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The application of PDA as mobile computing system on construction management

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Abstract

This paper reports a development of mobile computing system with personal digital assistants (PDA) for construction managers on construction sites. First, this paper describes the aim, the concept based on end user computing (EUC), and the essential element of the mobile system. This also shows the necessary functions for the mobile computing, and the concept of this computer-aided engineering system. Secondly, this paper describes the structure of the system and the outline of subsystems: Inspection System, Checklist and Reference System, Position Check System, and Progress Monitoring System. The system has two programs: the data input program in PDA and the output program in PC.

- Inspection System assists architects and construction managers to inspect the result of construction especially for finish works.
- Checklist and Reference System assists construction managers to access the checklist and the reference such as drawings and specifications.
- Position Check System assists construction managers to check and correct the position of structural members such as the steel column and the form.
- Progress Monitoring System assists construction managers to monitor the progress of projects.

Finally, this paper indicates the development of more refined process of construction management with the mobile computing device on construction sites.

Keywords: End user computing; Mobile computer; Personal digital assistants; Construction site; Inspection

1. Introduction

The office automation from the late 1980s has improved the productivity of office works rapidly. Construction managers have recently handled various

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types of digital information such as drawings, specification, checklists and daily reports [6,7]. However, they need to access the real construction site to manage the construction project. They usually use sheets of paper and/or field notes. As a result, they still have a lot of typical and routine jobs in construction site, such as the collection of construction data and the inspection. A gap in time and space between the outdoor construction site and the office, which leads to the low efficiency, occurs.

On the other hand, various kinds of mobile devices have been adopted to field jobs on construction sites [20]. In the case of Japan, the electric pocketbook had been used as mobile computing device in the early 1990s [1,12]. The laptop PC has been used too. During the mid of 1990s, some computer manufacturers have produced handheld PC and palm-size PC. Their function has advanced year after year. The current personal digital assistants (PDA), which is a current palm-size PC, can handle the various types of data including not only texts but also drawings and pictures. The processing speed of PDA has also developed.

The current mobile computing can improve the field work in construction, and enhance the productivity of construction management [17]. Some systems with the mobile computer have been developed [10,11,13,15,16,18]. The paper presents the mobile computing system based on the end user computing for project management.

2. Mobile computing and end user computing

2.1. What does the mobile computing change on construction site?

The Personal Computer is an essential tool in construction management today. However, construction managers usually use sheets of paper and/or field notes for their outdoor jobs. A gap in time and space between the outdoor construction site and the indoor office can cause the duplex, lack and confusion of data. The efficiency of construction management is not high.

The mobile computing can eliminate and/or decrease this gap. Construction managers can use digital data input with the mobile computing device on construction site effectively [2,6,7,19]. Moreover, some application software can enlarge the performance of the mobile computing. Their total system will realize the labor saving and rationalization of construction management. As each job in construction is strictly scheduled, construction managers must review the program and make decision within time. The mobile computing will help them.

2.2. What is necessary for the mobile computing of construction management?

Construction is usually outdoor. Authors arranged the necessary functions for the mobile computing system and its devices through the interview and discussion with construction managers.

- Mobility of Hardware: Construction managers want the pocket size of hardware.
- Durability of Hardware: The strength for the physical shock, the rain, the wet and the dust is necessary for hardware.
- Compatibility of Hardware and OS: It is suitable that the system can work on any hardware and any Operating System (OS).
- Compatibility of Data between the Mobile and PC: Construction managers want to handle the data in PC on the mobile device. The converse is also necessary.
- Expressivity of Display: The sufficient expressivity of drawings and pictures on the mobile device both indoor and outdoor is necessary.
- Stability of System: Total stability of system including OS, memory card and other devices is necessary.
- Operability of User Interface: Construction managers want to input data with gloves. Easy user interface such as pen-touch is suitable.
- Processing Speed: Start-up, Shutdown and each process in the mobile system needs quick response. The display speed especially of drawings and pictures is important.
- Continuous Computing Environment: The computing environment has recently changed quickly. Construction managers want to continue the use of the system for a long time. The computing environment that assures the long operation of systems is necessary.

