. Unlike lap-top or note-book computers, pen-based computers can be used while standing or walking. Therefore, they are easy for engineers to use on construction sites. It is inconvenient to pull out a lap-top computer and start typing in the middle of working at a job site. However, writing on the screen of a pen-computer is no more unwieldy than taking notes on a clipboard (Miastkowski 1992).

Pen-computers provide another advantage in that they can be used to keep handwriting records for legal purposes. For example, United Parcel Service (UPS) has replaced its drivers' traditional clipboards with electronic versions -- a form of the pen-computer. Package recipients no longer sign paper forms; instead, they sign their name directly on the drivers' computer. The signature image is stored together along with the delivery time and date. For public highway construction projects, numerous signatures are necessary for processing paperwork. The benefit can be tremendous if the signatures and relative documents can be

maintained in electronic format that can be easily processed and transferred between offices (McCullouch 1993).

In another area, pen-computing in the CAD market seems to be a natural evolution. The applicants can directly sketch markup in the field on their pen-computers by drawing an "X" over the defective beams that need repaired. Engineers checking field installations could carry pen-computers on their arms rather than carrying rolls of detailed drawings.

## 4. PENPI OVERVIEW

The PENPI is developed to assist the computerization of inspection processes for steel bridge painting. In this system, contractor and structure numbers are used as key fields in the database. By specifying the contractor and structure numbers, inspectors can create and assess the data belonging to different projects. There are a total of 20 pages of forms in the system. The PENPI system features a user-friendly interface that allows inspectors, by using a pen, to input the measured data directly on the pen-based computer at the construction sites. Meanwhile, the acceptance or rejection decisions will be automatically made when the data input is completed. This not only reduces the necessity of inspectors' statistical background, but also eliminate the tedious paper work. In addition, after the data are entered, these data can be transferred to a host computer to establish a database.

### 4.1 Methods of Data Entry

In the PENPI system, four methods have been designed for data entry. They include: 1)Hand Writing Recognition, 2)Simulated Key- board, 3)Pop-Up List, and 4)Control Buttons.

#### 4.1.1 Handwriting Recognition

For handwriting recognition, simply place the pen tip on the field, and it will zoom up a large field to facilitate users' hand writing input. Figure 1 shows the zoomed up field. The user can directly write alphabets and digits on the field. Then the system will recognize the symbols and convert them into the ASCII texts. After users finish handwriting entries, they touch the "OK" button on the left bottom of the zoomed field to accept the input.

#### 4.1.2 Simulated Keyboard

In some cases, the users' handwriting cannot be correctly recognized by the system. By touching a keyboard-like symbol on the bottom of the zoomed field, the users obtain a simulated keyboard shown in Figure 2. Then, users can place the pen tip on the simulated keyboard as if they are using a finger to type the desired data into the field.

#### 4.1.3 Pop-Up List

To write on the data field or to type on the simulated keyboard can still be as tedious as writing on a paper form; however, for many types of data, the possible data entries are limited and can be pre-defined. The PENPI has a pop-up system. For example: a bridge in Indiana managed by seven district agencies, has a pop-up list containing those seven possible choices. When the user touches the field with the pen tip, the list including all of the possible choices pops up as shown in Figure 3. After placing the pen tip on the desired choice, the chosen one will be inserted into the data field.

### 4.1.4 Control Buttons

Many simple inspection processes can also be presented by yes/no questions. This type of data entry can be presented by a set of yes/no radio buttons as shown in Figure 4. Users can simply place the pen tip on the radio buttons to toggle their answers. Control buttons are designed to control the functions and to navigate among the data base. These control buttons include: *Exit, Go To Previous Page, Go To Next Page, Erase, Save* and etc. Users can simply place the pen tip on the button to trigger the desired functions.

## 4.2 PENPI Design Objectives and Its Functions

Many objectives and functions must be fulfilled to make the PENPI superior to the conventional paper inspection form. The objective of the designs and its functions are summarized as follows:

### 4.2.1 Offer Better Protection from Non-Authorized Data Input

When a conventional paper form is used, the person recording the data can be recognized by his/her penmanship. Therefore, a non-authorized person attempting to falsify data can be detected. However, in pen-based computers, the user's handwriting is recognized and converted to a series of ASCII characters and the original handwriting is gone. As a result, there is no way to determine who entered the data. For this reason, the electronic forms require a better protection from non-authorized data input. To do so, the PENPI system has been designed so that the inspectors must enter a valid password to enter the program. Furthermore, to better assure the reliability of the data, inspectors' signatures are requested. Therefore, the recorded inspection forms can be regarded as legal documents.

