Design and implementation of a boxing robot based on fuzzy control

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Abstract. This paper developed a new, based on AirKiss and mobile phone WeChat remote control Home Entertainment Boxing Robot. In the boxing robot software design, the core control part puts forward the Fuzzy Control Speed Control Algorithm for DC Motor. In boxing design, a simplified programming method of inverse kinematics is presented. The remote control scheme uses WeChat mobile remote control based on AirKiss. Finally, we debug the robot, the results show that boxing robots can meet the home entertainment boxing match, can meet the design requirements and verify the feasibility of the design.

1. Introduction
The international federation of robotics (IFR) defines service robot as a semi-autonomous or fully autonomous robot that can complete the service work beneficial to human health [1]. With the improvement of living standards, there are service robots specially used for family leisure and entertainment. For this purpose, this paper designs a boxing robot for home entertainment. A boxing robot system was designed by Seul Jung and Poong Woo Jeon of Korea national university [2]. Boxing robot is designed as a pair of wheeled robots with simple freedom, which can simply imitate human boxing movements. The boxing robot is controlled by body sense, and the boxing action information is collected through the boxing sleeve equipped with gyroscope and acceleration sensor. There are four directional control sensors on the ground representing different directions. The controller sends a movement signal to the robot through his feet, controlling the robot go forward and backward, turn left and right. The boxing robot BalBot V, developed by Hyungjik Lee and others, is a self-balancing humanoid robot composed of a humanoid robot and a mobile inverted pendulum system [3]. BalBot V is controlled by a game handle. Its two-wheeled self-balancing design can effectively improve the mobile flexibility of the robot. The small-scale combat robot designed by China University of Mining and Technology is an effective exploration of related subjects. Its research involves mechanical structure, motion control system and communication system [4]. In this case, further development of entertainment boxer robot, so that it really into the family entertainment life, will become an important trend of its development [5]. Fuzzy control algorithm of DC deceleration motor is adopted in the mobile control of the robot designed in this paper. The remote control scheme uses WeChat mobile remote control based on AirKiss. Moreover, the robot can detect the situation of attack and give the corresponding score.
2. Related work

2.1. Robot hardware part

The structure of the boxer is shown in Figure 1. Boxing robot is divided into four basic parts: moving chassis unit, manipulator action unit, chest and head hit detection unit, information output unit.

The main controller of boxing robot selects STM32F4 Series High-Performance microcontroller STM32F407ZGT6. This design adopts the design scheme of wheeled moving chassis, and uses DC deceleration motor to drive the rear wheel to rotate, so as to provide power for chassis movement. The front wheel is controlled by steering gear. The arm unit of boxing robot combines the arm with the forearm through the linkage mechanism, uses the steering gear to drive the forearm, and uses the forearm to drive the forearm to complete the boxing action. The chest of the robot is equipped with a chest armor, under which a TIAIHUA mouse micro-switch is used as a hit detection sensor, and a steering gear is used to rotate the waist. Boxing robot head mechanical structure, using four-angle impact detection design to ensure that the head before and after any direction is hit, can detect accurate signals. In this way, when the head is hit, no matter which direction the strike force comes from, it can cause at least one touch of the switch action. The steering gear is controlled by multiple steering gear control modules. This design installs a LCD display screen for displaying boxing robot information behind the boxing robot. At the same time, BY8001-16P module is chosen as voice module. In the case of fist, effective hit, etc., with the corresponding voice effect. The remote control unit uses the design of WeChat remote control unit based on AirKiss. The remote terminal is a smart phone equipped with WeChat, and the remote receiver is a Wi-Fi module that supports AirKiss. For the robot's power supply unit, we use 18650 lithium batteries to form batteries. Also consider the protection of power supply [6]. We use HX-3S-FL10-A type three series lithium battery protection module to protect battery pack.

![Figure 1. Mechanical structure diagram of boxing robot.](image)

2.2. Control algorithm design of boxing robot

2.2.1. Design of chassis speed control algorithm based on fuzzy control. The controller receives the command from the mobile remote control, and the boxer starts to move. Here the initial speed is set at 0.3 m/s. Before the release signal is detected, the speed value increases by 0.3 m/s and the maximum speed is 0.9 m/s for each 1s increase. In order to improve the control accuracy and efficiency of the system, fuzzy control is adopted in the system [7–8]. In the design of fuzzy controller, the standard two-dimensional control structure is selected. The input is velocity deviation e and deviation change ec, and the output is control quantity u. Because the parameters of the motor are almost the same, and the quantization factors Ke, Kec and Ku are the same, two digital fuzzy controllers can be realized with only one program structure.

