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Research on the Internet of Things-based Auxiliary Infant Feeding System

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Abstract

Abstract: Nowadays young parents are found deficient in the skills to take care of their infants due to the quick pace of modern life and the heavy working stress. Actually it has become one of the problems that perplex young parents when they have no idea about the amount of milk given to the infants each time, unsure about the temperature of milk, often forgetting to feed the infants on schedule or even making the infants choke on milk during the feeding. In view of this, this paper utilizes the internet of things technology to implement an intelligent infant feeding system, which can provide real-time monitoring on the temperature of nursing bottle, checking if the bottle has tilted or seriously tilted in addition to memorizing the feeding times. The measured information and data will be uploaded to the background server after the access to the household internet of things gateway via zigbee. Then the parents can configure the working state of the nursing bottle and receive the warning message on their smart phones. With the design of the hardware, the structure and the software system of the intelligent nursing bottle, this paper takes the intelligent nursing bottle as a node device for the connection to the household internet of things and conducts the experimental verification. The verification result proves that this technology is feasible and able to guarantee a stable operation.

Keywords: *Internet of things, nursing bottle, auxiliary feeding, zigbee*

1. Introduction

Due to the accelerated pace of life and the increased working stress, now young parents are facing a big challenge regarding taking care of their babies. On one hand, the young first-time parents lack the experience in looking after their babies. On the other hand, busy work makes young parents hard to concentrate all of their time and energy on tending a baby. Under such a circumstance, baby feeding has become a headache problem to young parents. It has been reflected in the following aspects, including having no idea about the amount of milk suckled by the baby each time, not sure about the temperature of the milk, often forgetting to feed the babies on schedule or even making the infants choke on milk during the feeding.

As a kind of network technology extended and expanded based on the internet technology, the internet of things technology has been developed to implement the internet of everything so that the client side of the internet can be extended and expanded to and between everything. It has been widely recognized that the internet of things, which is a hierarchical network, consists of three layers, including the

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perception layer, the network layer and the application layer in the hierarchical structure.[1] [2]

Nowadays all of the commonly-used infant feeding bottles are made of glass or PP plastic materials. The users can find the amount of milk according to the scale marked on the bottle. Also they can determine if the milk temperature is appropriate by tasting or touch the milk. The intelligent nursing bottle designed in this paper has the following functions including temperature detection, volume detection, temperature adjustment, warning and alarm. Also with the zigbee communication function, it can be connected to the household internet of things gateway to upload the data information to the cloud server. The users can review the information about the nursing bottle on their smart terminals, such as cell phone. Furthermore, the cloud server can recommend nursing solutions to the users according to their customized requirements. It will guide the users to make a scientific planning on baby feeding by setting a proper feeding interval and milk volume. What's more, with the anti-choking function, our intelligent nursing bottle can give an alarm to the users when the nursing bottle is tilting too much to protect the infants from choking on milk.

2. The Overall Design of the Auxiliary Feeding System

This chapter introduces the overall design of this system based on the internet of things architecture. Figure 1 shows the general framework of the system.

As a device in the perception layer of the auxiliary feeding system, the intelligent nursing bottle can be connected to the household internet of things gateway through a zigbee module. Then in addition to forwarding and managing the zigbee-wifi data, the internet of things gateway will also upload the data information about the nursing bottle to the back-end cloud server, where the user permission management, the management on the state information of the nursing bottle, the data storage and the generation of various analysis statements can be made. In this way, the users can not only make a real-time checking on the state information of the nursing bottle, reviewing the analysis statements, but also send real-time commands to control the nursing bottle for heat preservation.

