

Control Component Development of Information Appliances on Networks*

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In this paper, an Information Appliance Control Platform (IACP) is presented. In this platform, users monitor and control appliances through a network-connected mobile device at home, even on the Internet. This platform is effectively built by the technologies of agent, embedded system, networking, database and serial communication. Three subsystems developed in this platform are User Interface Subsystem (UIS), Gateway subsystem (GS) and Information Appliance Network Subsystem (IANS). To efficiently set up an effective software process, a CMMI-style process management and a CVS (Concurrent Version System) are adopted to support the software process. Based on the flow of requirement analysis, specification definition, design, implementation, integration, validation, and verification, team members can transparently co-work in each stage. The results indicate that not only the control components can support a new digital living style, but also such a develop paradigm demonstrates a successful software process and improve the efficiency and effectiveness.

Keywords: information appliance, control component, mobile computing, agent, CMMI

1. INTRODUCTION

The continuous grow of Internet population encourages the innovation of new technology and application. The promising progress of computation technology make professional information systems embedded in residential environments. Thus the topic of digital home attracts lots of researcher devoting on how to employ computer and electronic technology to improve the living quality of people at home in recent years. The trend of digital home is not only presented in research but also demonstrated in industrial products. According to the statistics of Ministry of Economic Affairs, in Taiwan, up to 2004 Q2, the number of home connecting Internet reaches 5.2 million USD, about 77.5% [1]. The data from MIC [2] depicts that the export value of IA from Taiwan reaches USD 4.19 billions and grows up by 140.1%. This export is expected to be 6.4 billions USD by the end of 2005. In other words, IA industrial has become a significant and emerging one of information industrials. Moreover, the IA will step in a creative and productive style as the technologies of networking and embedded systems evolve. The popularity of

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wireless communication, mobile hand-held system and IA control technology prompts the feasibility of the remote control of Internet IA. However, the lack of software components is one of the obstacles on the development of digital home. In this paper, software components of mobile devices, database and appliance networks are investigated and implemented. Through the integration of mobile device, database system and networking technologies, a distributed, mobile and friendly IA monitor and control platform is demonstrated.

Actually, the research of digital home was initialized in 1987. Skrzypczak [3] proposed an intelligent house at 2010, in which people communicate with the outsiders through a home gateway. Additionally, this gateway also offers people with information and appliance control service. Such a user-gateway-service operational model still is representative of modern digital home. In a digital home, there are a variety of appliance devices with quite different functions and operations. How to integrate the heterogeneous devices and to establish a certain control and monitor mechanism is very challenging [4, 5]. In the proposed platform, there are three software components designed and developed for IA monitoring and control, including User Interface, Gateway and IA network. The Java technology is utilized to collaborate with database, mobile phone, wireless/wired networks and serial communication to exploit the control platform of IA. The proposed control platform has the following features, (1) excellent mobility to support both PDA/GSM and Desktop PC, (2) high heterogeneity contributed by Java to integrate computer network, telecommunication network and appliance networks as well as to build an interface between user and appliance, (3) admirable scalability to support not only the extension of control modules in appliance sites but also the expansion of user terminals, (4) reliable security to enable user authentication and authority to meet the requirements of home environments.

In addition to technology exploration of digital home, software process is also concerned in this work. To achieve the goals mentioned above in an effective and efficient way, a CMMI management mechanism is conducted to support the software process throughout. The software process follows flow of requirement analysis, specification definition, design, implementation, integration, validation, and verification. The documentation of requirement, project planning and testing are followed step by step. With the help of documentation, the work breakdown of the project is clear and easy to trace. Meanwhile the experience obtained by team members is also described in the detailed documents.

The rest of this paper is organized as follows. The related technologies and previous works are illustrated in section 2. The design of the proposed software components are presented in section 3. In section 4, the experience of software process management is shared. The implementation and experiments are illustrated in section 5. Finally, we conclude this work in section 6.