### 4.2.2 Detect Error Data Entries

Many erroneous data entries may happen during inspection. Therefore, an error-checking mechanism has been designed in the PENPI system. For instance, the contract number should begin with an alphabet followed by 5-digits. If a contract number with an incorrect format is entered, the system will detect this error and present a warning screen, make a beeping sound, and ask for a new input. In the course of inspection, many critical data must be fulfilled before further inspection can be taken. For example, the required surface cleanliness should be specified before the inspection of surface preparation. The PENPI has been designed to assure the users to finish those critical data entries before they can exit one form and enter another. All of these designs serve as essential error-checking mechanisms for the inspectors.

### 4.2.3 Provide Instruction for Data Entry

Instructions should be provided to assist data input. The PENPI has included many instructions on the screen to help users operate the program. For example, notes such as "Please place your pen on the field" gives the end-users a clear guide about what to do. In addition, the PENPI features the intelligence to automatically guide the user to take proper action. For example, the attribute double sampling method has been adopted as the decision-making mechanism in the PENPI system. If the measured data lead to the decision of taking a second sample, then the PENPI will automatically remind the users to take the second sample by switching to the pages of the second sample. Furthermore, several types of beep-sounds and rhythms are utilized to remind the users to take certain actions. For example, after the data are input, the acceptance or rejection decision is made automatically. If the product should be accepted, a smooth and short rhythm is produced. On the contrary, if the product should be

rejected, an unpleasant and long rhythm is presented to remind the inspector to reject the products. All these designs are aimed to provide the users with audio and video instruction.

### 4.2.4 Remain Compatible with the Down Stream Application

The PENPI system is designed for integration with a database in the highway agency's central office. To do so, the "dbf" file format is used to store the measured data. The "dbf" format has become a standard data file that is accepted by most commercial database and spreadsheet packages. Additionally, the image files for drawings and signatures are stored in the format of "pcx" files. Once these data are recorded, the data files can be efficiently transferred to other computers. Its final goal is to integrate the field inspection data to establish a database so that the users can retrieve and analyze construction quality.

### 4.2.5 Provide Drawing Capability

A picture may save thousands of words. Therefore, the PENPI has been designed to provide a drawing capability. A drawing board in the PENPI helps inspectors store information that cannot be easily described in words. The drawing board provides three basic functions: 1)free hand drawing, 2)eraser, and 3)stamp. Figure 5 shows that the defective area requiring rework is marked on the bridge drawing.

### 4.2.6 Allow Freedom to Navigate Among Forms

The PENPI is designed to allow the user to switch among the inspection forms. During the course of a painting construction, the contractor may have two work teams for sandblasting and priming on different areas of the bridge at the same time. In this case, the inspectors need to efficiently flip among different inspection forms. Many control buttons in the PENPI are designed to provide the users with freedom to navigate around different forms.

### 4.2.7 Incorporate with Decision-Making Algorithms

In the PENPI system, the algorithm of the statistical acceptance sampling plan has been encoded into the system. Inspectors should enter the measured data in the system, then the decision can be automatically made. This capability can break the barrier of applying advanced decision-making algorithms on construction sites.

## 4.3 Hardware

State-of-art pen-computers were reviewed (Barr and Neubarth 1993). In evaluating the pen computers, "portability" is one of the most important criteria. The candidate pen-computers must be both small and light-weight to allow inspectors to carry them easily to construction sites. In addition, a construction site for steel bridge painting may be over a river or a highway. Complete protection of the computer is absolutely necessary as rain and water may come in contact with the computers. Using these criteria, one brand of pen-computer was chosen which features basic water-proof capability. It is classified as a palm-sized pen-computer and is light enough for long periods of use. Its dimensions are 1.9 x 9 x 6.2 inches; weighing 2.9 pounds. It is shock-resistant, and cushioned by a rubberized plastic casing. These specifications makes the pen-computer the final candidate for harsh construction sites in the research. Even though it is small, the chosen pen-computer features a screen of 640 x 400 resolutions, which is close to the general PC used every day (Rowell 1993).

### 4.4 Software

The following four major operation systems currently available in the pen-computer market were evaluated. They include: 1)Window for pen, 2)Penpoint, 3)PenRight, and 4)PenDOS (O'Connor 1992, Brown 1992; Brown 1993). PenRight was chosen because of its compatibility with the chosen pen computer's proprietary hardware. It is a software platform for executing mission-specific applications on top of MS-DOS. In addition, the pen-based data entry system was developed under the package "PENPAL."

## 5. CONCLUSIONS AND RECOMMENDATIONS

This paper presents the information gained by applying pen-computers to the area of construction inspection. This system called PENPI has been developed. It includes the functions of signature, error detection, drawing capability, form navigation, user instruction, and decision making.

