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Design of a Smart Small Dishwasher Control System Based on STM32

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Abstract: This paper presents the design and implementation of a smart mini dishwasher control system based on the STM32F103C8T6 microcontroller. Aimed at addressing the limitations of traditional dishwashers—such as large size, rigid control logic, and lack of remote monitoring—this system integrates precise environmental sensing, a finite state machine (FSM)-based workflow, and Internet of Things (IoT) connectivity. The hardware platform incorporates DS18B20 temperature sensors, analog water level sensors, a DRV8833 motor driver for washing action, servo-controlled valves, and relay-driven actuators (PTC heater, fan, UV lamp). The software employs a non-blocking FSM to manage the washing cycle (filling, heating, washing, draining, drying, disinfection), ensuring robust safety with timeout alarms. For IoT capabilities, an ESP32-C3 module enables MQTT-based communication, allowing real-time data upload and remote command dispatch via a cloud platform. System testing demonstrates stable performance: the temperature control error is within ±0.5°C, actuator response time is ≤2 seconds, and the remote command packet loss rate is less than 0.1%. The system offers a low-cost, reliable, and remotely accessible solution for small-family dish-cleaning needs.

Keywords: STM32 Microcontroller; Smart Dishwasher; Internet of Things (IoT); Finite State Machine (FSM); ESP32-C3; Embedded System

1. INTRODUCTION

With the rapid advancement of the Internet of Things (IoT) and smart home technologies, there is a growing demand for intelligent and miniaturized home appliances [1]. Modern lifestyles, characterized by smaller family units and fast-paced routines, require kitchen appliances that are not only efficient but also compact and smart. Traditional dishwashers, while effective, often suffer from limitations such as large physical footprints, high water and energy consumption, rigid control logic without flexibility, and the absence of modern remote monitoring and control features [2].

To address these challenges, this paper proposes a novel smart mini dishwasher control system. The primary objectives of this research are: (1) to develop a compact and cost-effective control system using the STM32F103C8T6 microcontroller; (2) to implement a robust and safe control algorithm based on a Finite State Machine (FSM) to manage the multi-stage washing process; and (3) to integrate IoT capabilities for remote monitoring and control, thereby enhancing user convenience. This system achieves high-precision environmental monitoring using DS18B20 and analog water level sensors. It employs a PWM-driven servo for valve control, a DRV8833 motor driver for the washing pump, and relays for managing high-power loads like the PTC heater, drying fan, and UV disinfection lamp. The ESP32-C3 module bridges the local system to the cloud via the MQTT protocol, enabling users to monitor real-time sensor data and issue control commands from a mobile application.

This paper is organized as follows: Section 2 describes the overall system architecture and hardware design. Section 3 details the software design, focusing on the FSM implementation. Section 4 presents the system testing and results. Section 5 concludes the paper and discusses future work.

2. SYSTEM ARCHITECTURE AND HARDWARE DESIGN

2.1 Overall System Architecture

The proposed system follows a modular, bottom-up design philosophy, comprising four main layers: data acquisition, core computation, peripheral actuation, and cloud communication. The STM32F103C8T6 serves as the central processing unit, managing sensor data, executing the state machine logic, and issuing commands to actuators. The data acquisition layer includes a DS18B20 temperature sensor for water temperature and an analog water level sensor for precise water level monitoring. The actuation layer is composed of a DRV8833-driven DC motor for the washing mechanism, a servo for controlling inlet/outlet valves, and relay-controlled circuits for the PTC heater, drying fan, and UV lamp. A 0.96-inch OLED display and a 4-key keypad form the local human-machine interface (HMI). For IoT connectivity, an ESP32-C3 Mini module acts as a transparent Wi-Fi gateway, serial-communicating with the main MCU to publish data to and receive commands from the cloud platform. The overall system block diagram is shown in Figure 1.