2. RELATED TECHNOLOGIES AND PREVIOUS WORKS

Home automation had been a goal of information technology for a long time [6, 7]. There have been many existing approaches, for example: X10, Lonworks, CEBus and RS-232. In a X.10 network [8], power line is the communication channel between con-

troller and devices. The power waveform of 60Hz is the carrier modulating with a 120kHz wave to send digital control commands of appliances. Controller submits an instruction through the uni-directional channel with a rate less than 10 Kbps and the number of the controlled devices is limited below 256. Although X.10 is simple and cheap to setup, the noise-immunity, scalability and reliability are questioned. CEBus [9] proposed by EIA was improved from X.10 by using better modulation technique, spectrum spread. CEBus has better data rate, higher noise immunity and more controlled devices. Lonworks [10] is a better solution and uses a variety of communication channel, including power line, Ethernet and IrDa. These channels have the advantages of duplex channel and flexibility. In the combination of various communication channels, Lonworks supports be a wider coverage and up to several thousand devices. However, in Lonworks, a hardware chip is attached to the controlled appliance to enable the connection between the controller and the controlled device. The amendment of appliances causes the setup cost and limits. High setup cost obstacles the popularity of this approach.

Although modern home network technologies have effectively connected many home appliances, there are still some obstacles in unifying the operations of various appliances to a single interface. These obstacles are (1) heterogenous operation models, (2) scalability, and (3) security. In general, appliances have different operational models. Light usually has on and off states in switch and electric fan likely has multiple states to operate as shown in Fig. 1. Thus heterogenous operational models of various appliances confound the integration of home appliances network. Besides, because home appliance may change dynamically, the home network should have the ability to adapt this change and to scale its deployment. Finally, the home appliance network could be connected through Internet. Security is also concerned about how to prevent the appliances from malicious accesses.

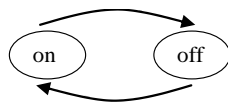


Fig. 1. (a) State diagram of on/off switch.

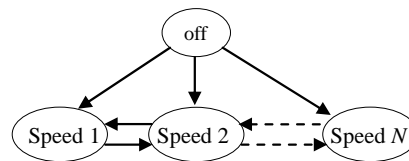


Fig. 1. (b) State diagram of multi-level switch.

In contrast, the low cost and high popularity of RS-232 technology facilitate its possible success in home automation. The valuable features of RS232 technology, including high immunity to noise and easy connection to hosts, effectively benefit the construction of appliance network. In the appliance networks, a RS-232 connection technology, called as Industrial Control Product (ICP) modules, is introduced to connect and control the appliances. ICP modules are originally designated for on-line data gathering of manufacturing factory. Due to its generality and simplicity, ICP modules are also suitable for home automation. We can use ICP module to connect light switches, fan devices, position sensors, thermal sensor and so on. ICP modules are interconnected with each other through the interfaces of RS-232 and RS-485. Each ICP modules are programmable to configure before deployment. Because of the high reliability, feasibility and low cost, ICP are definitely suitable to establish home appliance networks. Additionally, software

components are developed to effectively merge the operations of appliances and to offer a unified interface. Simultaneously, user management securing the remote access is considered and implemented in this platform.

3. DESIGN OF SOFTWARE COMPONENTS FOR IA CONTROL

The architecture of the control platform illustrated in Fig. 2 is composed of handheld mobile device, home gateway and information appliance networks. The handheld mobile device is designed for user interface. Users inquiry and adjust the status of home appliances via a handheld device. The instructions issued by users will be transmitted over Internet or GSM network and received by the home gateway of this house. The functions of a home gateway include user management, user instruction logging and status maintenance of home appliances. When a home gateway receives an instruction from a handheld device, it first authenticates and authorizes the user. Authentication is to check the validation of the logging user and authorization is to determine the operations admitting for the user. After the authentication and authorization, the received instruction will be recorded in the database of the home gateway and be processed by the appliance device agent. The home gateway is also connected to an ICP network through a RS-232 port. The ICP network interconnects with various ICP modules such digital switch, analog switch, digital input and analog input. The switches are engaged to adjust appliances and the input modules are used to read the sensing data from sensors.

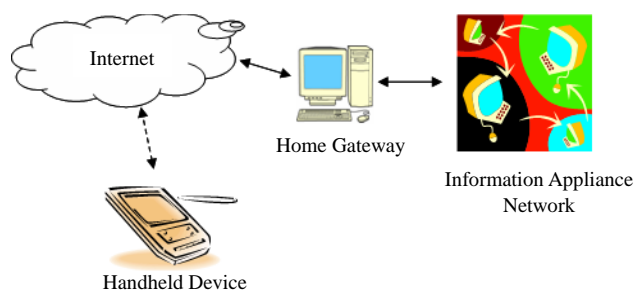


Fig. 2. Architecture of information appliance control platform (IACP).