After discussing the necessary functions as the mobile computing system and devices of construction management, authors have adopted PDA as mobile computer to deal with current assignments. The current PDA meets the above requirements.

2.3. How can computer systems acquire the request of construction managers?

Construction is usually based on a project, which has unique features and limitations. Construction managers need the flexibility of computing system for each project. The concept of end user computing (EUC) is suitable for construction managers to achieve it. Authors have introduced the EUC to their computing systems including the mobile one [8,9]. However, the realization of EUC has some difficulties such as the computer literacy of end users, the environment of the easy and rapid development, and so on.

On the other hand, design patterns provide a reusable piece of design of a design that solves a recurring design problem in software construction [4,5]. Many design patterns enhance flexibility or extensibility [3,4]. Authors think that the important component of design pattern for the communication between end users and system developers is the user interface especially for the data input with the mobile computer, and prepare some design patterns in the development. End users can arrange and create the flowchart of the system with them. System developer realizes the request of end users by the flowchart with user interfaces. Chapter 3 explains the detail of design patterns in the proposed application.

Authors think that the collaboration of end users and system developers, which is based on the concept of EUC, can consider the unique features and limitations in construction projects.

3. EUC in the mobile computing

3.1. Correspondence to the variety of needs

Construction projects have unique features and limitations. On the other hand, the basic of process of construction management is same even though the detail of process can be different in projects. Authors think that a job in management is composed of common formalized unit ones, and that the variation of combination of them can correspond to the difference of jobs in projects.

3.2. Design patterns in the proposed system

Authors extract the formalized unit jobs in data input from some outdoor ones that are suitable for the use of the mobile computing, such as the progress monitoring, the inspection, the position check, and so on. The design patterns are shown as user interface in this system. Each user interface has each formalized procedure.

Fig. 1 shows six design patterns of user interface for the data input that authors arranged [14].

Type-A is the format for the display of graphics such as drawings and pictures. Users can plot the position on graphics in this format.

Type-B is the format for the selection of item from a prepared list.

Type-C is the format for the selection of an element from prepared ones.

Type-D is the format for the data input of numerical value with scroll bar. The scroll bar is useful for the outdoor field manager. Three sets of scroll bar means three-dimension.

Type-E is the format for the data input of the condition value such as “start” and “completion” in the progress of construction.

Type-F is the format for the data input of text. This format is an attached function with OS. This has four kinds of input board such as keyboard and free writing board. Especially the character recognition enhances the actual use of PDA outdoor.

Users can arrange and change the prepared content in each format easily with the program in PC. This variability of content in the system supports EUC.

Fig. 1 also shows the concept of the combination of user interface formats. This means how to establish the workflow with them. End users can arrange the workflow freely, considering the process and content of construction management. Once the workflow is established, system developers can develop the

