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SMART HOME CONTEXT-AWARE AUTOMATIONBY A RULE-BASED SERVICE CUSTOMIZATION STRATEGY

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Abstract—The continuous technical progress of the smartphone built-in modules and embedded sensing techniques has created chances for context-aware automation and decision support in home environments. Studies in this area mainly focus on feasibility demonstrations of the emerging techniques and system architecture design that are applicable to the different use cases. It lacks service customization strategies tailoring the computing service to proactively satisfy users' expectations. This investigation aims to chart the challenges to take advantage of the dynamic varying context information, and provide solutions to customize the computing service to the contextual situations. This work presents a rule-based service customization strategy which employs a semantic distance-based rule matching method for context-aware service decision making and a Rough Set Theory-based rule generation method to supervise the service customization. The simulation study reveals the trend of the algorithms in time complexity with the number of rules and context items. A prototype smart home system is implemented based on smartphones and commercially available low-cost sensors and embedded electronics. Results demonstrate the feasibility of the proposed strategy in handling the heterogeneous context for decision making and dealing with history context to discover the underlying rules. It shows great potential in employing the proposed strategy for context-aware automation and decision support in smart home applications.

Index Terms- **Smart home, context-aware automation, decision support, service customization, rule generation**

I. INTRODUCTION

The flexible built-in sensors of mobile devices and embedded sensing techniques have fostered the contextaware computing paradigm, which involves the sensor data as implicit input to customize the computing service to specific contextual situations. The smart environment systems such as homes, workplaces, hospitals, and vehicles are typical use cases which integrate sensors and actuators to assist occupants to interact with the physical environment more efficiently. It is widely recognized that the context-aware computing concept based on various mobile device built-in modules and embedded sensing techniques can be considered a promising solution to better satisfy users' expectations and facilitate people's daily lives. The Wireless Sensor Actuator Network (WSAN) becomes an active research area in which sensors and actuators can be used to enhance the interaction between human and the physical world. It is estimated that there will be over 50 billion devices connected to the Internet by 2020, and paradigm shift is now being promoted, in which every object becomes interactive. In addition to the embedded sensing techniques, the Smartphone becomes more and more powerful in computation and communication. The shipment of various built in sensors, the wide acceptance amongst users, and its popularity in daily use make the Smartphone an ideal platform appropriate for characterizing users' preferences and the ambient environment.

II. LITERATURE REVIEW

2.1. A review of smart homes – past, present, and future:M.R. Alam, M.B.I. Reaz, M.A.M. Ali, IEEE Transactions on Systems, Man, and Cybernetics–Part C: Applications and Reviews, vol. 42, no. 6, pp. 1190-1203, 2012.

A smart home is an application of ubiquitous computing in which the home environment is monitored

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by ambient intelligence to provide context-aware services and facilitate remote home control. This paper presents an overview of previous smart home research as well as the associated technologies. It describes collective information about sensors, multimedia devices, communication protocols, and systems, which are widely used in smart home implementation. Special algorithms from different fields and their significance are explained according to their scope of use in smart homes. This paper also presents a concrete guideline for future researchers to follow in developing a practical and sustainable smart home.

2.2 Wireless sensor/actuator network design for mobile control applications :F. Xia, Y.-C. Tian, Y. Li, Y. Sung, Sensors, vol. 7, no. 10, pp. 2157-2173, 2007.
Wireless sensor/actuator networks (WSANs) are emerging as a new generation of sensor networks. Serving as the backbone of control applications, WSANs will enable an unprecedented degree of distributed and mobile control. With emphasis on the reliability issue, this paper presents an application-level design methodology for WSANs in mobile control applications. The solution is generic in that it is independent of the underlying platforms, environment, control system models, and controller design. To capture the link quality characteristics in terms of packet loss rate, experiments are conducted on a real WSAN system. From the experimental observations, a simple yet efficient method is proposed to deal with unpredictable packet loss on actuator nodes. Trace-based simulations give promising results, which demonstrate the effectiveness of the proposed approach.