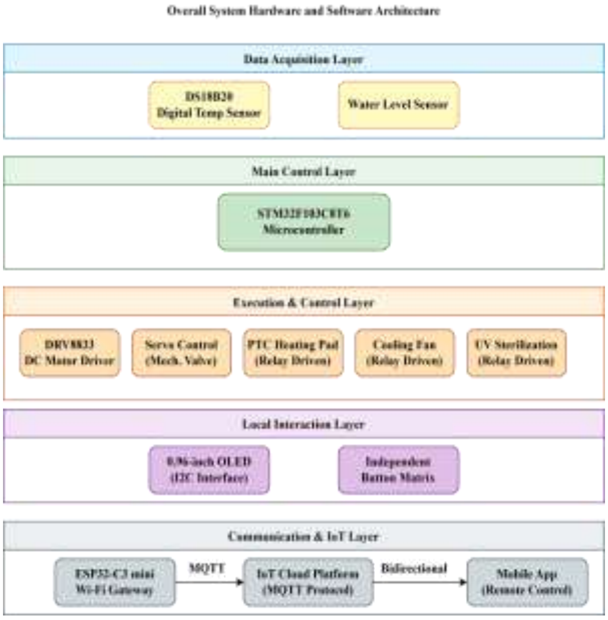

Figure 1: System Overall Hardware Architecture Block Diagram

2.2 STM32F103C8T6 and Key Hardware Modules

TThe STM32F103C8T6 microcontroller, based on the ARM Cortex-M3 core, was chosen for its balance of performance (72 MHz), low power consumption, and rich peripheral set[3], including multiple ADCs, timers, and communication interfaces (I2C, USART). Its 64 KB Flash and 20 KB SRAM provide sufficient space for the application code and data buffers.

For precise temperature control, the DS18B20 digital temperature sensor was selected. Its 1-Wire interface simplifies wiring, and its ±0.5°C accuracy meets the requirements for the heating process. The analog water level sensor, which outputs a voltage linearly proportional to water depth, is interfaced with the MCU's ADC. This allows for flexible threshold setting and continuous monitoring.

The washing action is driven by a DC motor controlled by a DRV8833 dual H-bridge motor driver. This compact module was chosen over the L298N for its lower on-resistance and built-in overcurrent and thermal protection. The STM32's advanced timer (TIM1) generates PWM signals to precisely control the motor's speed.

To safely manage high-power loads (heater, fan, UV lamp), a relay driver circuit based on an NPN transistor (S8050) was implemented. This provides galvanic isolation between the MCU's low-voltage logic and the high-power circuits. The inlet and outlet valves are simulated using a servo motor. The MCU generates specific PWM pulses to rotate the servo to distinct angles (e.g., 180° for fill, 0° for drain), providing a compact and precise valve control solution.

3. SOFTWARE DESIGN AND IMPLEMENTATION

3.1 Main Program Flow

The system software is written in C and is designed to be non-blocking, relying on a main loop and a system tick timer. Upon startup, the system initializes all peripherals (ADC, timers, I2C, UART), sensors, and the OLED display. After initialization, the system enters an infinite main loop. In each cycle, the program performs four key tasks: (1) parsing incoming commands from the ESP32-C3 module, (2) reading and processing sensor data via DMA, (3) scanning physical keys for user input, and (4) executing the core washing state machine and refreshing the OLED display. This structure ensures that all tasks are handled efficiently without delays.

3.2 Core Washing Finite State Machine (FSM)

The core of the system's control logic is a Finite State Machine (FSM) designed to manage the sequential washing process[4]. The FSM includes the following states: **IDLE**, **FILLING**, **WCHK** (Water Check), **HEATING**, **WASHING**, **DRAINING**, **DCHK** (Drain Check), **DRYING**, **UV**, **DONE**, and **ERROR**. The transitions between states are triggered by sensor readings (e.g., water level reaching the set threshold) or timer events (e.g., washing time elapsed). A critical feature of this design is the integration of watchdog timers for safety-critical states like FILLING, HEATING, and DRAINING. If a state persists beyond a predefined timeout, the FSM automatically transitions to the ERROR state, which shuts down all actuators and triggers an alarm. This prevents issues such as dry heating or water overflow. The FSM flowchart is depicted in Figure 2.