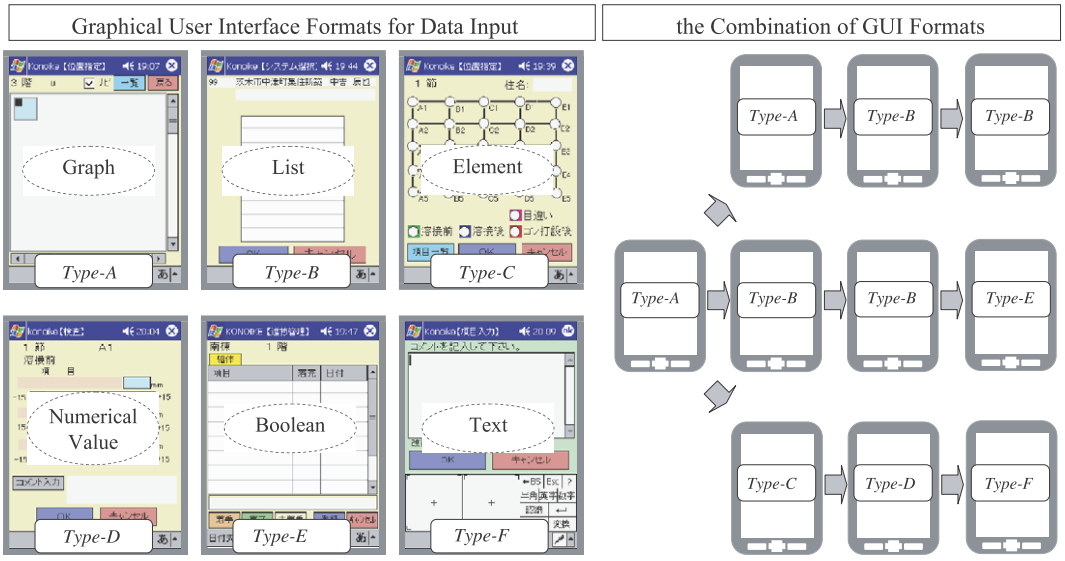

Fig. 1. Graphical user interface formats and their combination.

system easily and quickly, which meets the requirements of end users.

3.3. Basic structure and common process of the mobile computing system

The Mobile Computing System is composed of two programs: the data input program in PDA and the output and analysis program in the spreadsheet application software of PC. An application software is a suitable tool for EUC. It can be select and combined freely according to the request of end users.

Fig. 2 shows the operation of two programs and data transfer between them. The medium of the current system for the data transfer is a memory card.

Data Input with PDA **Output and Analysis with PC**

Fig. 2. Data transfer between PDA and PC.

The data transfer with mobile phone or infrared communication is possible.

The proposed system needs at least 4 MB as the memory for the program execution in PDA. All of data related to the project, such as drawing files and list content files, is stored in a memory card attached to PDA. The data generated by the operation on PDA is also stored in it. On the other hand, the different subsystems need to access the same information. The system shares the common information effectively. The memory limitation agrees with the capacity of memory card.

Users transfer the data from the memory card to the spreadsheet software in PC. All users can share all of the data, output various kinds of instructions, and analyze the data by the system and/or other applications. At the same time, they also can use the system individually.

Fig. 3 shows the flowchart with user interfaces of PDA in the proposed system. The top row of flowchart shows the common process. It uses the Type-B format of user interface. The left one is the cover screen of the Mobile Computing System. Users select project name, and user name or inspection type such as general contractor's inspection, architect's inspection and supervisor's inspection. The next one