2.2.1.1 Fuzzy interface design. 1. Define the linguistic values of language variables. Taking the deviation linguistic variable E, the universe Z = {-3, -2, -1, 0, +1, +2, +3}, and the fuzzy subset on the universe is A_i (i = 1, 2, ..., 7). The corresponding linguistic values are {positive large (PB), median
(PM), positive small (PS), zero (Z), negative small (NS), negative medium (NM), negative large (NB). Indicates that the current relative speed setting values are: extremely low, very low, too low, just right, too high, very high, very high. In the same way, taking the deviation variation language variable as EC, the universe \( Z = \{-3, -2, -1, 0, +1, +2, +3\} \), and the fuzzy subset on the domain is \( B_j \) (\( j = 1, 2, ..., 5 \)). And the output value language variable is \( U \), the universe \( Z = \{-3, -2, -1, 0, +1, +2, +3\} \), and the fuzzy subset on the universe is \( C_k \) (\( k = 1, 2, ..., 7 \)).

2. Define the membership function of each linguistic value. Here, we choose triangle function as membership function. The analytic function of triangle membership function is:

\[
f(x, a, b, c) = \begin{cases} 
0, & x \leq a \\
\frac{x-a}{b-a}, & a \leq x \leq b \\
\frac{c-x}{c-b}, & b \leq x \leq c \\
0, & x \geq c
\end{cases}
\]

(1)

Where \( a \leq b \leq c \).

![Figure 2. Speed deviation E membership function](image)

The membership function design of motor speed deviation \( E \) is shown in Figure 2. Similarly, the membership function of the motor speed deviation rate \( EC \) and the fuzzy controller output \( U \) can be written.

| EC   | PB | PM | PS | Z  | NS | NM | NB |
|------|----|----|----|----|----|----|----|
| PB   | NM | NS | Z  | PS | PM | PB | PB |
| PS   | NM | NM | Z  | PS | PS | PB | PB |
| Z    | NB | NM | NS | Z  | PS | PM | PB |
| NS   | NB | NB | NS | NS | Z  | PM | PM |
| NB   | NB | NB | NM | NS | Z  | PS | PM |

2.2.1.2 Building fuzzy rule base and fuzzy relation. Combined with the experience of chassis motor speed control, a fuzzy control rule table for output \( U \) can be established, as shown in Table 1.

Then the membership function table of the fuzzy set of the deviation \( E \), the deviation rate of change \( EC \) and the output \( U \) can be written and the fuzzy relation \( R \) can be calculated:

\[
R = \begin{bmatrix}
0 & 0.3 & 0.35 & 0.6 & 0.65 & 1 & 1 \\
0.3 & 0.3 & 0.65 & 0.65 & 0.75 & 0.75 & 0.7 \\
0.4 & 0.65 & 0.65 & 1 & 0.65 & 1 & 0.7 \\
0.6 & 0.7 & 1 & 1 & 1 & 0.7 & 0.65 \\
0.7 & 1 & 0.65 & 1 & 0.65 & 0.65 & 0.4 \\
0.7 & 0.75 & 0.75 & 0.65 & 0.65 & 0.35 & 0.3 \\
0.7 & 1 & 0.65 & 0.6 & 0.35 & 0.3 & 0
\end{bmatrix}
\]
2.2.1.3 Fuzzy reasoning and fuzzy. After the fuzzy relation $R$ of the designed fuzzy controller is obtained, the fuzzy value vector of the output control variable can be solved by the synthetic reasoning method.

$$ U_1 = e^* \circ R_A \ I \ ec^* \circ R_B $$

(3)

At this point, the total output $U$ of the controller is the union of all $U_1$. We can get $U$:

$$ U = e^* \circ R_A \ I \ ec^* \circ R_B $$

(4)