The research shows that the elaborately designed pen-computer system is suitable for non-computer-literate users. The benefits of computerization is not only cost-saving, the downstream benefits from the electronic data are also important. Once the information is recorded electronically, the processing effort is simplified. This project provides an automated system that stores the information in electronic format. No conversion effort is needed for downstream data processing. Moreover, with the power of computers, it can automatically make the decision to accept or reject the quality of constructed products.

In summary, a pen-based computer system will provide many benefits: the reduction of tedious paperwork and the downstream benefits are valuable for electronic data integration. As a result, the collected data will be more accurate, providing the users with more information to make better decisions. Before pen-computers can completely change the current data input practice, certain barriers must be overcome. Because of the tough and harsh operating environments at construction sites, pen-computers must be rugged and durable, shock-resistance and water-proof standards must be enhanced, and the handwriting recognition accuracy needs to be improved. The increasing competition and advancing technology will prompt the popularity of the pen-computers. The authors believe that the explosion of computer technology will soon bring us more powerful, smaller, and solid pen-computers with lower prices.

## 6. REFERENCES

Baran, Nicholas. 1992. The Out Looking for Pen Computing. Byte Magazine, September, pp. 159-163.

Barr, Christopher. 1992. Pen PCs. PC Magazine, Nov., pp. 175-178.

Barr, Christopher & Neubarth, Michael. 1993. Pen Pal. PC Magazine, October, pp 117-182.

Brown, Bruce. 1992. Pen-Software. PC Magazine, Nov., pp. 202-203.

Brown, Bruce. 1993. Pen Operating System. PC Magazine, Oct. 172 p.

Chang, Luh Maan & Hsie, Machine 1992. Development of Quality Assurance Specification for Steel Bridge Painting Contract. Joint Highway Research Project: Purdue University, West Lafayette, Indiana.

McCullouch, G. Bob. 1993. Construction Field Data Acquisition with Pen-Based Computers. Journal of Construction Engineering and Management, Vol. 119 n, June, pp 374-384.

Miastkowski, Stan. 1992. Keyboardless Sense. Byte Magazine, February, pp 36-37.

O'Connor, Thom. 1992. Pen-Techniques on the Desktop. PC Magazine, November, pp 182-200.

Quain R. John. 1993. No Tabula Rasa: Handwriting. PC Magazine, October, 176 p.

Rowell, Dave. 1993. Pen-Based Computers -- The Next Generation. PC Sources, May, pp 157-184.