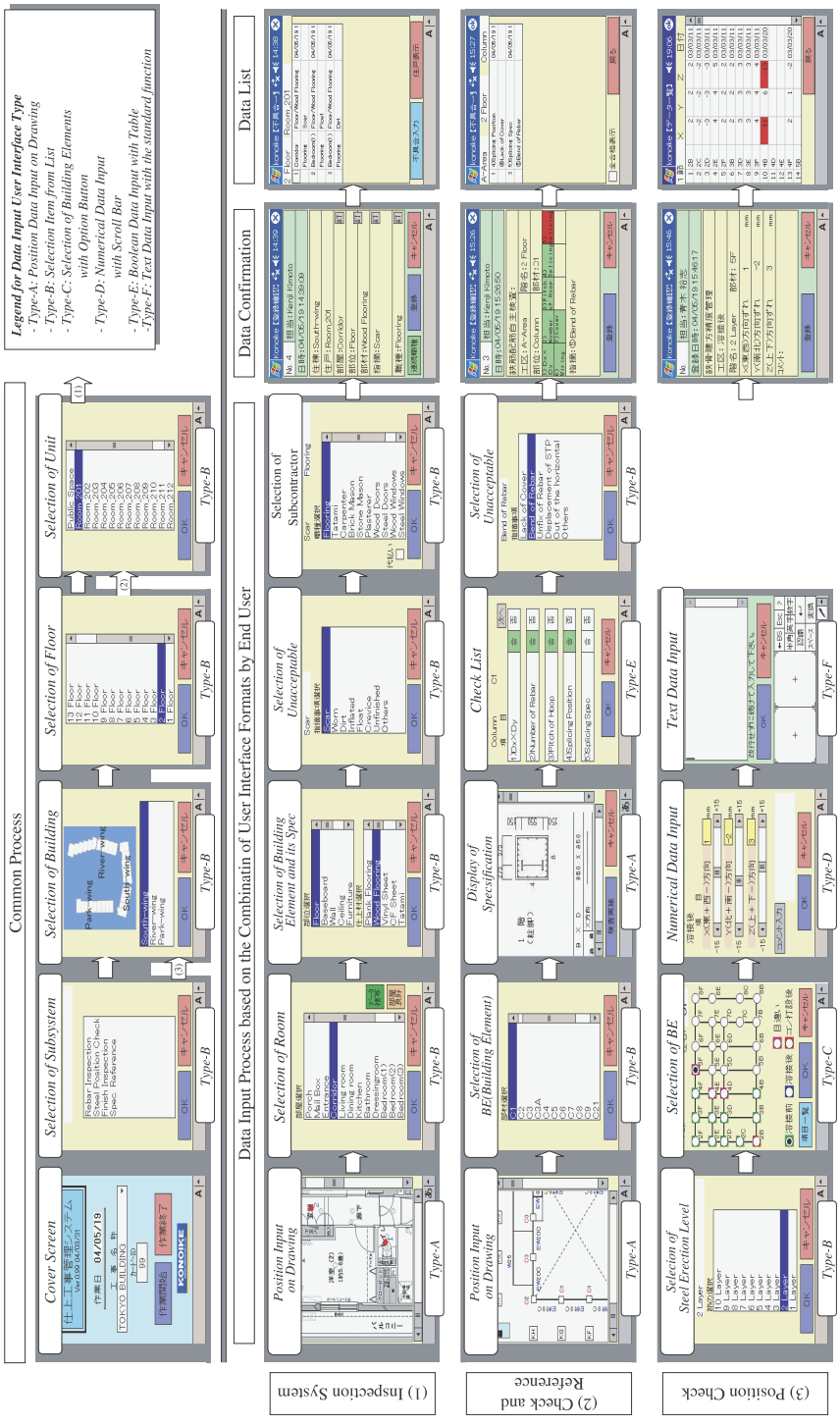

Fig. 3. User interface flow in the developed system.

shows the screen of selection of the subsystems such as Inspection System, Checklist and Reference System, Position Check System, and Progress Monitoring System. The next one shows the selection of building. When the project has only one building, users can skip this process. The next one shows the selection of floor. In the case of Position Check System for the steel erection, the erection layer instead of the floor is shown. The next one shows the selection of dwelling unit.

In the case of apartment buildings, the semi-order style for dwelling unit has widely spread in Japan. For instance, dwellers can select the color and height of kitchen of dwelling units freely. Construction managers must always grasp the specification each dwelling unit. In the proposed system, users can refer the specification of a room or a dwelling unit with Type-B format.

4. Inspection System

4.1. Aim and process

Inspection System is to inspect the executed works, especially for finish works, and to make the instructions for subcontractors. Users select the item from the list, which they can make it out previously, and/or input the contents freely on PDA. This system is more useful for multiple dwellings because they have many dwelling units and rooms.