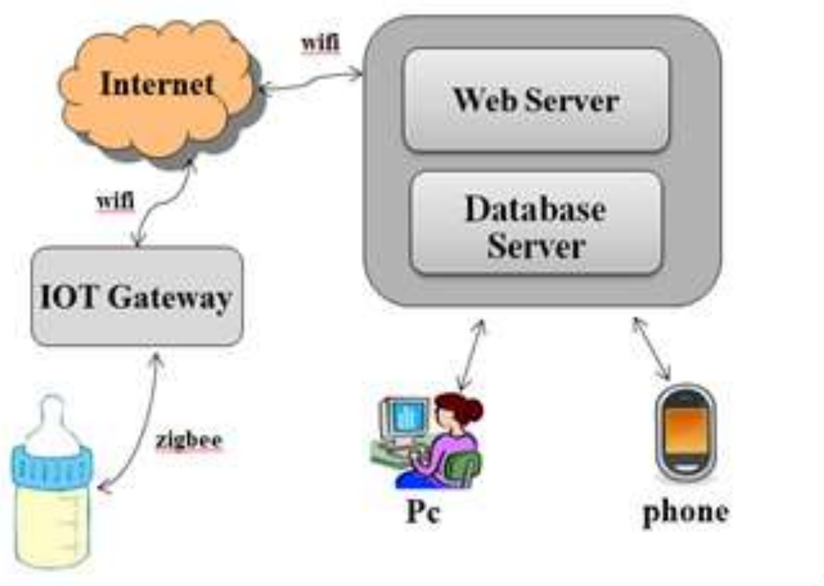

Figure 1 . Architecture Diagram of the System

The background server has been integrated with the WEB server and the database server. The WEB server has been built with the Apache Tomcat technology with the adoption of the JSP technology to feed back the web information. Also both of the JavaBean and Servlet technologies have been applied to make a response to the user requests and process the transactions. As to the web server, it has adopted the JDBC access method to get access to the MySQL database.

3. Hardware Design of the Intelligent Nursing Bottle

As a device in the perception layer, the intelligent nursing bottle has played a significant role in the auxiliary feeding system. In this chapter, it makes an introduction on the structural design and the hardware circuit of the intelligent nursing bottle.

3.1 Structural Design

Our nursing bottle has been designed in a form that the smart holder module is structurally separated from the bottle so that the bottle can be taken away separately for cleaning and replacement. The material of the nursing bottle can be common glass or pp polymer. However the smart holder module is made of silica gel with room left inside to contain the hardware controller. During the usage, just place an ordinary nursing bottle onto the intelligent nursing bottle holder. Within the smart holder module, there are the infrared temperature sensor, the weighing module, the three-axis angle sensor and the zigbee communication module. Adopt the STM32 microcontroller equipped with the ARM CortexM3 core as the main controller. The experimental prototype of intelligent nursing bottle is shown in Figure 2.