When $e^*$=NS (negative small), that is, the actual speed of the motor is slightly higher than the given value, and the motor speed change rate $ec$=PS (positive small), that is, the motor speed slightly increased trend, from equation (2.5), then the control can be derived $U = (0.65 \ 0.65 \ 0.65 \ 0.65 \ 0.65 \ 0.65 \ 0.65 \ 0.65)$ for the controller output $U$ fuzzy vector can be expressed. For:

$$ U = \frac{0.65}{-3} + \frac{1}{-2} + \frac{0.7}{-1} + \frac{0.7}{0} + \frac{0.65}{1} + \frac{0.65}{2} + \frac{0.65}{3} $$

(5)

When the maximum membership method is used to solve the ambiguity, the control output $U$ is taken as the average value of the two adjacent maximum membership values:

$$ U = -2 $$

(6)

Similarly, when $e^*$=NS, $ec^*$=PB (positive large), then:

$$ U = -3 $$

(7)

According to the quantization level of the linguistic variables $E$ and $EC$, a fuzzy control query table with a capacity of 7x7 can be obtained according to the above synthetic reasoning and defuzzification methods. As shown in Table 2.

| EC  | -3 | -2 | -1 | 0  | 1  | 2  | 3  |
|-----|----|----|----|----|----|----|----|
| -3  | 0  | 0  | 1  | 2  | 3  | 3  | 3  |
| -2  | 1  | 0  | 0  | 1  | 2  | 3  | 3  |
| -1  | 2  | 1  | 0  | 1  | 2  | 3  | 3  |
| 0   | 3  | 2  | 1  | 0  | 1  | 2  | 3  |
| 1   | 4  | 3  | 2  | 1  | 0  | 1  | 2  |
| 2   | 5  | 4  | 3  | 2  | 1  | 0  | 1  |
| 3   | 6  | 5  | 4  | 3  | 2  | 1  | 0  |

| $2.2.1.4$ Algorithm design of fuzzy controller. Before programming, we need to determine the respective quantization factors $Ke$, $Kec$ and $Ku$.For example, in practice, the continuous range of deviation $e$ is $[e_L, e_H]$, where $e_i$ represents the minimum, $e_H$ represents the maximum, and $2m$ is the width of the scope of deviation $E$. The relationship between $Ke$ and $e_L$ and $e_H$ is as follows:

$$ Ke = \frac{2m}{e_H - e_L} $$

(8)

Similarly, the quantization factor $Kec$ and the scale factor $Ku$ can be determined.

When the car body reaches a maximum speed of $V_m$, the wheel speed is $n$ from the diameter of the chassis wheel to 4.8cm:

$$ n = \frac{V_m}{\pi d} $$

(9)

From $V_m$ to 0.9m/s, $n$ is 6r/s. The maximum speed of the motor is 10800r/min. Program setup time and digital controller control cycle are 20ms. We can get $Ke$ is 0.01, $Kec$ is 0.01, and $Ku$ is 0.33.

After determining the quantization factor and the scale factor, the error $e$ and the error change rate $ec$ can be converted down to the input $E$ and $EC$ of the fuzzy controller.

$$ E = Ke \cdot e $$

$$ EC = Kec \cdot ec $$

(10)
The output $U$ of the fuzzy controller can be converted to the actual output value by $u$:

$$u = Ku \cdot U$$

(12)

According to the fuzzy control query table, a specific algorithm of the digital fuzzy controller for motor speed regulation can be obtained.

2.2.2. Steering engine steering algorithm design. Good steering characteristics have an important impact on the stability, motion capability and even motor protection of the whole system. In order to ensure that the wheels of the car body turn naturally without side slip, the wheels should, as far as possible, meet the Ackerman steering principle [9]. The steering gear steering algorithm is analyzed by using Ackerman steering model. Specifically, the encoder detects the speed relationship between the two rear driving wheels in real time, and feeds the speed back to the controller, which controls the output of the front wheel steering angle through the steering algorithm. This ensures smooth steering and steering efficiency of chassis wheels. When the chassis mobile control is programmed, the speed ratio of the left and right driving wheels can be measured according to the encoder. The control pulse width of the steering gear is obtained by selecting the structure of the program, and the automatic control of the steering wheel with the change of the speed ratio of the driving wheel is realized.

2.2.3. Reverse analysis and design of boxing action. Boxing robot action programming, mainly using the steering control board of the upper computer on-line manual teaching programming method [10]. This programming method, using the analysis principle of robot inverse kinematics, adjusts the action of boxing robot through experiment, records the rotation angle of each joint steering gear, and then determines the composition and execution process of the action. The boxer's boxing action is designed and downloaded to the steering control panel.