The second row in Fig. 3 shows the process of data input of one indication in the inspection for finish work. This process is organized with the combination of user interface formats. The left end is Type-A format and shows a drawing of one dwelling unit on PDA. Users can understand the type and room planning of the dwelling unit. When they want to input the data of unacceptable, they point out the position of unacceptable on the screen of PDA by pen-touch. The screen on PDA moves the next one automatically. It is Type-B format and shows a screen of selection of room name such as “living room” and “kitchen.” They select an item from the lists. They can input other content with Type-F format. The next is Type-B format and shows a screen of selection of building element such as “wall” and “floor,” and finish material such as “wall paper” and “carpet tile.” The content of finish material depends on the one of building element. For instance, a user select “floor” as building element, the list of finish material shows only the related contents to “floor” such as “carpet tile” and “tatami mat.” This relation enhances the efficiency of selection of item from the list. The next is Type-B format and shows a screen of selection of unacceptable such as “dirt” and “crack.” The next is Type-B format and shows a screen of selection of subcontractors such as “finishing carpentry” and “glazing work.” The lists: unacceptable and subcontractors also depend on the result of selection of finish material. Finally the users confirm the input data of one indication on the next screen. The right end shows an input data list of multiple indications.

Moreover, users can prepare multiple patterns for one list in the lists of room name and subcontractors because different dwelling units may have different kinds of rooms, and multiple subcontractors may be engaged in the same work of one project.

4.2. Output and effect

(1) and (2) in Fig. 4 show examples of output of instruction for subcontractors in the inspection for finish work. There are two kinds of output formats: (1) the horizontal type and (2) the vertical type. Users select the suitable one case by case. The system reproduces the position and contents of unacceptable and/or notifications. They can coordinate the output by the sort function. They usually make the output for each subcontractor, and each inspection type such as general contractor’s inspection and supervisor’s inspection.

Digital data are convenient for the value-added. For instance, Fig. 5 shows the organization of room in unacceptable indication, and that of building element in its living room, in the inspection of one dwelling unit. This analysis will influence the next planning and management for better.

One aim in the Mobile Computing System is the improvement of productivity of construction management. Fig. 6 shows the comparison of productivities of the inspection for finish work per 30 dwelling units. The result of conventional system is a simulation based on construction manager’s experience. The job with PDA needs more time for the preparation but