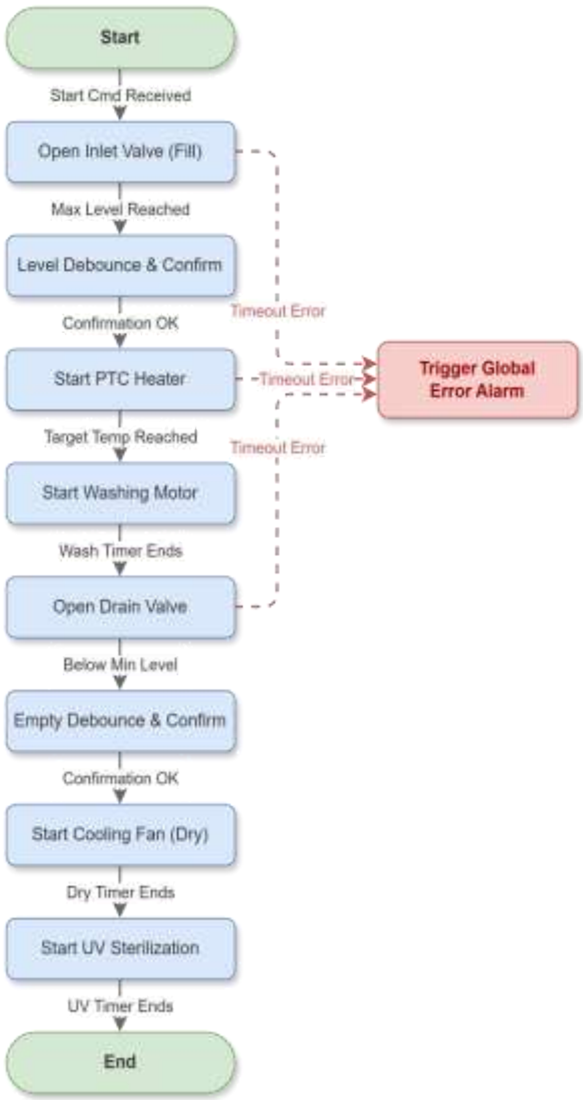

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Figure 2: Core Washing Finite State Machine

3.3 IoT Communication and Local HMI

The IoT functionality is realized via the ESP32-C3 Mini module. The STM32 packages sensor data and system status into a JSON format (e.g., {"temp": 25.5, "water": 15.2, "state":"HEATING"}) and sends it over UART to the ESP32-C3. The ESP32-C3 connects to a Wi-Fi network, establishes an MQTT connection to a cloud platform (e.g., ThingsCloud), and publishes the data at regular intervals[5]. Simultaneously, it subscribes to a command topic, listening for incoming messages. These messages, which are also in JSON format (e.g., {"cmd":"start"}, {"temp_target":45}), are forwarded to the STM32 for parsing and execution.

The local HMI consists of a 0.96" OLED display and four keys (KEY1-KEY4). The system provides three display pages: a sensor data page, a washing status page, and an actuator status page. Users can toggle between these pages using KEY4. The system supports two user modes: normal operation mode and threshold-setting mode. By pressing KEY1 and KEY2 simultaneously, users can enter the setting mode to adjust parameters like target temperature, washing time, and water level thresholds[6]. The local interaction logic is shown in Figure 3.

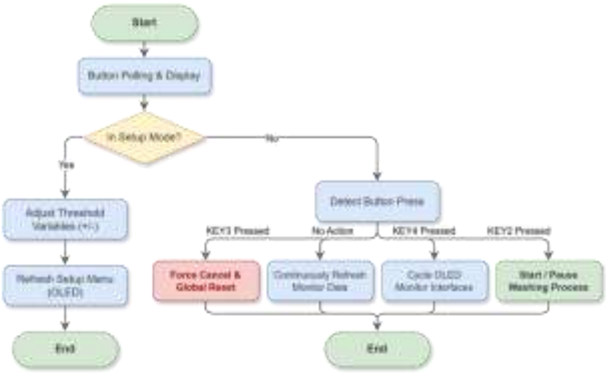

Figure 3: Local Human-Machine Interaction (HMI) Polling Logic Flowchart

4. SYSTEM TESTING AND RESULTS

A physical prototype of the system was built and tested to verify its performance, focusing on sensor accuracy, actuator control, FSM logic, and IoT functionality. The tests confirmed the stability and reliability of the system.

4.1 Sensor Data Acquisition and Local HMI

Upon power-up, the OLED display initializes correctly. In the sensor data page, the system correctly displays the temperature, water level, and raw ADC value. For an empty tank, the water level was correctly shown as 0.0 mm, with an ADC reading of 3. The temperature sensor reported an ambient temperature of 18.3°C (see Figure 4). The washing status page (Figure 5) correctly showed the initial **IDLE** state, and the actuator page (Figure 6) showed all actuators in their initial **OFF** state, confirming the safety of the initial logic.