2.3. A smarter smart home: case studies of ambient intelligence:S. Makonin, L. Bartram, F. Popowich, IEEE Pervasive Computing, vol. 12, no. 1, pp. 58-66, 2013.
Technological support for sustainable home use lies in more subtle and contextually appropriate interventions that integrate informative models of occupant behavior, provide hybrid levels of automated control, and use ambient sensing for localized decisions. A key concept in ambient intelligence is that its operation should have to be explicitly learned or managed by the occupant. This has been a problem for smart homes in general, where poor usability and intrusive and inappropriate operation have overwhelmed users. Monitoring home occupancy using power monitoring and ambient light sensors is a first step toward achieving an adaptive HVAC system.

2.4. A survey on the IETF protocol suite for the Internet of Things: standards, challenges, and opportunities: Z. Sheng, et al., IEEE Wireless Communications, vol. 20, pp. 91-98, 2013
Technologies to support the Internet-of-Things (IoT) is becoming more important as the need to better understand our environments and make them smart increases. As a result it is predicted that intelligent devices and networks, such as wireless sensor networks (WSN), will not be isolated but connected and integrated composing computer networks. So far, the IP based Internet is the largest network in the world, therefore there are great strides to connect WSN with the Internet. To this end, the IETF has developed a suite of protocols and open standards for accessing applications and services for wireless resource constrained networks. Thus, it becomes critically important to study how the current approaches to standardization in this area can be improved, and at the same time better understand the opportunities for the research community to contribute to the IoT field.

2.5. A survey on topology control in wireless sensor networks: taxonomy, comparative study, and open issues:
M. Li, Z. Li, A. V. Vasilakos, Proceedings of the IEEE, vol. 101, no. 12, pp. 2538- 2557, 2013
Topology issues have received more and more attentions in Wireless Sensor Networks (WSN). While WSN applications are normally optimized by the given underlying network topology, another trend is to optimize WSN by means of topology control. A number of approaches have been invested in this area, such as topology directed routing, cooperating schemes, sensor coverage based topology control and network connectivity based topology control. Most of the schemes have proven to be able to provide a better network monitoring and communication performance with prolonged system lifetime. In this survey paper, we provide a full view of the studies in this area. By summarizing previous achievements and analyzing existed problems, we also point out possible research directions for future work. In this paper, we present a comprehensive survey on topology issues for WSNs. We provide our classifications of the problems and approaches. Under this frame, we list, review and compare some classical works in the field. At last, we highlight the challenges in this topic and point out some future research directions.

2.6. Semantic space: an infrastructure for smart spaces:
X. Wang, et al, "IEEE Pervasive Computing, Vol. 3(3), pp.32-39, 2004
Semantic Space is a pervasive computing infrastructure that exploits Semantic Web technologies to support

explicit representation, expressive querying, and flexible reasoning of contexts in smart spaces. Current pervasive computing research tries to merge the material and digital worlds by incorporating physical and computing entities into smart spaces. Homes, workplaces, classrooms, vehicles, and other spaces use embedded sensors, augmented appliances, stationary computers, and mobile handheld devices to gather information about users' locations, companions, and other aspects of their activities. Applications in such environments must be context aware so that they can adapt to rapidly changing conditions as users move about in their environments. The dynamic nature of smartspaces poses several challenges in developing context-aware applications.

2.7. Proactive fuzzy control and adaptation methods for smart homes: A. M. Vainio, et al., IEEE Intelligent System, vol. 23, pp. 42-49, 2008

In this paper we describe a context-sensitive way to change an active mobile phone profile. We present a method to create a proactive and adaptive phone profile control system that automatically adapts the profile to the best alternative based on the current context. The adaptation is based on recognizing patterns of human practices, which may change over time. The control system is implemented with a fuzzy controller that supports reinforcement learning. The operation of the system is demonstrated with a mobile phone that is controlled by a PC. The PC lets a user to simulate the context parameters, and the phone works as a user interface for profile selection and display. In this paper, we have presented a context-aware, proactive, and adaptive phone-profile control system, which was provided for hands-on testing for conference attendees.