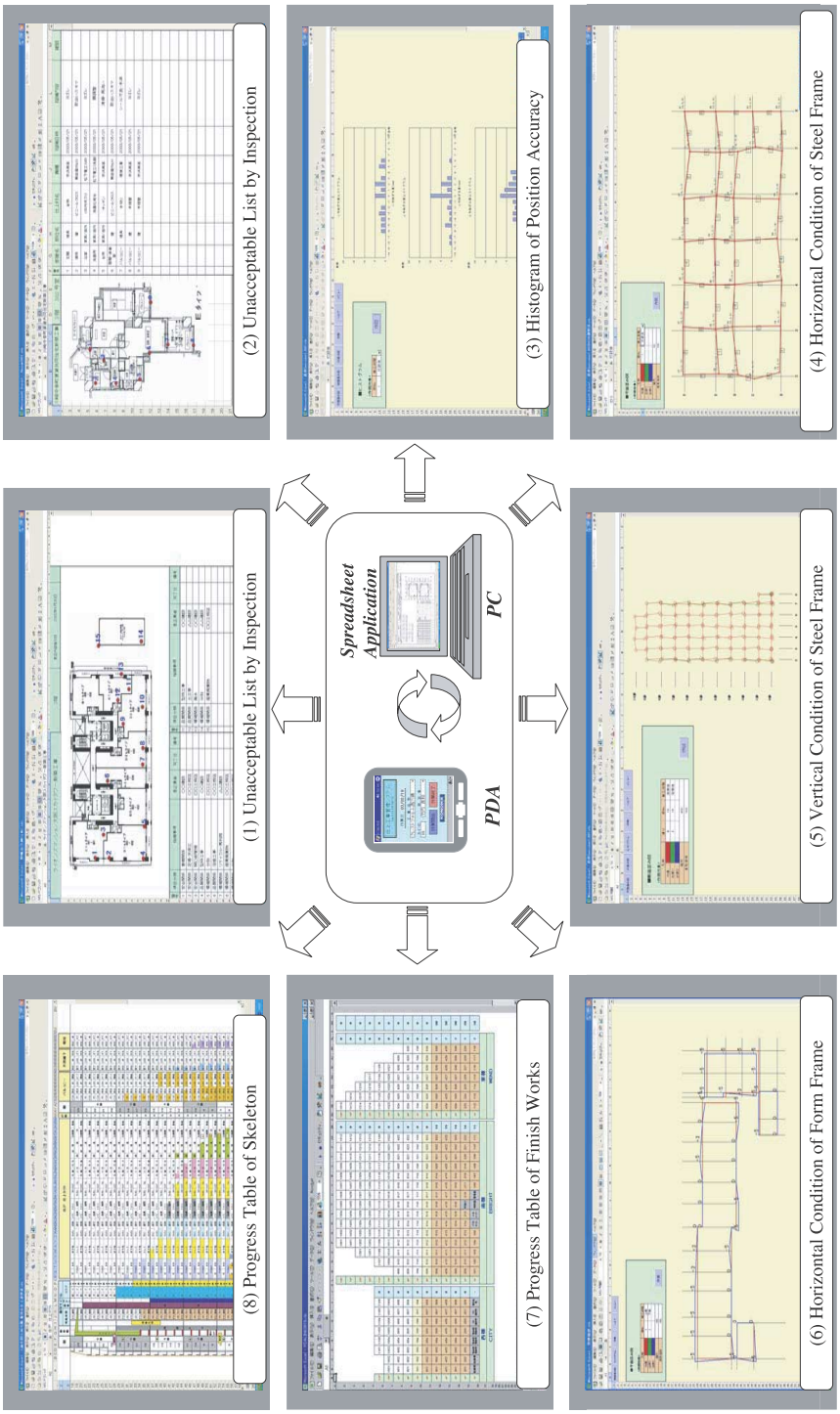

Fig. 4. Various kinds of outputs in the developed system.

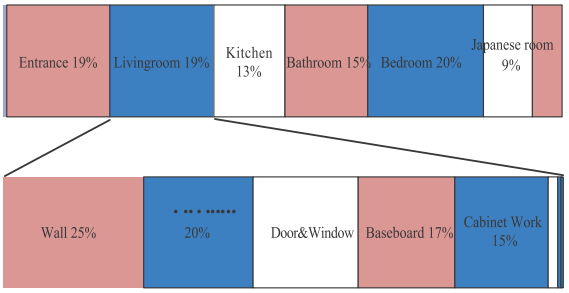

Fig. 5. Analysis of inspection data.

reduces the time of the data reduction and instruction print.

4.3. Variation of Inspection System

Field Note System, a variation of Inspection System, is to note various unacceptable or notifications on construction site, and to make the instructions for subcontractors.

Like Inspection System for finish work, users determine the position of unacceptable. After that, they input the contents. As noted above, they can select an item from the list that is prepared previously, and/or can input the content freely on PDA. The content in this system is classified into three categories: Safety Management, Quality Management, and Environmental Management. These are daily jobs for construction managers.

The output of instruction for subcontractors is same as (1) and (2) in Fig. 4. This system reproduces the position and contents of unacceptable or notifications on the output. Similarly, users can coordinate the content on the output by the sort function. They usually print the output for each subcontractor.

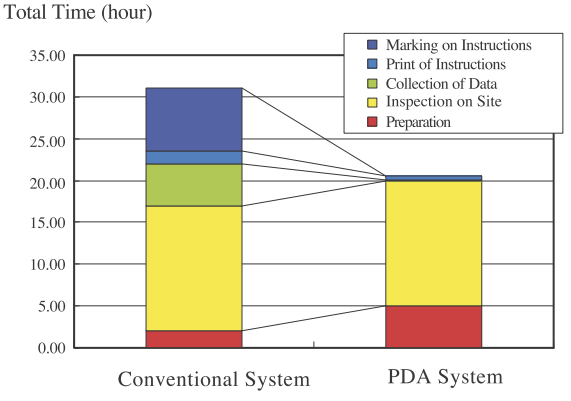

Fig. 6. Comparison of productivity.