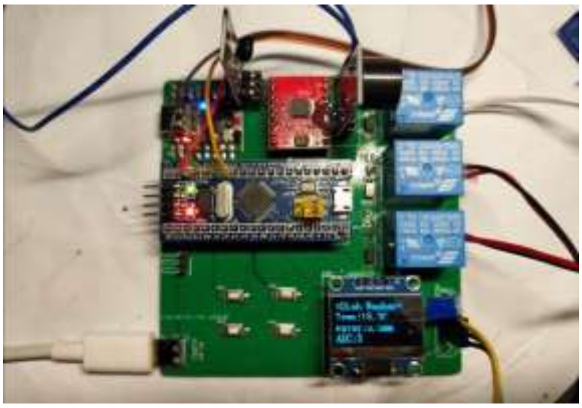

Figure 4: Sensor Data Monitoring Interface

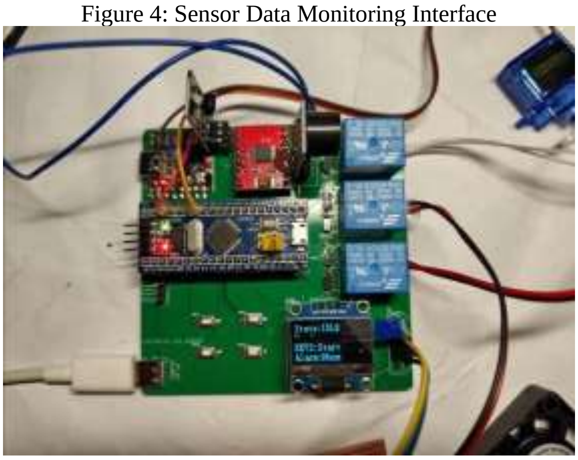

Figure 5: Washing Status and Interaction Interface

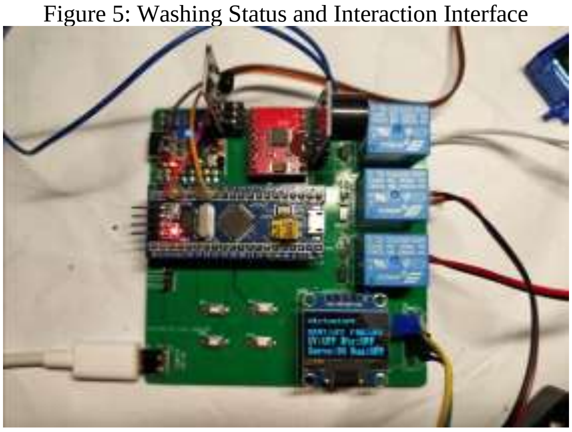

Figure 6: Actuator Status Monitoring Interface

4.2 Washing Cycle Process Test

The core washing cycle was tested from start to finish. When the **START** command was issued, the system transitioned to **FILLING** (Figure 7), and the servo rotated to open the inlet valve. Upon reaching the water level threshold, it moved to the heating state. The **HEATING** state (Figure 8) successfully activated the heater, and the displayed temperature increased to the target. After heating, the system entered **WASHING** (Figure 9), with the DRV8833 driving the DC motor smoothly. Following the washing cycle, it transitioned to **DRAINING**, **DRYING** (Figure 10), and finally **UV** (Figure 11) disinfection. The entire sequence executed without any logic errors, demonstrating the robustness of the FSM.