Regarding to software architecture, IACP is divided into three subsystems which are User Interface Subsystem (UIS), Gateway Subsystem (GS) and Information Appliance Network Subsystem (IANS). In each subsystem, a software component is designed to collaborate and to accomplish the desired control platform functions. The three software components are manager agent, gateway agent and device agent as shown in Fig. 3. Agent is a software module capable of interacting with the external environment and other agents to either achieve a specified goal or transit the system to a desired state. In this proposed scheme, internal behavior of each agent is modeled as a finite state machine (FSM). The received messages are regarded as the system event to conduct the state transition of each agent. Manager agent operates in handheld device as the user interface responsible for issuing an instruction and receiving message from gateway.

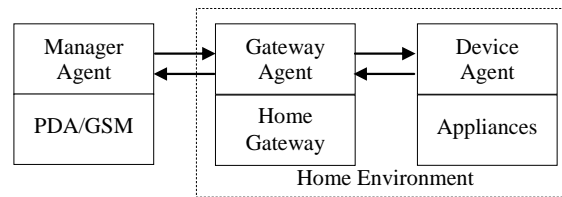


Fig. 3. Agent design and interacting relationship in IACP.

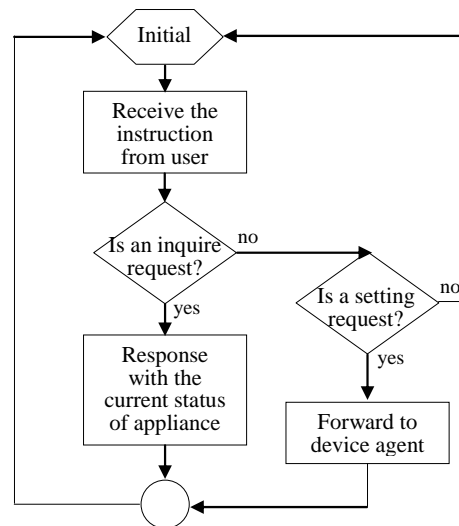


Fig. 4. The flow chart of gateway agent.

Gateway agent and device agent are performed on the home gateway. Gateway agent communicates with manger agent and device agent on the heterogonous networks. There are two main functions of gateway agent; (1) forwarding the instruction of appliances from manger agent to device agent and (2) transporting the appliance information from device agent to manger agent, as shown Fig. 4. The collaboration of three agents performs the control and monitoring of home appliance. The software model of manger agent is shown in Fig. 5. The manager agent is developed on a Linux/WinCE-based mobile phone set and a PDA. To ensure the compatibility between various mobile devices and the developed software, JAVA technology is applied. J2ME (Java 2 Platform, Micro Edition) technology is a scaled-down version of the Java 2 Platform Standard Edition (J2SE) technology designed for deployment on small, resource-limited devices such as PDAs and mobile phones. The Mobile Information Device Profile (MIDP), combined with the Connected Limited Device Configuration (CLDC), is the Java runtime environment for mobile devices. Making use of MIDP, we can write applications once, and then deploy them quickly to a wide variety of mobile information devices. Based on MIDP, the manager agent is developed to offer mobile user with an interface to operate the remote home appliances in two connection types. Users can access the appliance service by socket and web service. Certainly, the manager agent functions as an interface to

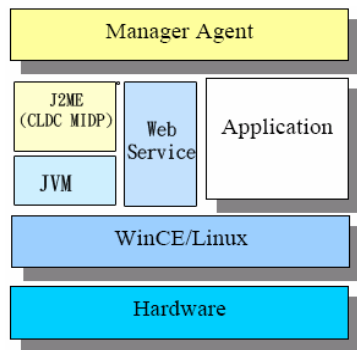


Fig. 5. Software architecture of user interface subsystem.

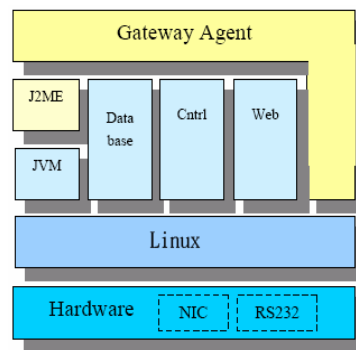


Fig. 6. Software architecture of gateway subsystem.

connect gateway agent at home. Thus the manager agent sends user instruction to gateway agent and displays the response message from gateway agent.