5. Checklist and Reference System

5.1. Aim and process

Checklist and Reference System assists construction managers in inspecting the executed works, especially for the formalized procedure such as the reinforcing inspection. The system shows the related checklist. They determine whether the object is accepted or rejected with the checklist. They can refer the specification and code at any time on construction site.

Users can coordinate the content of checklist and input the inspection result easily with PDA. They can output the inspection result for owners and inspectors.

The third row in Fig. 4 show the process of data input in this system for the reinforcing inspection. This process is quite formalized. This process is also organized with the combination of formats of user interfaces. The left end is Type-A format and shows a drawing of one plan on PDA. Users can understand the position of building element and the type of reinforcing. The next one is Type-B format and shows the selection of building member. The next one is Type-A format and shows the specification corresponding to the selected building element. The next one is Type-E format and shows the checklist. They can compare the executed works with it. When they indicate the rejection, they input the reason from the list. The next one shows an example of all input data of one building element in this system.

5.2. Output and effect

The output of the check result about the reinforcing work for owners and inspectors is similar to (1) and (2) in Fig. 4. The system reproduces the position and results of inspection, the related specification, the contents of unacceptable, and the results of the repair.

A building is usually composed of many building members. The volume of drawing and specification of one building is immense. This system is easy to carry and offer the information effectively. Moreover, this system is widely useful for the inspection especially for the formalized procedure. The checklist helps users' inspection procedure.

6. Position Check System

6.1. Aim and process

Position Check System is to check and record the accuracy of the position of building members, especially for the steel erection, and to show the actual condition of construction graphically. The system also analyzes the data and makes the histogram to show the scatter. Users, construction managers, can grasp the actual condition quickly and take a measure to correct it under construction. This feedback to the construction planning is useful especially for the high-rise steel erection.

The bottom row in Fig. 3 shows the process of data input of the position accuracy for steel erection. This process is also organized with the combination of formats of user interfaces.

The left end is Type-B format and shows the selection of steel erection layer. The next one is Type-C format and shows the screen of selection of steel members on PDA. At this time, users decide the condition of construction in the data input: "before welding," "after welding" and "after concrete-casting." The system analyzes the difference between them. The next one is Type-D format and shows the screen of numerical data input of the position accuracy. This system adopts the scroll bar for users on construction site to input data easily and quickly. The number of data input for one member is three to correspond to the three-dimension. Users can arrange the range and unit of numerical data by scroll bar. Moreover, they can change the number of data set in one building member. For instance, they can set two data boxes with scroll bars in one member to correspond to two-dimension frame. They can input the comment with Type-F format.

The next one shows an example of all input data of one position of building member in Position Check System. The right end shows a list of input data of multiple position. If the data is out of the specified value of position accuracy margin, the value will be highlighted.

The input data with PDA are transferred to the system in PC. Users can analyze them and make some graphical outputs easily and quickly.

6.2. Output and effect

First, the program in Position Check System shows the distribution of their positions with the histogram by dimension. (3) in Fig. 4 shows an example.

Secondly, it can also show the current condition of steel frame on PC graphically. (4) in Fig. 4 is an example of horizontal actual condition of steel members: columns and beams. The positioning errors are enlarged 150 times. The numerical values in the graphics are the three-dimensional position of the top of steel columns, and the expansion or contraction of steel beams. Users can lap and compare multiple layers in PC. This comparison shows the change of frame with time. (5) Fig. 4 is an example of vertical actual condition of steel members. They can select any section of building.

These outputs also serve as the report of quality management for the steel erection. In the near future, three-dimensional graphics will be available. The graphical expression of data is useful for construction managers to understand the actual condition and the trend of distortion of the frame visually.

One cause of the distortion of steel frame is the welding of steel members. Users will be able to grasp the effect of the welding by the comparison of steel frames between "before the welding" and "after the welding." Another is the error of size of steel members. The feedback of the result for the planning and management is important. This system enhances the speed and accuracy of feedback. As a result, they can take a measure quickly.

