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Design and Implementation of an Interactive Robot for a Connect Four Game

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***Abstract*—This paper proposes an interactive robot with entertainment application for a connect four game. The proposed interactive robot contains the main body of the robot mechanism, the servo motor module, the light sensor module, the touch switch module, the text-to-speech module, the servo card and the core board. The main body contains an XY stage to scan the colored disks position which the users put and a putting colored disk institution can be used for the action of the game artificial intelligence. Servo motor module is used to control the position of DC servo motor and light sensor modules to detect the board information. Through the user pressing the touch switch module, it indicates that the user has completed the colored disks action, and it is the robot turn to play colored disks. In the core board selection, this paper takes the advantages of high performance, low price of ARM Cortex-M3 microcontroller (LM3S1138) to be the whole core of the operation. The experimental results of the paper show that the proposed interactive robot can reach the goal to enhance entertainment.**

Keywords*—Interactive robot. Entertainment application. Connect four game. Microcontroller.

I. Introduction

Robotics industry, a technology integration and high skill value-added industries, is a combination of mechanical, automation, electrical, electronics, information software, communications and creative content related to technology [1, 2]. For national development and the overall development of the national economic and industrial, it is on critical indicator status. Since the industrial uses toward service use and the factories into the crowd, it has been recognized the trend of the development of a robot with the tidal flow. It can be expected that the robots are going to enter the home environment to become a part of ordinary people's lives [3]. Particularly in the face of the world and the question of an aging society in Taiwan, the population of senior citizens over such a gradual increase.

The technologies and industries of robotics have become the technological industries with proactive development all over the world. The research of the robot in various areas through the world puts in much manpower and cost. From the beginning of biologically inspired robots, researchers have been fascinated by the possibility of interaction between a robot and its environment, and by the possibility of robots interacting with each other [4-6]. Most researchers working on human-robot interactive communication are motivated to make scientific contribution for understanding human cognition and/or engineering contribution for making interactive robots smarter.

For the control applications, a DSP with high-speed analog-to-digital converters can be a solution for the real-time control applications and an FPGA is a fast prototyping IC component which incorporates the architecture of a gate array and programmability of a programmable logic device. The advantage of the controller implemented by a DSP and an FPGA includes short development cycles, small size, fast system execution speed and high flexibility [7-11]. However, the high cost restricts their applications. On the other hand, a microcontroller can be integrated with some analog peripherals that can compensate for the limitation in computing power while expanding their functionalities at low cost [12-14].

Connect four game as shown in Fig. 1 is a two-player game in which the players first choose a color and then take turns dropping colored discs from the top into a seven-column, six-row vertically-suspended grid [15]. The game was first sold under the famous Connect four game trademark by Milton Bradley in February 1974. The object of the game is to connect four of one's own discs of the same color next to each other vertically, horizontally, or diagonally before your opponent.

This paper proposes an interactive robot for a connect four game using a low-cost 32-bit ARM Cortex-M3 microcontroller to verify the design performance. The proposed interactive robot contains the main body of the robot mechanism, the servo motor module, the light sensor module, the touch switch module, the text-to-speech module, the servo card, and the core board. Through the user pressing the touch switch module, it indicates that the user has completed the colored disks action, and it's the robot turn to play colored disks. Moreover, the developed game artificial intelligence can connect four of its own discs before users. The real-time experimental results show that the proposed interactive robot can reach the goal to enhance entertainment.

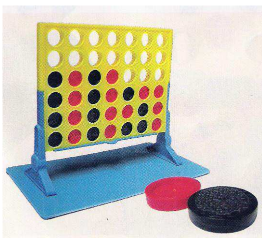

Fig. 1. Connect four game.

II. Hardware Architectures

The Stellaris family of microcontrollers brings high-performance 32-bit computing to cost-sensitive embedded microcontroller applications. The LM3S1138 microcontroller is targeted for industrial applications, including remote monitoring, electronic point-of-sale machines, test and measurement equipment, network appliances and switches, factory automation, HVAC and building control, gaming equipment, motion control, medical instrumentation, and fire and security [16]. In addition, the LM3S1138 microcontroller offers the advantages of ARM's widely available development tools, system-on-chip infrastructure IP applications, and a large user community.