The GS architecture depicted in Fig. 6 is composed of a database system, web server and control modules. A gateway agent is developed for merging these modules. Web server offers http service for user to access the gateway in more general way, even for desktop users. Control modules are used for data exchange between database and web server, as well as socket connections. In the database of GS, there are three data tables maintained in the database system; they are user tables (UT), appliance table (AT) and instruction record table (IRT). User table with the valid user information is used for authentication and authorization purposes. Appliance table indicates the appliance locations, the corresponding ICP module address and the permitted operations. Finally, user instructions received from mobile devices are registered in the instruction record table. The device agent periodically checks IRT and the device agent operates the home appliances accordingly. The partial entity-relationship (ER) model of the database system is illustrated in Fig. 7.

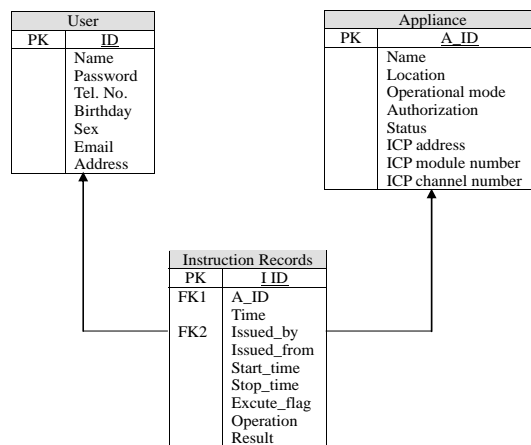


Fig. 7. ER model of the database at home gateway.

IANS is an appliance network, based on ICP-modules, to connect home appliances. ICP modules are connected by RS-485, a shielded version of RS-232. This ICP network is attached to home gateway via a RS-232 converter. A device agent is designed to configure each ICP modules attached in this IANS when the appliance network is initialized. The device agent should set each appliance with a unique ICP address and its default configuration according to the profile kept in the database of the home gateway. After the initialization, the device agent will check the instruction records of database to adjust the appliance settings. In other words, the device agent periodically scans the IRT of home gateway and check whether the device status complies with the last user instruction or not. If not, the device agent will send ICP command to amend the appliance status accordingly. The detailed model of a device agent is shown as in Fig. 8.

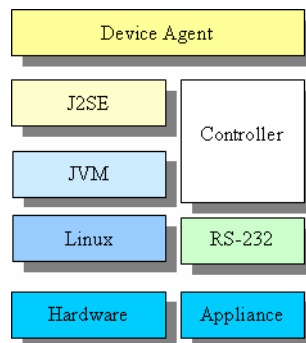


Fig. 8. Software architecture of information appliance network subsystem.

4. SOFTWARE PROCESS MANAGEMENT

Addition to the technology development, software process management is also concerned in this work. The goals of software process management are (1) to improve productivity of software work (2) to streamline software development processes (3) to have better efficient resource utilization (4) to reduce process cycle. To achieve these goals, the software process first should be defined and described. There were methodologies proposed for software developments in aspects of various software scales. One of them has been widely employed is waterfall model [11]. Based on waterfall model, a software process is organized with several phases including requirement analysis, specification definition, design, implementation, integration, validation, and verification. In each phase, entry criteria and deliverable products are defined. The structures of requirement analysis, project plan and test plan and are shown in Tables 1 to 3.

Table 1 shows the items investigated in the requirement analysis of this work. There are 16 items covering system overview, functional requirements and non-functional requirements. Based on the guidance of the items, the detailed requirements of IACP are carefully checked and derived. The project planning is characterized by the items depicted in Table 2.

Table 1. Structure of requirement analysis.

1. System Description	11. Design and Implementation Constrains
2. Operational Concepts	12. Technological Limitations
3. Functional Requirements	13. End User Issue
4. Performance Requirements	14. Risk Management
5. Safety Requirements	15. Test Requirements ◆ Acceptance Criteria
6. Reliability Requirements	16. Interface Requirements ◆ Internal Interface ◆ External interface ◆ User Interface Requirement
7. Maintainability Requirements	
8. Delivery Requirements	
9. Installation Requirements	
10. Environmental Requirements	

Table 2. Structure of project plan.