3. Debugging of boxing robot system

3.1. Commissioning of boxing robot function unit

After completing the design of hardware and control software of each unit, the functional unit of the boxing robot needs to be verified and debugged.

3.1.1. Debugging of information output unit. The display unit is the main information output unit of the boxing robot. When the boxer is powered on, it can see the display information. The boxer starts with a 100-point original score, which is automatically deducted when hit. Users will be reminded to charge when there is insufficient power. Figure 3 shows the display information in different conditions, respectively.

![Figure 3. The display basic information of LCD appearance](image-url)
3.1.2. Mobile chassis unit debugging. The key of moving chassis unit debugging is the effect debugging of motor closed-loop speed regulation and the testing and debugging of Chassis steering performance.

1. In order to verify the fuzzy control effect of the driving motor, the upper computer of Labview serial oscilloscope is selected to draw the motor speed curve with time. The speed of DC deceleration motor before deceleration is taken as the control object. When the moving speed of boxing robot is set at 0.6 m/s, the motor speed after deceleration is 4 r/s and that before deceleration is 7200 r/min. Figure 4 is a speed chart under fuzzy control. It can be seen that in the speed regulation of DC motor controlled by fuzzy controller, there is almost no overshoot and deviation of motor speed, and the control effect is better, which will hardly affect the movement of boxing robot.

2. By testing the boxer's left and right turning and moving ability, the trajectory of its moving path can be obtained, as shown in Figure 5. The white wide line is the ideal turning path, and the thin line is the actual walking path of the robot. Through testing the left and right turning ability and the movement ability of the boxing robot, we can see that the movement track of the robot deviates from the preset path, but it is within the reasonable range of deviation.
3.1.3. Boxing action debugging. Due to the current stage, only one physical prototype is temporarily unable to conduct actual confrontation. So some static objects are set up to simulate the game scenes indirectly. Figure 6 shows the process of knocking down the target.

The results show that when the boxer hits a stationary target, it can effectively approach the target quickly by remote control, knock down the stationary object and achieve the designed target. The remote-controlled boxing robot knocks down each obstacle in turn, and verifies that it can complete the corresponding tasks set.

4. Summary

Aiming at the problems of lack of entertainment and practicality, single function and complicated control in the design of the current home entertainment boxing robot, this paper presents a new design scheme and completes the design and implementation of the boxing robot, which can establish remote control connection quickly through the mobile phone WeChat. The movement and boxing movements of the boxing robot are well executed. The detection unit is sensitive, and the display unit and the voice unit work normally, which meets the overall design requirements.

Reference

[1] Chen Liang 2016 IFR released the latest global service robot statistics report Robot industry 3:33-36
[2] Seul Jung, Poong Woo Jeon, Hyun Taek Cho 2002 Interface between robot and human: application to boxing robot IFAC Mechatronic Systems 1:779-784
[3] Hyungjik Lee 2009 Center of Gravity Based Control of a Humanoid Balancing Robot for Boxing Games: BalBot V Journal of field robotics 13:124-128
[4] Zheng Yaguang 2016 Research and design of small humanoid combat robot Beijing: China University of Mining and Technology
[5] Huang Jun, Ren Yu Zheng 2016 Design of two wheel mobile robot software architecture based on ROS Electronic technology design and application 11(15):49-52
[6] Guo Li-jin, Cao Xue-si 2016 Study on the Method of Battery Soc Monitoring and Optimization Computer Simulation 33(8):101-104
[7] Yu Zhangwei 2017 Dynamics and control of a 6-DOF space robot with flexible panels Proceedings of the institution of mechanical engineers part g-journal of aerospace engineering 231(6):1022-1034
[8] Zhu Junchi 2017 Research on the Improved Fuzzy Control of Brushless DC Motor for Electric Vehicles Machinery & Electronics 35(6):51-59
[9] Zeng Jinfeng, Chen Chen, Yang Meng'ai 2017 Design of Four-Wheel Steering Mechanism Based on Ackerman Steering Principle Light industry machinery 35(6):51-59
[10] Zhang Lige, Bi Shu Sheng, Gao Jinlei 2010 Human Motion Data Acquiring and Analyzing Method for Humanoid Robot Motion Designing Journal of automation 36(1):107-112