2.8. A data fusion approach to context-aware service delivery in heterogeneous network environments: P. TalebiFard, V. C.M. Leung, Procedia Computer Science, vol. 5, pp. 312-319, 2011

Context-awareness is a key ingredient in any ubiquitous and pervasive system and provides intelligence to the system, allowing computing devices make appropriate and timely decisions on behalf of users. Context-awareness in mobile computing refers to internal and external adaptation of the environment and applications to the context state of each other. Such systems should adapt to the changes and variations of user's context such as location, device status, connectivity and etc. In this paper we present our perspective of a context-aware service platform which is based on the idea of utilizing network information as services that is delivered via application programming interfaces and propose a fuzzy MADM method and a context similarity measure. We take into account the quality of contextual information in aggregating contextual information from different sources.

III. PROPOSED SYSTEM

3.1 Smart Home Context-Aware Automation

This work presents a rule-based service customization strategy which employs a semantic distance-based rule matching method for context-aware service decision making and a Rough Set Theory-based rule generation method to supervise the service customization. A prototype smart home system is implemented based on smart phones and commercially available low-cost sensors and embedded electronics. Results demonstrate the feasibility of the proposed strategy in handling the heterogeneous context for decision making and dealing with history context to discover the underlying rules.

3.2 Context Aware Service

A system is context-aware, if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task.The early stage investigations on smart home mainly focus on context acquisition and distribution with the novel sensing techniques and wireless network solutions for proof of concept development, such as indoor environment monitoring , wireless smart home sensor network , WSN topology control for network coverage and connectivity, WSAN for production automation, interoperable device usage , graphic user interface for remote control, network protocols and standards , trust and security, and service oriented smart home architecture.For the context-aware computing systems, some mathematical models for context-aware service decision making are introduced, such as Fuzzy Multi-Attribute Decision Making (FMADM), Multi-facet Item based method, Multi-Attribute Utility Theory (MAUT), probability-based model, Adaptive Neuro-Fuzzy Inference System (ANFIS), Fuzzy Logic, and Rough-Fuzzy method.

FMADM - This method can be used as a generalized approach to collect the context of mobile devices, and compare the context with the advertised service based on feature similarity. The fuzzy set is appropriate for presenting the uncertainty of context data, and the similarity measurement provides a way to evaluate the context and the service conditions.

MAUT - The MAUT is widely used for product evaluation in consumer organizations. It is also an applicable method for context-aware service customization. For context-aware computing systems, the contextaware service can be regarded as the evaluation result, the relevant context information can be considered to be the attributes, and the weight is the impact of context to the decision of service composition.

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Probability-Based Model -It based on context information and music content analysis by exploring the rich sensing capability of mobile devices. By monitoring the user's operations, user preference is updated in real-time to adapt to a particular user. This probability-based method is lightweight in computation and easy to implement, and it can adapt to new uses immediately without training procedures.

ANFIS - It aims to adapt the learning content to learners' needs within different learning context scenarios. ANFIS uses Fuzzy Logic to transform given inputs into a desired output through highly interconnected Neural Network processing elements and weighted information connections. ANFIS integrates the Fuzzy Logic and Neural Network.

Rough-Fuzzy Method- In this rough-fuzzy method, fuzzy sets are used to handle real-valued weight in the document, and the rough-fuzzy method named Variable Precision Rough Set Model (VPRSM) is used to discover user preference. This rough-fuzzy method integrates the rough set and fuzzy set, which are appropriate to deal with important tasks of personalized Web information retrieval.

Fuzzy Computing – An Ambient Intelligence fuzzy computing system based on multi-agent and fuzzy theory is proposed to pursue autonomous intelligence satisfying the needs of inhabitants without human intervention. The proposed AmI fuzzy computing focuses on the learning strategy capable of capturing the dynamic context feature and user preference to generate intelligent service that controls the environment to satisfy users' requirements.