1. Project planning and Milestones ◆ Technical Approach ◆ Work Breakdown Structure ◆ Work Breakdown and Item Estimation ◆ List of Work items ◆ Planned schedule and Milestones	5. Configuration Management Plan ◆ Establish Baselines ◆ Identify Configuration Items ◆ Track and Control Changes
2. Task assignment of team members	6. Risk Management
3. Resource requirement	7. Measure and Analysis Plan
4. Documents and data management	8. Process and Product Quality Assurance Plan

Table 3. Structure of test plan.

1. Test overview and Strategies	4. Test cases
2. Personnel and Responsibility	5. Test Procedures and Schedule
3. Testing Environment	6. Test Results and Analysis

First, the project is broken to pieces of works and shown in the work breakdown structure. Each piece of works is clearly defined in a work sheet to indicate the correspondent, work products, required resources and the estimated schedule. Certainly, the milestone and check points of the project process are also planned in advance. Personnel involved in this project is assigned and described in this planning. The resource requirement should be estimated and planned evidently. The resources are available materials, budgets, people and time. We should estimate the required resources in this project and arrange the resource allocations during the project process. Then, document and data generated by the software process should be securely maintained. Thus the management of document and project data should be clearly identified. Configuration Management (CM) is very important to the software process. The goal of CM is to make the project process responsive to the possible environment and requirement changes. Thus, we have to establish the baselines about the target project and determine the configuration items. Then, these steps enable us to track and control the possible project changes. To make

the development process reliable and fault-tolerance, risk management is necessary. Risk management includes risk identification, risk reduction and damage control. Certain preparations for possible risks destructive to the software process definitely are worth and significant. In the end of the project planning, quality assurances of process and product are also discussed.

The structure of test plan is depicted in Table 3. The purpose of testing is to find possible errors hidden in the developed software components. In general, test approaches are categorized as two different types; black box and white box. In this work, a black box approach is utilized to verify the software modules. Then, the people involved in the test procedure and responsibility are illustrated. The establishment of testing environment is presented to show the requirements of software and hardware in test. Test cases show the scenarios in which the interactions not only between user and agents, but also between agents. From test cases, the further testing procedure and schedule are derived to ensure the test procedure to be finished correctly and in time. Once any error is encountered in the test procedure, the error report is made to record and analyze the cause of this error. Based on the result and analysis, the debug process is designed and executed.

To facilitate the project efficiency, concurrent version system (CVS) is introduced in this project. CVS has a client-server architecture [12]. Team member is at the client site. The CVS server is a repository of source codes and documents. Client connecting the CVS server will deliver its product to the server and download the materials from server. CVS server can record the history of sources files, and documents. The feature of CVS system are (1) centralized management of documents and codes, (2) detailed recording of software version evolution, (3) real-time trace back of prior software versions, (4) flexible authorization of various users.

5. IMPLEMENTATION AND EXPERIMENT

The proposed design and of information appliance control platform has been implemented as a prototype to realize a part of digital home. The specification of this implemented platform is shown in Table 4.

Table 4. Specification of IACP prototype.

User Interface Subsystem (UIS)	Gateway Subsystem (GS)	Information Appliance Network Subsystem (IANS)
Hardware: 1. Ericsson K700 2. Compaq Pocket PC Software: 1. J2ME MIDP1.0 2. GPRS socket 3. Manager agent	Hardware: 1. Pentium 3, 1.7 GHz 2. RS-232 port 3. Fast Ethernet port Software: 1. Linux Red Hat 2. MySQL database system 3. Tomcat web server 4. JSP scripts 5. Gateway agent	Hardware: 1. ICP converter module 2. ICP analogy switch 3. ICP digital switch 4. ICP analogy input 5. ICP digital input Software: 1. ICP drivers 2. Device agent

UIS has been implemented and verified on an Ericsson K700 mobile phone and Compaq Pocket PC. UIS can access GS either by GPRS or by Web service. The manager agent in UIS is developed in J2ME programming and packed in the form of Java Archive (JAR). The jar file can be deployed directly from the web server to mobile devices. GS is currently realized by a desktop computer equipped by RS-232 and Ethernet to connect UIS and IANS, respectively. In GS, MySQL is set up to maintain the information of valid users, connected appliances, control instructions issued by users. Then the content of the database will be updated by the user commands from UIS to drive the appliance control and monitor. In IANS, lots of ICP modules are employed to construct a home appliance network. In this prototype, the connected appliances are lights, electric fans, heaters and so on.