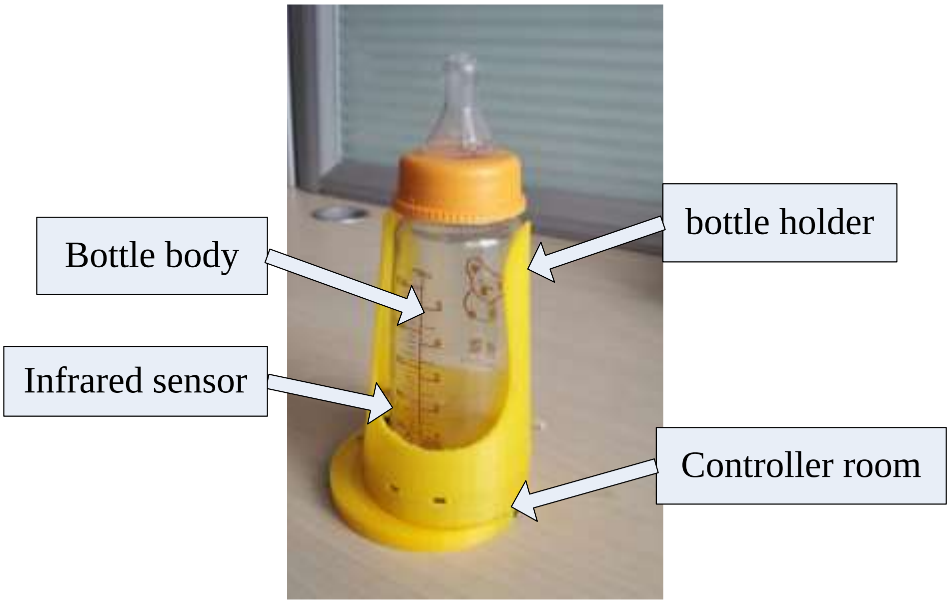

Figure 2 . Prototype of Intelligent Nursing Bottle

3.2 Hardware Design

The availability of the controller located within the control box of the nursing bottle holder makes it possible to implement the intelligent temperature measurement, the angular measurement and the remote communication of the nursing bottle. Figure 3 shows the structural diagram of the controller, which adopts the STM32 microcontroller equipped with the ARM CortexM3 kernel as the core. The communication between the weighing circuit, the infrared temperature measurement circuit and the angular measurement circuit with the STM32 can be made via the IIC bus. Also the communication between the zigbee module and the STM32 can be established through the UART serial interface. As the controller has the LED indication function, the LED will flash to indicate the low battery or give an alarm. What's more, with the buzzer alarm function, it will give a buzzer alarm to the parents when they forget to feed the infants.

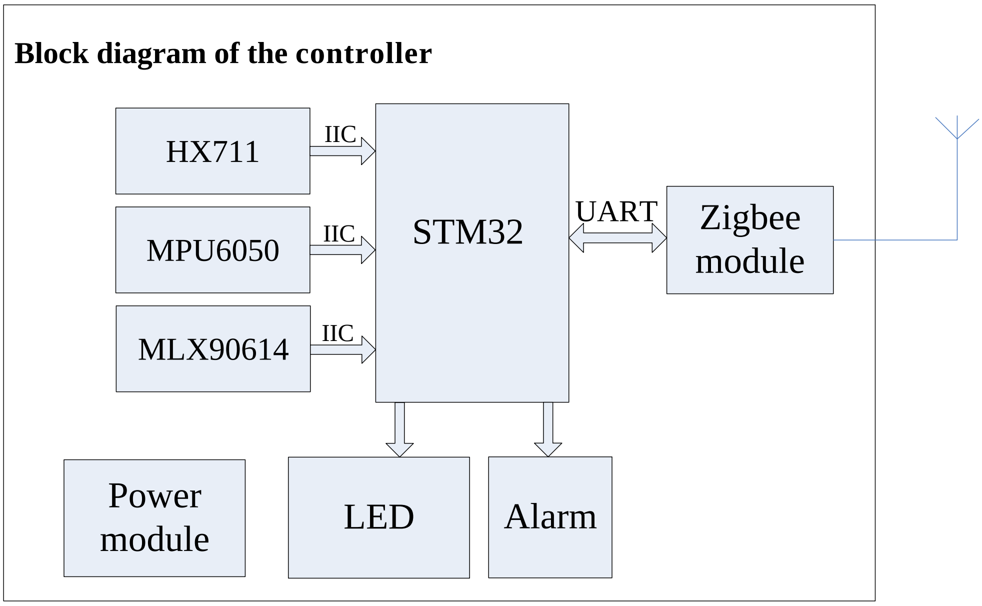

Figure 3. Block Diagram of the Controller

Adopt STM32F103RBT6 as the main control chip, which is incorporated with the high-performance ARMCortex-M3™ 32-bit RISC core operating at a 72 MHz frequency with the flash memory and the SRAM separately up to 128K and 20K. With the diversified peripherals, it's equipped with two 12-bit ADCs, three GP 16-bit timers, an independent PWM timer and three asynchronous serial ports[3]. In this design, as Serial Port 1 and zigbee module are adopted for the communication, then this chip can fully meet the design requirements on computing speed and the external communication interfaces.

Adopt HX711 as the core chip during the design of the weighting circuit. HX711 is a 24-bit A/D converter chip with MCU processing designed purposely for the high-precision electronic scale.

Adopt MLX90614 to design the infrared temperature measurement circuit. Applied specially in the non-contact infrared temperature sensor, MLX90614 has been integrated with the infrared thermopile chip and the dedicated integrated circuit for signal processing in a TO-39 package. [4]Also it's equipped with a low noise amplifier (LNA), a 17-bit ADC and a powerful DSP processing unit. Integrated with all of the peripheral circuits required in the other similar types of chips such as the regulated power supply and the on-chip clock oscillator, this chip takes the single-armed circuit consisting of strain gauge and resistance as the input of HX711, which will then take the numerical voltage value of the single-armed circuit as the output to facilitate the full integration. All of the sensors are calibrated before the delivery in terms of the measurement results. Meanwhile use the digital PWM and SMBus (System Management Bus) output as the data interface. As a continuous output, the 10-bit PWM output will be configured in a range from -20˚C to 120˚C with an output resolution of 0.14˚C.