3.3Method Employed for Context Aware Service Customization Strategy

The primary strength of the context-aware system compared with the traditional ones is its capability to automatically gather the context information as implicit input to customize the computing service.

According to Weiser's viewpoint on context-aware computing, the context-aware system provides the context-aware computing service S_C according to the user's explicit request R_E and computing context information C related to the computation. This investigation presents the functional model of context-aware computing system with formula (1).

$S_C=F(R_C)=F(R_E,C)$(1)

Moreover, the system can predict the expected service with the context only to provide the proactive computing service automatically as formula (2) presents.

$S=F(R_C)=F(C)$ (2)

where C={Cu,Cd,Cn,Ce,Ch,…}, and Cu, Cd, Cn, Ce, Ch,… are the context information of computing tasks such as user context, device context, network context, environment context, and history context. Thus, with the implicit input C, the computing service SC is customized to the computational context.

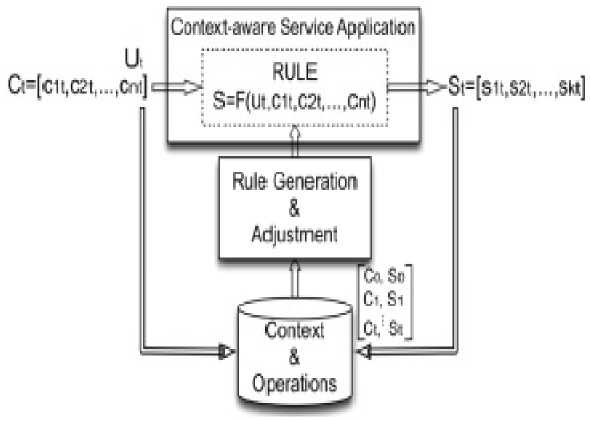

Fig 3.1.Functional model of Context-Aware Service Customization

According to this theory, a rule-based context-aware service customization strategy is therefore proposed:
(1) The context-aware computing system is regarded as a decision information system, where the context items are the condition attributes and the computing service parameters are the decision attributes. The principle can be described with the functional model diagram in Fig.3.1.
(2) Use the rule matching method for decision making of service customization, and use the rule generation method to derive new rules using the history context. In this investigation, the semantic distance-based rule matching method and the rough set theory-based rule generation method are selected. As shown in Fig. 1, the computing service at time t - St is determined by the Rule St=F(Ut,Ct), where Ut and Ct are the user operation and context at t. The context data, user operations, and service decisions are saved for rule generation to supervise the service composition. Then, the service customization method and rule generation method are illustrated as follows.

3.3.1Semantic Distance-based Rule Matching Method

In the context-aware service model, the service customization can be accomplished with semantic distance based rule matching, which compares the current context and the context–aware customization rules. Let C be the attribute vector of context items, U be a sample of context value, and V be the rule vector. The distance between vectors can be calculated with the Manhattan Distance.

3.3.2 RST-based Rule Generation to Supervise the Service Customization

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Essentially, the rule generation in the context-aware automation is a Knowledge Discovery in Database (KDD) method, and the rule is the knowledge to supervise control of home facilities. Some mathematical models can be employed, such as Decision Tree, Bayesian Networks, Fuzzy Logic, Support Vector Machine, and K-Nearest Neighbors. In this investigation, the Rough Set Theory proposed is employed for contextaware service rule generation due to its strength in handling uncertainty and imperfection of context data.

3.4 Design and Implementation

In order to prove the proposed context-aware service customization methods and algorithms, a prototype smart home system is implemented and evaluations are performed through experimental studies. In this prototype system, a table light and table fan testing case is adopted, because the operations can be immediately observed. For this implementation, only several sensors are need to observe and characterize the environmental context.