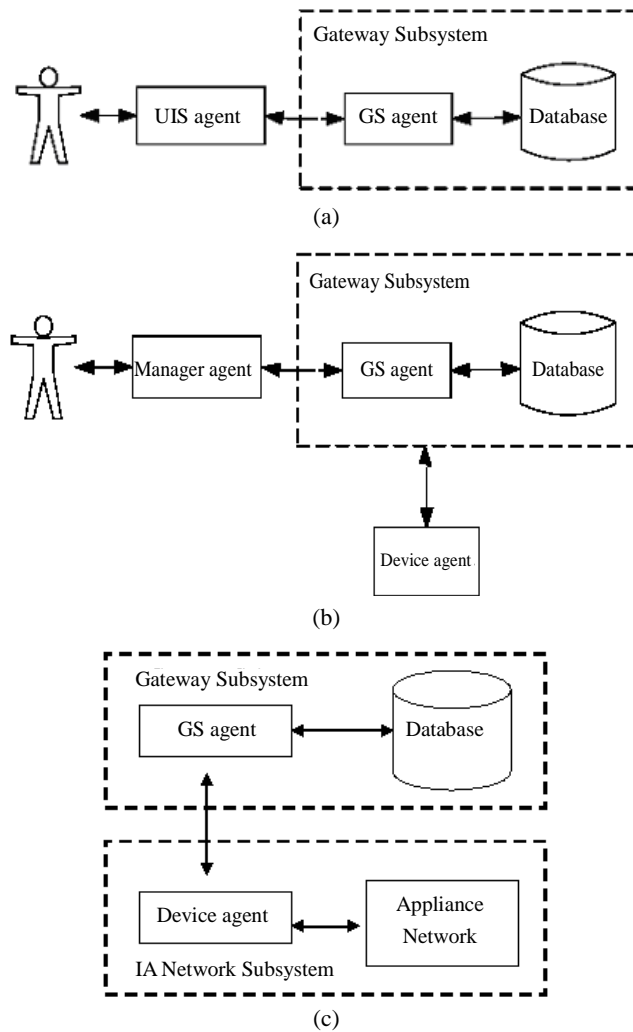


Fig. 9. Examples of test cases for IACP.

Test cases designed for verifying the developed platform are partially shown in Fig. 9. In Fig. 9 (a), the individual functions of UIS and GS are first verified; including user management, data. Besides, the interoperability between UIS and GS is also validated. In this case, user instruction is caught by manager agent, forwarded to gateway manager via wireless channels and stored in data tables of database finally. The test case shown in Fig. 9 (b) is for the testing of device agent to check whether device agent can correctly acquire the stored instructions or not. The functions of information appliance network are validated in the case shown in Fig. 9 (c). In this case, device agent will access the user instruction table of MySQL system, translate to the ICP command string and deliver the command to the ICP module.

The experimental results demonstrate that IACP has the real-time and recoverable features. First, through GPRS transmission, the response time of the instruction issued by remote users is less than 2 seconds; even users can use the joy stick on mobile phone to control the speed of an electric fan. Second, IACP has the recoverability of home appliances, even after a power failure. The recoverability comes from the natives of IACP. After a power failure, device agent is activated to adjust the appliance status according to the last user instruction stored in GS.

6. CONCLUSION

In this paper, we present an approach to information appliance control platform to show how to use handheld mobile device to monitor and control home appliances. In this platform, there are handheld devices for user interface, a gateway server for management services and an appliance network for connecting home devices. Certainly, necessary software components are also developed to collaborate and to integrate the spread hardware entities. In the development of software components, software components are modeled as manager agent, gateway agent and device agent which are embedded in handheld device, home gateway and appliance device, respectively. The three agents perform their dedicated works to collaborate and interact with each other to achieve the goal of appliance control and monitoring.

Additionally, in this team work, a standard software process and a CVS system are employed to formulate and manage the project progress. Following the style of CMMI, requirement analysis, specification definition, system decomposition, design, implementation, validation and testing are performed step by step and documented. Due to the project planning in advance, the deliverable products at each stage are well defined and the schedule is monitored and checked at each stage. The results depicts that CVS system are good at not only maintaining code versions but also documentation evolution. This on-line system also offers team members with a real-time available source of documents and module codes for system design, implementation and testing.

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