Adopt MPU6050 to design the angle of the nursing bottle and the tilting measurement module. As a 6-axis motion sensor, MPU-6050 has been integrated with a 3-axis MEMS gyroscope, a 3-axis MEMS accelerometer and an extensible DMP (digital motion processor). [5]Both of the 3-axis angular velocity and the 3-axis acceleration data will be sent to STM32 via the IIC bus.

4. Key Technology

4.1 Monitoring on the Tilting Angle

Researches prove that baby milk choking is closely related to feeding position. They recommend that feeding position must be at an angle of 30°-45° when the infants recline in their mothers' arms. The nursing bottle must be placed perpendicular to the infant's mouth. It's considered as improper feeding position when the angle of the tilting nursing bottle is too big or too small, which will make the infants more prone to choking on milk. [6]Therefore it's necessary to remind the feeder of this with the indicator. The monitoring on the position of the nursing bottle has become the key to make an early warning on milk choking during the feeding of infants.

Assume that the geodetic coordinate system is the reference coordinate system, and the position of the nursing bottle is the motion state of the nursing bottle in the object coordinate system compared with the reference coordinate system. The common ways to express the object position include the direction cosine matrix, the quaternion and the Euler angles. C_b^e is the direction cosine matrix, where every column represents the projection of every unit vector measured based on the object coordinate system on the reference coordinate system. ψ , θ and ϕ represent separately the deflection angle, the roll angle and the pitch angle in the object coordinate system compared with the reference coordinate system. [7][8]

$$C_b^e = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{32} \end{bmatrix}$$

$$= \begin{bmatrix} \cos\psi\cos\phi & \cos\psi\sin\theta\sin\phi - \sin\psi\sin\phi & \cos\psi\sin\theta\cos\phi + \sin\psi\sin\phi \\ \sin\psi\cos\theta & \sin\psi\sin\theta\sin\phi - \cos\psi\cos\phi & \sin\psi\sin\theta\cos\phi - \sin\phi\cos\psi \\ -\sin\theta & \cos\theta\sin\phi & \cos\theta\cos\phi \end{bmatrix} \quad (1)$$

As a vector with four parameters, quaternion consists of a real component and three imaginary components. Therefore it can also be considered as a four-dimensional space variable[], $\vec{q} = q_0 + \vec{i}q_1 + \vec{j}q_2 + \vec{k}q_3$. The adoption of quaternion for position calculation shows the characteristics of simplicity and low calculation amount. The relationship between the quaternion and the direction cosine matrix C_b^e is indicated as below:

$$C_b^e = \begin{bmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{32} \end{bmatrix} =$$

$$\begin{bmatrix} (q_0{}^2+q_1{}^2-q_2{}^2-q_3{}^2) & 2(q_1q_2-q_0q_3) & 2(q_1q_3+q_0q_2) \\ 2(q_1q_2+q_0q_3) & (q_0{}^2-q_1{}^2+q_2{}^2-q_3{}^2) & 2(q_2q_3-q_0q_1) \\ 2(q_1q_3-q_0q_2) & 2(q_2q_3+q_0q_1) & (q_0{}^2-q_1{}^2-q_2{}^2+q_3{}^2) \end{bmatrix} \quad (2)$$

Then the outputted position can be expressed as below with the application of the Euler angle method:

$$\psi = \arctan\left[\tfrac{T_{32}}{T_{33}}\right] \quad (3)$$

$$\theta = \arcsin\left[-T_{31}\right] \quad (4)$$

$$\varphi = \arctan\left[\tfrac{T_{21}}{T_{11}}\right] \quad (5)$$

4.2 Result Evaluation of Feeding based on Fuzzy Set Theory

When the bottle is in the inclination angle for more than 5s, it will be considered as in feeding process. A young parent's feeding process is evaluated comprehensively based on milk temperature and inclination angle of milk bottle during the feeding process. Since the evaluation is fuzzy, use fuzzy set theory for data processing, which is known as a method of fuzzification processing. Set milk temperature and inclination angle of milk bottle as input variable of fuzzy information processing, and comprehensive evaluation as output variable.