In this paper, a microcontroller-based interactive entertainment robot is proposed as shown in Fig. 2. This interactive robot for connect four game contains the main body of the robot mechanism, the servo motor module, the light sensor module, the touch switch module, the text-to-sound module, the text-to-speech module, the servo card, and the core board. The main body of the robot mechanism contains an XY stage to scan the colored disks position which the users put and a putting colored disks institution can be used for the action of the game artificial intelligence. The servo motor module is used to control the position of DC servo motor. The light sensor module is designed to detect the board information and the text-to-speech module is designed to convert a stream of digital text into natural-sounding speech. Through the user pressing the touch switch module, it indicates that the user has completed the colored disks action, and it's the robot turn to play colored disks.

III. Interactive Robot Design

Based on the advantages of ARM Cortex-M3 microcontroller, a prototype implementation of an interactive robot for a connect four game is shown in Fig. 3. The light sensor module is used to measure the ambient light level in the environment as perceived by the human eye. The text-to-speech module converts normal language text into natural sounding voice recognition. Moreover, the rotation of the driving wheel is controlled by a pulse-width-modulation (PWM) signal from the micro-controller. A cycle counter repeatedly generates a 12-bit up-count wave to compare with the motor control commands for modulating the duty widths of the PWM signals.

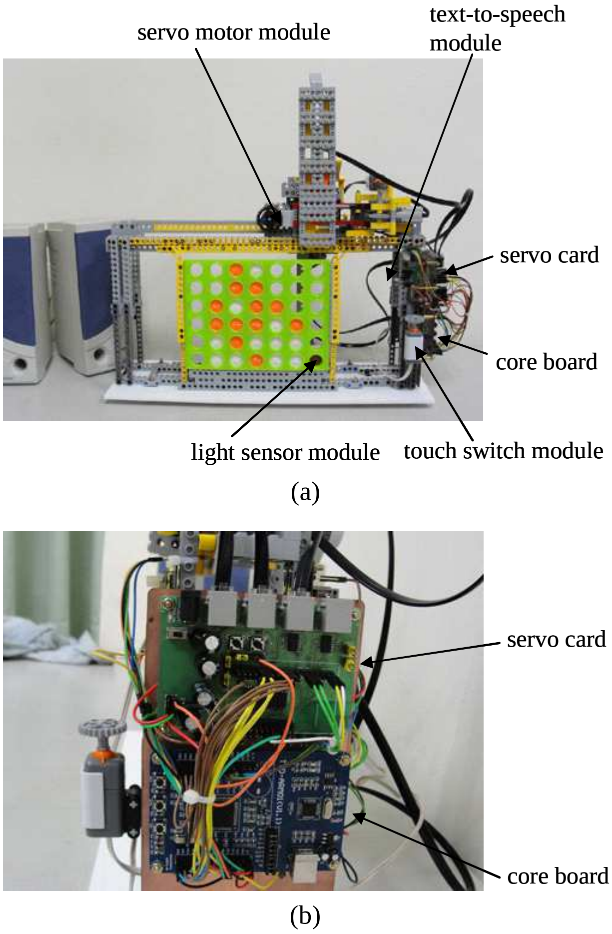

Fig. 2. The hardware architectures of the proposed interactive robot.