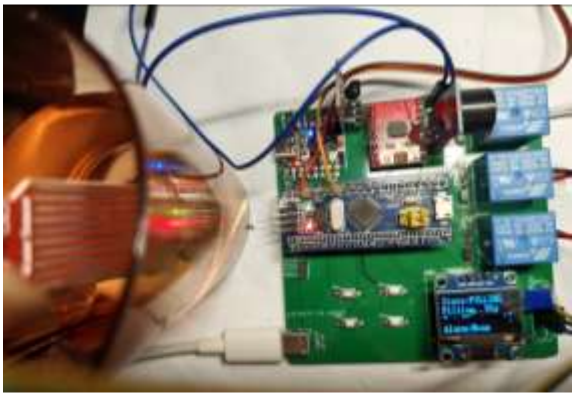

Figure 7: Filling Test

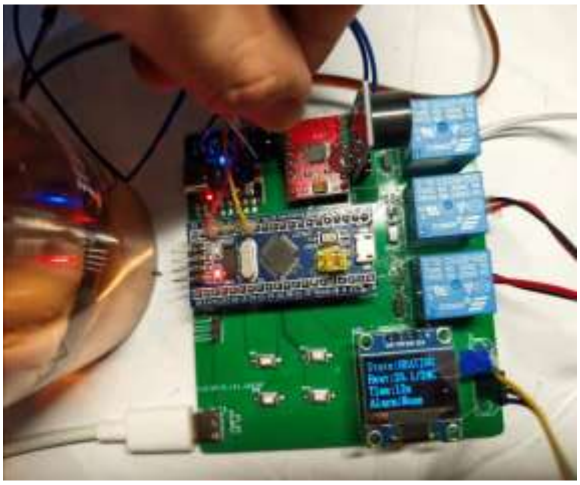

Figure 8: Heating Tes

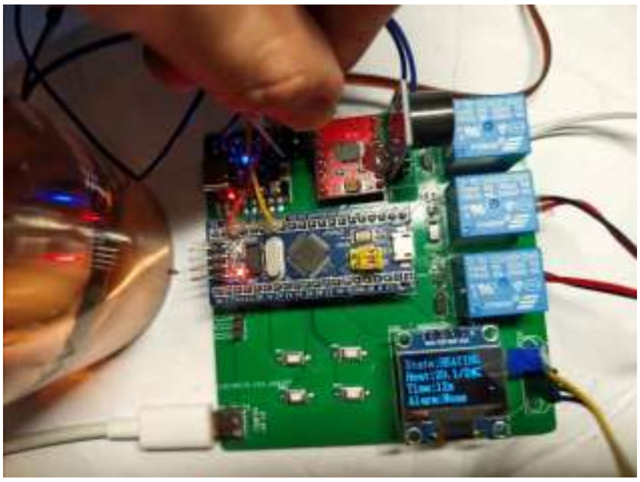

Figure 9: Washing Test

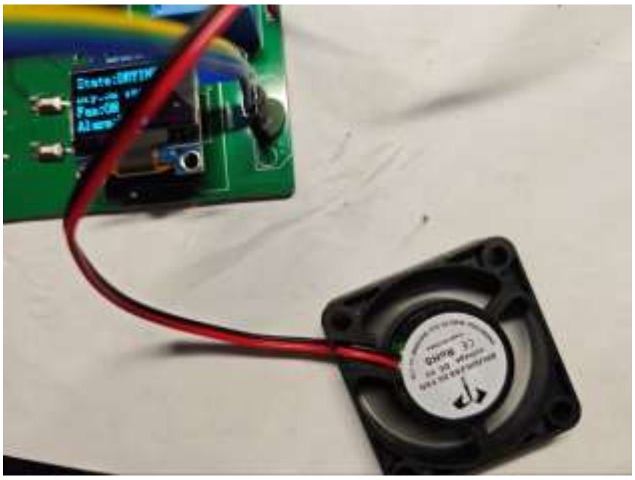

Figure 10: Drying Test

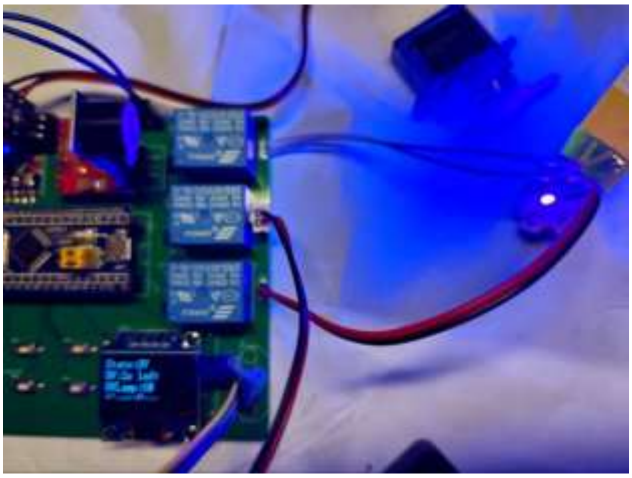

Figure 11: Disinfection Test

4.3 IoT Remote Monitoring and Control Test

The remote monitoring function was tested using a mobile application. The app successfully displayed the real-time data (temperature, water level, system state) received from the system, matching the data shown on the local OLED display with minimal latency (see Figure 12). Remote configuration commands, such as adjusting the target temperature from 20°C to 24°C, were sent from the app. The system successfully received and applied these new thresholds, demonstrating full two-way communication[7].