1.Selection of fuzzy linguistic values

Before selecting a fuzzy membership function, define fuzzy linguistic value for two inputs and one output.

Temperature: High (NH), Moderate (NM), Low (NL)

Tilt angle: Large (NH), Moderate (NM), Low (NL)

Evaluation: Terrific (NH) Keep good (NM) Bad (NL)

2. Selection of fuzzy interval corresponding to fuzzy linguistic values.

Set the physics domain range of milk temperature as $\left[T_{\min}, T_{\max}\right] = \left[0-50\right]$, convert to domain of limited fuzzy set as $K = \left[-p, -p+1, ..., 0, ..., p-1, p\right]$, let p =5, then $K = \left[-5, -4, ..., 0, ..., 4, 5\right]$.

Set the physics domain range of inclination angle of milk bottle as $\left[A_{\min}, A_{\max}\right] = \left[0-90\right]$, convert to domain of limited fuzzy set as $A = \left[-q, -q+1, ..., 0, ..., q-1, q\right]$, let q=5, then $A = \left[-5, -4, ..., 0, ..., 4, 5\right]$.

For output variable, define comprehensive evaluation as $R = \left[-s, -s+1, ..., 0, ..., s-1, s\right]$, let s=5, then $R = \left[-5, -4, ..., 0, ..., 4, 5\right]$.

The quantization factor of input variable is:

$$K_t = \frac{T_{\max} - T_{\min}}{2*p} = 5 \quad K_a = \frac{A_{\max} - A_{\min}}{2*q} = 9 \quad (6)$$

3. Define fuzzy membership function

Use triangular and trapezoidal distribution function as fuzzy membership function, the expression is shown as Figure 4:

$$U(x)=\begin{cases}0 & (x<a)\\ \frac{x-a}{b-a} & (a\le x<b)\\ \frac{c-x}{c-b} & (b\le x<c)\\ 0 & (x\ge c)\end{cases} \quad (7)$$

$$U(x)=\begin{cases}0 & (x<a)\\ \frac{x-a}{b-a} & (a\le x<b)\\ 1 & (b\le x<c)\\ \frac{d-x}{d-c} & (c\le x<d)\\ 0 & (x\ge d)\end{cases} \quad (8)$$

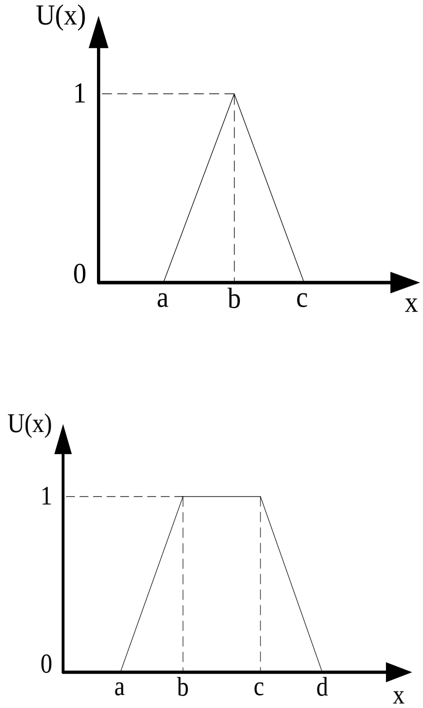

Figure 4. Triangular and Trapezoidal Distribution Function

After selecting type of fuzzy membership function, use Mamdani reasoning model for fuzzy reasoning, and then generate comprehensive evaluation result after defuzzification.

5. Experimental Verification

5.1 Experiment on System Functions

This experiment has been conducted mainly to verify if the device in the perception layer can upload the measured data correctly to the background server, if the gateway and the devices in the node layer can be displayed correctly in the background software and if the APP on the smart phone can acquire correctly the measured data from the background server to realize remote control.