3.4.1 Prototype System Architecture Design

The prototype system can be described using the diagram in Fig.3.2 Commercially available low-cost sensors and electronics are employed for the implementation of the system. The Wi-Fi network is employed for the connection between the electronic devices as it is widely available in most home areas. The sensors and actuators are connected with the wireless infrastructure to collect the sensor data and perform the control actions. The user interacts with the system through his/her Smartphone. The control service corresponding to the context data is produced at the central controller with the decision making algorithms, and execution of decision commands is performed with relaysas actuators.

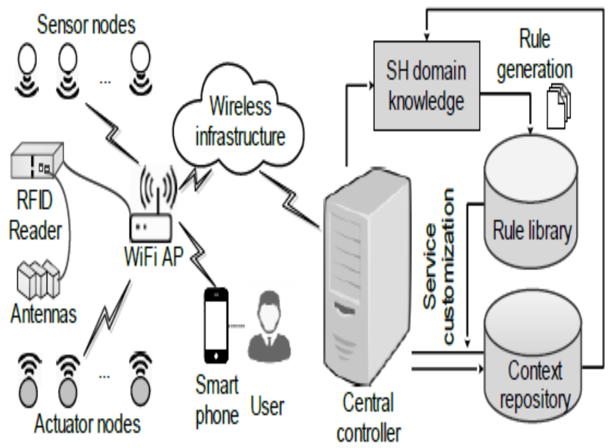

Fig.3.2. Architecture of the Prototype system

In this prototype system, the interface and communication are through the following ways:

1. Sensors are interfaced with the embedded controllers which are integrated with WiFi adaptors.
2. WiFi adaptors access to the wireless infrastructure with TCP socket.
3. The service end of central controller employs Apache/MySQL/PHP server.
4. User's ID is recognized by RFID reader controlled by a laptop, which talks to central controller with TCP socket.

The context information is observed by sensor modules and updated in the database of remote central controller through wireless infrastructure and TCP/IP protocol. Decision commands are produced with the current context and rules, and then responded to actuators for execution. Rule generation is executed in the service end with supervision of smart home domain knowledge.

3.4.2 DEVICES EMPLOYED IN THE PROTOTYPE SYSTEM

The devices used are embedded sensors, actuators, AVR microcontroller,WiFi Adapter, WiFi Access point, RFID reader, and a smart phone. The input given is different sensors and RFID card. The block diagram is shown below.

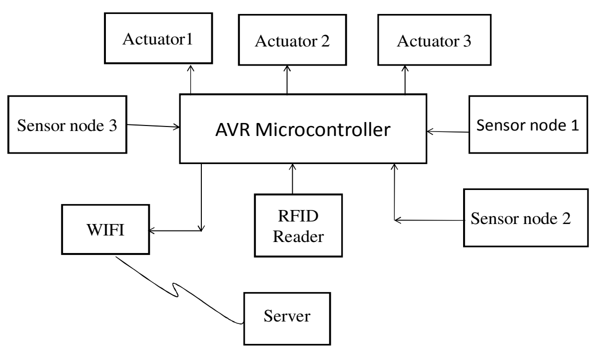

Fig.3.3 Block diagram representing a prototype system

AVR MICROCONTROLLER:

The AVR is a modified Harvard architecture machine, where program and data are stored in separate physical memory systems that appear in different address spaces, but having the ability to read data items from program memory using special instructions.

SENSOR:

In the broadest definition, a sensor is an object whose purpose is to detect events or changes in its environment, and then provide a corresponding output. A sensor is a type oftransducer; sensors may provide various types of output, but typically use electrical or optical signals. For example, a thermocouple generates a known voltage (the output) in response to its temperature (the environment). A mercury-in-glass thermometer, similarly, converts measured temperature into expansion and contraction of a liquid, which can be read on a calibrated glass tube.

ACTUATOR:

An actuator is a type of motor that is responsible for moving or controlling a mechanism or system. It is operated by a source of energy, typically electric current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion. These two are static and dynamic loads. Static load is the force capability of the actuator while not in motion. Conversely, the dynamic load of the actuator is the force capability while in motion.