6.3. Variation of positioning accuracy check system for form work

Position Check System is also available for form work. In the case of the form, the horizontal position accuracy of the exterior wall, the tilt of the form panel, is important. The user interface for the data input of the numerical value in this system has two data boxes with scroll bars for one point.

(6) in Fig. 4 shows an example of actual condition of the form. The number of each point in the output means the difference between the actual position and the designated one.

7. Progress Monitoring System

7.1. Aim and process

Progress Monitoring System assists construction managers in monitoring the progress of construction work. They can set the division of management process freely. The number and scope of items in work progress depends on their management policy. This system is available for the progress monitoring of both skeleton and finish work. The application of this system for finish work in apartment building projects is more useful because finish works of multi-dwellings progress at several places simultaneously.

For each progress item, users input the progress information such as "not yet started," "start," and "completion." The date and time are automatically input when they input the new information about progress with PDA.

7.2. Output and effect

(7) in Fig. 4 is a graphical expression of the progress of finish works each dwelling unit on PC by Progress Monitoring System. This model has three buildings and nearly 360 dwelling units. (8) in Fig. 4 is an example of skeleton each floor. Users can arrange the output and link between the input and the output. These tables are easy for the stakeholders to understand the progress.

The bigger the project, the more the volume of the object of management. It usually exceeds the capacity of construction managers. They divide the task and share the information. This system is useful for the share among construction managers in the project.

8. Summary and conclusions

This paper describes the aim and outline of the development of the proposed Mobile Computing System with PDA on construction management.

First, necessary functions for the mobile system from this research are as follows:

- Mobility of Hardware
- Durability of Hardware
- Compatibility of Hardware and OS
- Compatibility of Data between Mobile and PC
- Expressivity of Display
- Stability of System
- Operability of User Interface
- Processing Speed

As a result, PDA is adopted as mobile computer in this research. It meets the requirements of construction managers.

Secondly, the system is based on the concept of EUC. It is useful especially in the application of computer-aided engineering for construction management because construction projects have many unique features and limitations. Users can make up the suitable workflow with the combination of formalized user interfaces as design pattern in this system. Moreover, users and system developers can create subsystems through this flowchart easily and quickly. The developed subsystems in this research are as follows:

- Inspection System assists architects and construction managers to inspect the executed works for finish works, safety management and environmental management.
- Checklist and Reference System assists construction managers to access the checklist and reference such as drawings and specifications for the reinforcing inspection.
- Position Check System assists construction managers to check and correct the position of building members for the steel members and the form panel.

– Progress Monitoring System assists construction managers to monitor the progress of projects for the skeleton and the finish works.

The effect of the development of the Mobile Computing System from this research is as follows:

– Mobility of Information: The mobile system can offer a lot of information on the construction site.
– Elimination of Gap in time and space: The users can directly input the data with the mobile device on construction site. The mobile system eliminates the duplicate work.
– Increase of Productivity: The mobile system can realize the increase of productivity of construction manager. Although the preparation needs more time, the manpower for data reduction and output is decreased.
– Link of Existing CAE tools: The data input with the mobile system realize the effective use of data with the link of existing computer-aided engineering tools. Spreadsheet software shows the effective outputs such as histograms, tables, and graphical figures. For instance, it will be possible to link between the Progress Monitoring System and scheduling software. Construction managers will be able to establish the new process of scheduling.

Finally, the Mobile Computing System has much possibility in the future. Authors indicate the Next Generation of this system as follows:

– Digital Camera: Digital camera has already installed the mobile computing devices. The function of attaching the information to each picture on the mobile easily is necessary. The digital movie is also useful.
– Speech Recognition: The function of speech recognition has already established. The elimination of noise on construction site and the conversion from speech about construction to character are needed.
– Real Time Data Exchange: Various construction works on construction site proceed simultaneously. Real time recognition of construction site leads better management. The application of mobile phone will be possible and suitable.
– Compatibility of Hardware and OS: In actual, various types of mobile computer and OS exist. The compatibility will be necessary to spread the application of computer-aided engineering.

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