Figure 5 shows the screen shot of a nursing bottle, which is in a real-time working status displayed on the mobile APP. All of the information including the temperature and the volume of the nursing bottle can be displayed on the software interface. Figure 6 shows the screen shot of a nursing bottle with the working mode having been configured through the APP. Figure 7 shows the temperature measurement interface and Figure 8 shows the main settings interface.

Figure 5. Working Status Display Interface

Figure 6. Configuration Interface

Figure 7. Temperature Interface

Figure 8. Main Settings Interface

5.2 Experiment on the Tilt Angle Measurement

In this experiment, data about the pose state calculated in a controller will be uploaded to the monitoring software installed in the host computer. The circuit board shown in the figure 7 is the master control circuit board of the intelligent nursing bottle. The visual testing software installed in the host computer reveals that the position calculation is correct.

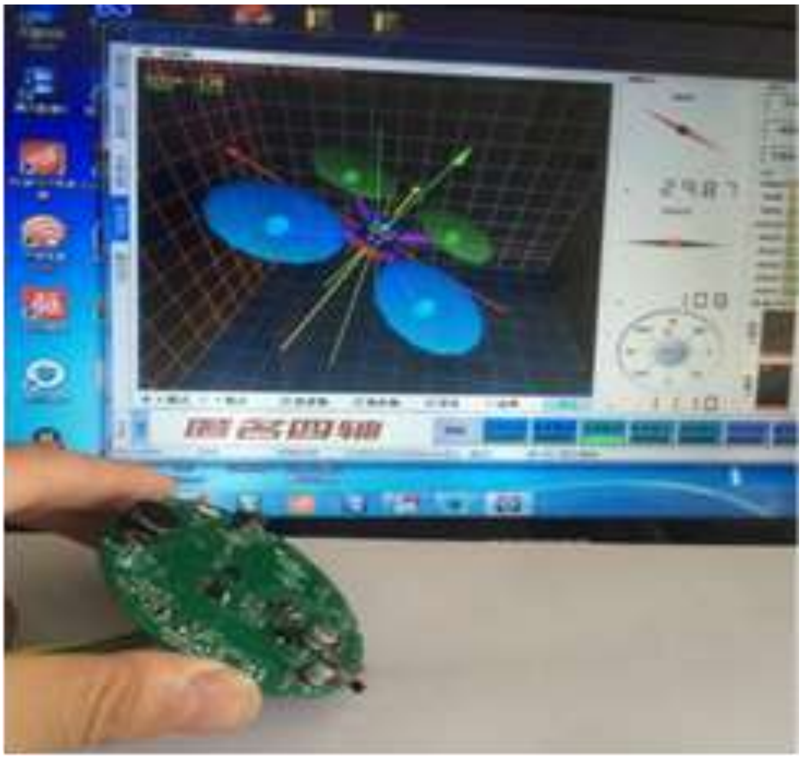

Figure 7. Position Calculation

As shown in Table 1, the measured angle will be displayed on the host computer after the control board is fixed at a certain angel. It reveals that the error in angular measurement is within 3%.

Table 1. Angle Measurement Test Results

Fixed angel（°）	Angle measurement（°）	Error
20	20.56	2.8%
25	24.8	-0.8%
30	30.7	2.3%
35	35.45	1.29%
40	40.57	1.43%
45	45.9	2%
50	49.46	-1.08%
55	55.87	-0.35%
60	60.43	1.58%
65	65.4	0.62%
70	70.2	0.29%
75	74.81	-0.25%
80	80.17	0.21%
85	84.78	-0.33%

5.3 Experiment on the Temperature Measurement

As shown in Table 2, It reveals that the error in temperature measurement is within 2%.