Fig3.4. Actuator

WIFI:

Wi-Fi is a wireless networking technology that allows computers and other devices to communicate over a wireless signal. Wi-Fi is the standard way computers connect to wireless networks. Nearly all modern computers have built-in Wi-Fi chips that allow users to find and connect to wireless routers. When a device establishes a Wi-Fi connection with a router, it can communicate with the router and other devices on the network. However, the router must be connected to the Internet (via a DSL or cable modem) in order to provide Internet access to connected devices. Therefore, it is possible to have a Wi-Fi connection, but no Internet access.

RFID READER

Radio-frequency identification (RFID) is the wireless use of electromagnetic fields to transfer data, for the purposes of automatically identifying and tracking tags attached to objects. RFID tags and reader are used to provide access to the unique person. The tags contain electronically stored information. Some types collect energy from the interrogating radio waves and act as a passive transponder. Unlike a barcode, the tag does not necessarily need to be within line of sight of the reader and may be embedded in the tracked object. RFID is one method for Automatic Identification and Data Capture (AIDC).

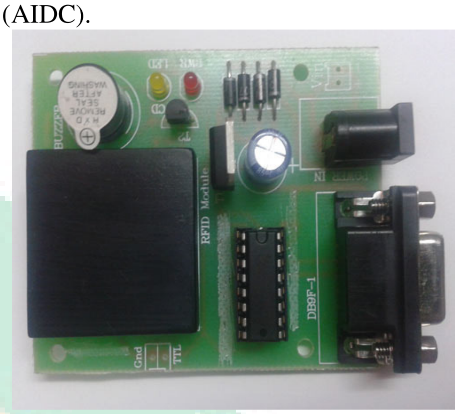

Fig.3.5. RFID Reader

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

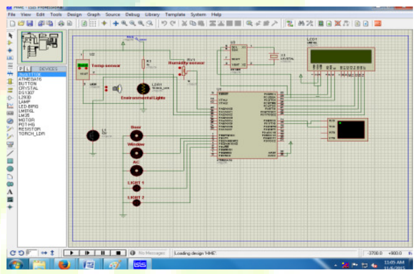

Fig 4.1 Overall Design

A prototype smart home system is implemented based on smart phones and commercially available low-cost sensors and embedded electronics. The sensors and actuators are connected with the wireless infrastructure to collect the sensor data and perform the control actions. The control service corresponding to the context data is produced at the central controller with the decision making algorithms, and execution of decision commands is per-formed with relays as actuators.

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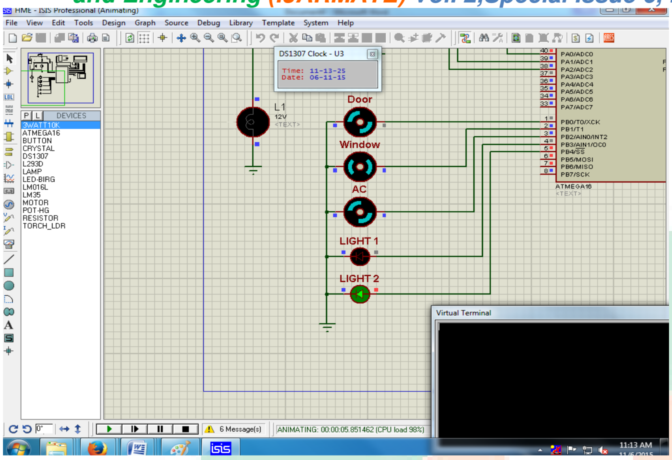

Fig 4.2 Control of various appliances

Sensors are interfaced with the embedded controllers which are integrated with Wi-Fi adaptors.Wi-Fi adaptors access to the wireless infrastructure with TCP socket. User's ID is recognized by RFID reader controlled by a laptop, which talks to central controller with TCP socket, here we indicated with LED for Authentication purposes.