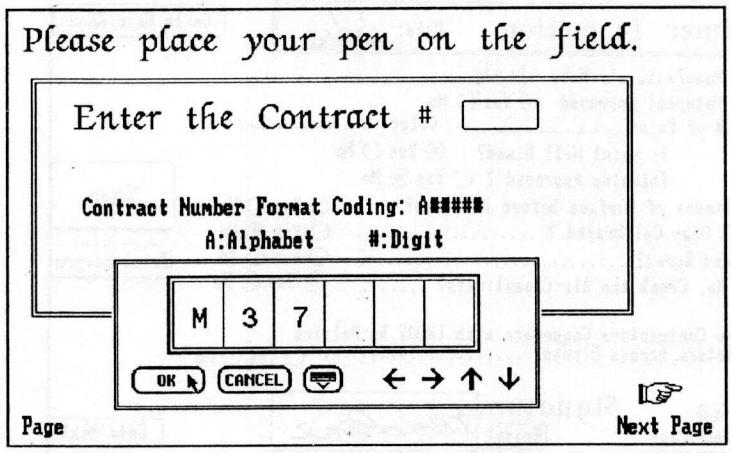


Figure 1. Hand Writing Recognition Screen

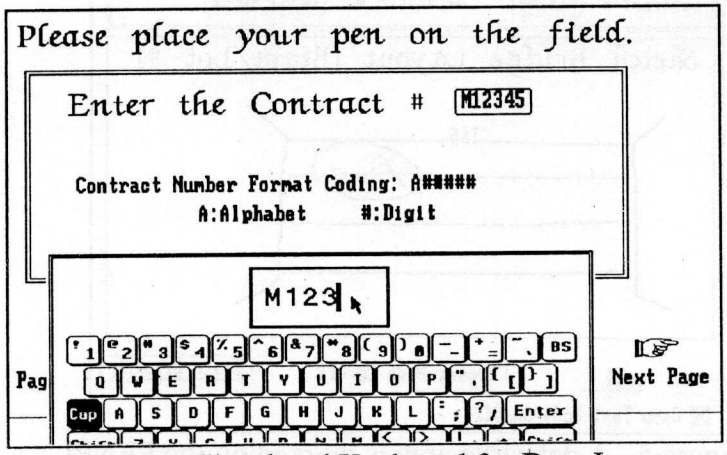


Figure 2. Simulated Keyboard for Data Input

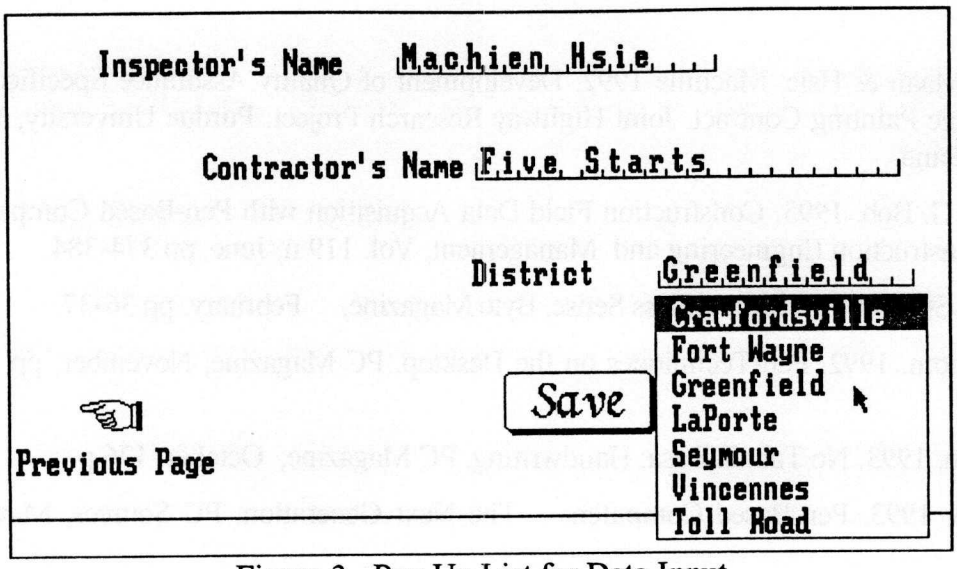


Figure 3. Pop Up List for Data Input

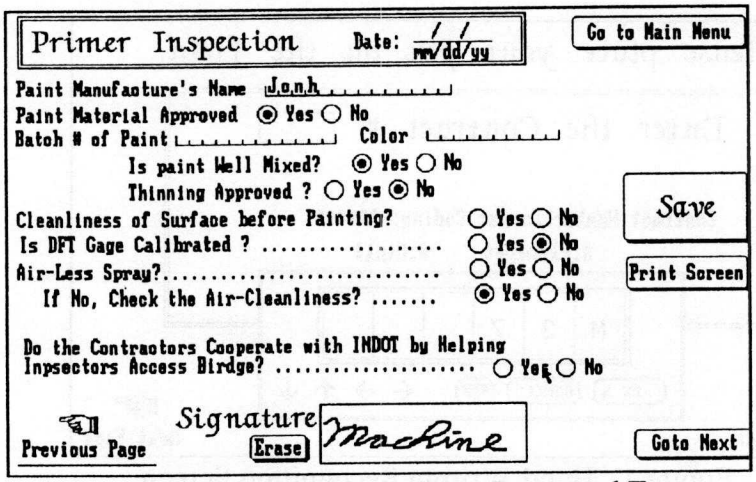


Figure 4. Control Button for Data Input and Form Navigation.

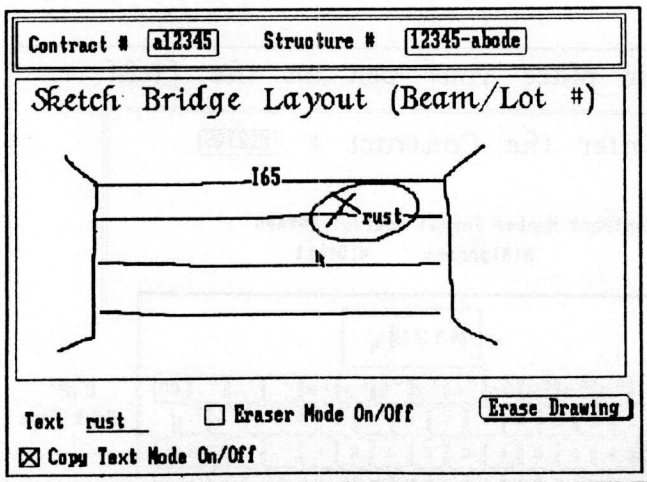


Figure 5. A defective area is marked on the PENPI system.