Table 2. Temperature Measurement Test Results

Standard temperature (℃)	Temperature measurement (℃)	Error
10	10.12	1.2%
15	15.2	1.3%
20	19.86	-0.7%
25	25.3	1.2%
30	30.14	0.46%
35	34.95	-0.14%
40	40.23	0.58%
45	45.1	0.22%
50	50.26	0.52%
55	54.89	-0.2%
60	60.17	0.28%
65	64.78	-0.34%
70	70.15	0.21%
75	74.81	-0.25%
80	80.12	0.15%

5.4 Simulation of Fuzzy Inference Algorithm

Use Matlab Simulink toolbox to simulate the comprehensive evaluation result of feeding process. 11 fuzzy rules are established:

If（Temperature is NH） and (Angle is NH)THEN(Result is NL)
If（Temperature is NH） and (Angle is NL)THEN(Result is NL)
If（Temperature is NL） and (Angle is NH)THEN(Result is NL)
If（Temperature is NL） and (Angle is NL)THEN(Result is NL)
If（Temperature is NH） and (Angle is NM)THEN(Result is NL)
If（Temperature is NM） and (Angle is NH)THEN(Result is NL)
If（Temperature is NM） and (Angle is NM)THEN(Result is NH)
If（Temperature is NM） or (Angle is NL)THEN(Result is NM)
If（Temperature is NM） or (Angle is NH)THEN(Result is NM)
If（Temperature is NH） or (Angle is NM)THEN(Result is NM)
If（Temperature is NL） or (Angle is NM)THEN(Result is NM)

Use Mamdani model for fuzzy reasoning, the simulation result is shown as figure 8:

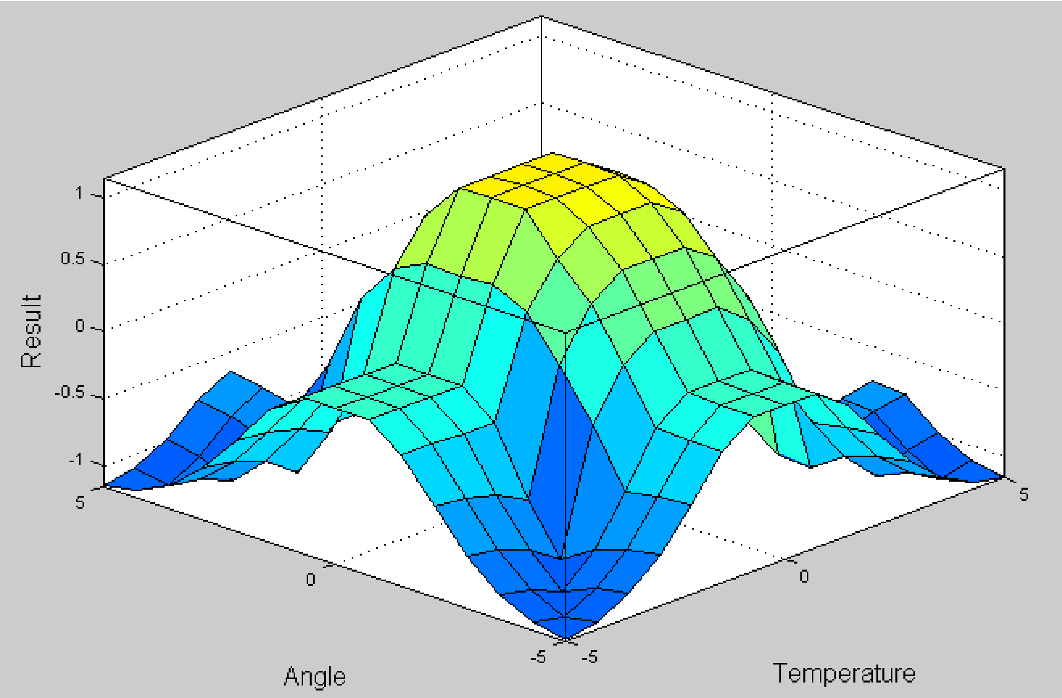

Figure 8. Simulation Result

6.Conclusions

This paper designs an internet of things-based auxiliary infant feeding system. Aiming at the problem that young parents in modern society lack the experience in raising children, this paper designs an intelligent nursing bottle that can be connected to the household internet of things. Also the zigbee communication function makes it possible to upload the working state of the nursing bottle to the background server in addition to the implementation of regular alarm function. What's more, the detection of tilting angle makes the nursing bottle characterized by the anti-choking function.

In addition to the design of mobile APP and the background server, this paper also prepares a prototype of intelligent nursing bottle. The experiment has verified the implementation of various functions, showing an accuracy of less than 3% in angular measurement.

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