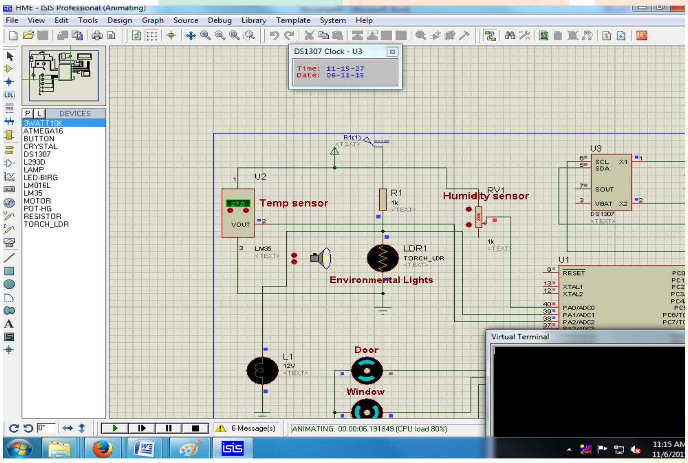

Fig 4.3 Output result-1

The prototype system integrates the Smartphone and embedded sensors into a home environment for home facilities automatic control with a context-aware computing framework.

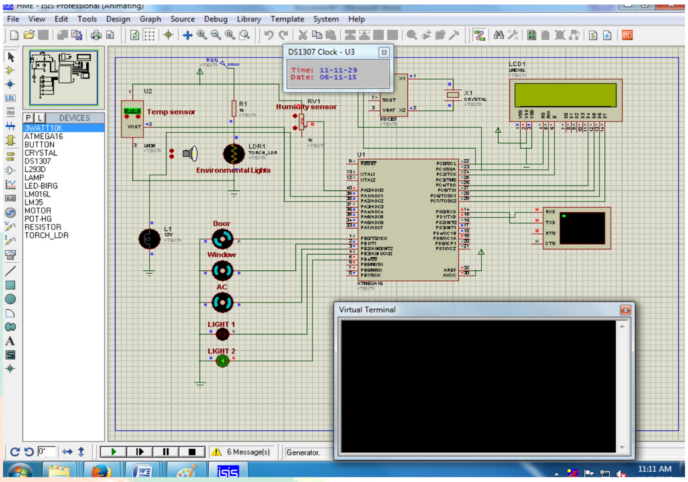

Fig 4.4 Output result-2

Embedded Sensors like Temperature, Humidity, Brightness, human body, sound are used for Controlling the appliances by context aware provider using smart phones. The Actuators are triggered according to input from the sensors.

Normally, the computation tasks are related to users' preferences and the ambient environment in a sophisticated relationship, and the practical home environment is usually complicated. The proposed service customization strategy separates the two steps of computing service decision making and rule generation. The rule matching method can be used for decision making of control service using the current context, and the rule generation method is then used to determine new rules.

V. CONCLUSION

A hardware platform that consists of two ARM-based m This investigation introduces a context-aware computing service customization strategy and implements a smart home prototype system for home facility automatic control, with smartphones and commercially available lowcost sensing techniques. Results and evaluation demonstrate that the proposed service customization strategy is feasible to determine the appropriate computing service and is capable of timely generation of the potential rules. By generating and updating new rules, the system can autonomously learn through its observation to anticipate users' expectations.

icrocontrollers, each fed separately by variable voltages. This platform is very suitable for evaluating embedded systems with low energy consumption and fault tolerance requirements. In this platform, we provide DVFS capability for the whole microcontroller including the processor core, PLL, memory, and I/O. Physical experiments show that applying DVFS on the whole microcontroller is considerably more efficient in reducing power/energy consumption compared with applying DVFS only on the processor core or using power-down policies that are currently used by most embedded processors. Physical experiments show that applying DVFS on the whole microcontroller provides up to 47% and 12% energy saving compared with the sole use of dynamic power management and applying DVFS only on the core, respectively. In addition, the platform is equipped with accurate energy/power measurement units, debugging ports, and facilities for evaluating fault-tolerance techniques. Although the platform is designed for ARM-based microcontrollers, it is general, and other COTS devices and embedded processors can be similarly used in the design of the platform.

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