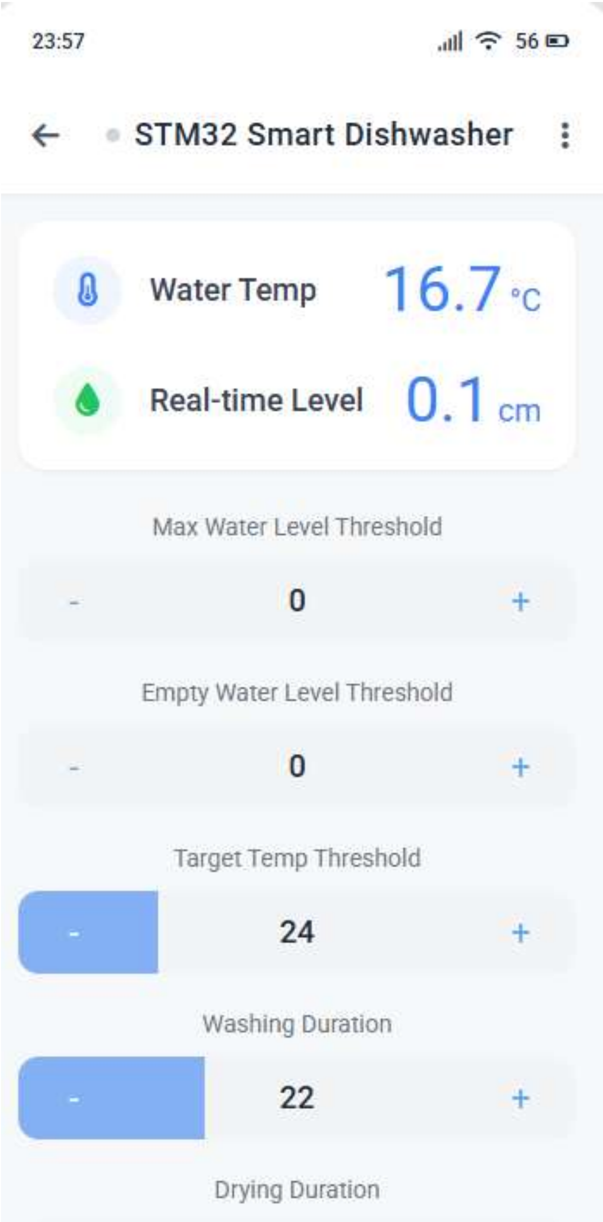

Figure 12: Cloud Platform and Mobile App Remote Monitoring and Control Test

5. CONCLUSION AND FUTURE WORK

PThis paper presented a comprehensive design and implementation of a smart mini dishwasher control system based on the STM32F103C8T6 microcontroller. The system integrates key sensor technologies, a robust Finite State Machine (FSM) control algorithm, and IoT connectivity. It effectively addresses the limitations of traditional dishwashers by offering a compact, flexible, and remotely accessible solution. The test results validate the system's performance in managing the multi-stage washing process, maintaining temperature accuracy within ±0.5°C, and providing reliable remote monitoring and control with a packet loss rate of less than 0.1%. The project provides a valuable reference for the development of smart home appliances.

Future work will focus on enhancing the system's intelligence. This includes incorporating a turbidity sensor to enable adaptive washing cycles based on the level of soiling, using a PID (Proportional-Integral-Derivative) control algorithm for smoother and more precise temperature regulation, and upgrading the drive motor to a more efficient and quieter Brushless DC (BLDC) motor with Field-Oriented Control (FOC). Furthermore, integrating the system into mainstream smart home ecosystems for enhanced automation and voice control would be a valuable next step.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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