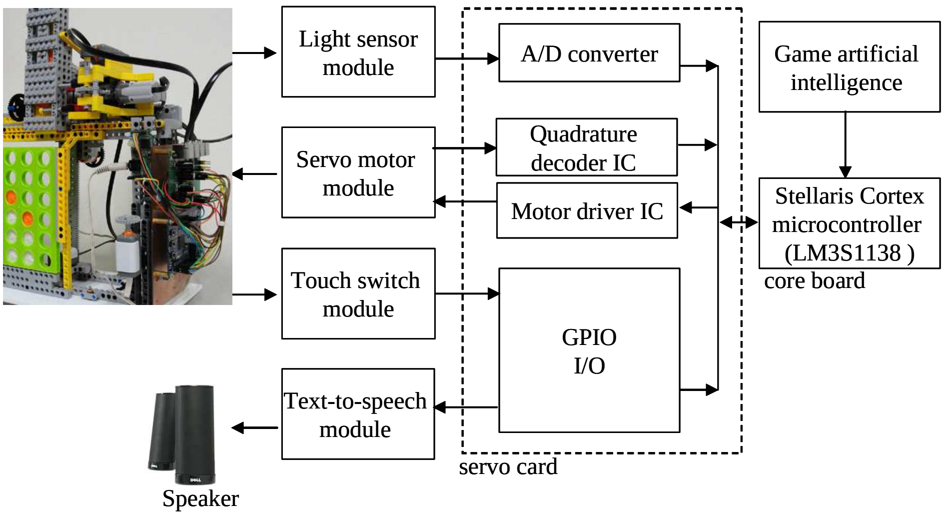

Fig. 3. Photograph of the interactive robot for a connect four game.

A. Motor Control

The interactive robot uses two 9V DC servomotors to contain an XY stage which can scan the user's colored disks position and uses one 9V DC servomotor to contain a putting colored disks institution. The LEGO NXT servomotor is specific to LEGO Mindstorms NXT set. The DC servomotor uses many gears to get high torque. These gears are not precisely manufactured and assembled; therefore, this results in certain amount of mechanical backlash. The motion equation of a DC servomotor can be simplified as [17, 18]

$$J_w\ddot{\theta} + B_w\dot{\theta} = T_e \tag{1}$$

where J_w is the moment of inertia, B_w is the damping coefficient, θ is the rotor position, and T_e denotes the electric torque. The electric torque is defined as

$$T_e = K_t i_w \tag{2}$$

where K_t is the torque constant and i_w is the torque current. The electric equation of a DC servomotor can be simplified as

$$v_w = R_w i_a + K_b\dot{\theta} + L_w\frac{di_w}{dt} \tag{3}$$

where R_w is the DC servomotor resistance, K_b is the back electromotive force coefficient, L_w is the DC servomotor inductance, and v_w is the DC servomotor voltage. Ignoring the DC servomotor's inductance and damping coefficient, the dynamic equation of the DC servomotor can be represented as

$$\ddot{\theta} = -\frac{K_t K_b}{J_w R_w}\dot{\theta} + \frac{K_t}{J_w R_w}u \tag{4}$$

where $u = v_w$ is the control input in voltage.

The control objective of the motor control is to find a control law so that the rotor position θ can track a position command θ_c closely. To achieve the control objective, define the position errors as

$$e = \theta_c - \theta \tag{5}$$

Fuzzy control using linguistic information can model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analyses. It also possesses several advantages such as robustness, model-free, universal approximation theorem and rule-based algorithm. Most of the operations in a fuzzy control use the error and change-of-error as the fuzzy input variables. However, the huge amount of fuzzy rules makes the analysis complex. For a fuzzy sliding-mode controller design, a sliding surface is defined as the fuzzy input variable to reduce the fuzzy rules. Thus, define a sliding surface as

$$s = \dot{e} + \lambda e \tag{6}$$

where λ is a positive constant. According to the fuzzy sliding-mode control design method, the fuzzy rules of the motor control are designed as

Rule i: IF s is F_i, THEN u is α_i, $i = 1,2,\cdots,7$ (7)

where F_i and α_i are the labels of the fuzzy sets characterized by the fuzzy membership functions. Since the microcontroller can only handle integer arithmetic, the membership functions of IF-part and THEN-part are shown in Figs. 4(a) and 4(b), respectively. The fuzzy labels are negative big (NB), negative medium (NM), negative small (NS), zero (ZO), positive small (PS), positive medium (PM) and positive big (PB). The defuzzification of the output is accomplished by the method of center-of-gravity as

$$u = \frac{\sum_{i=1}^{7} w_i \times \alpha_i}{\sum_{i=1}^{7} w_i} \tag{8}$$

where w_i are the firing weights of the ith rules of Eq. (7). The fuzzy rules of the motor control are summarized in Table 1, which is constructed by the sense that s will approach to zero with fast rise time and without large overshoot.

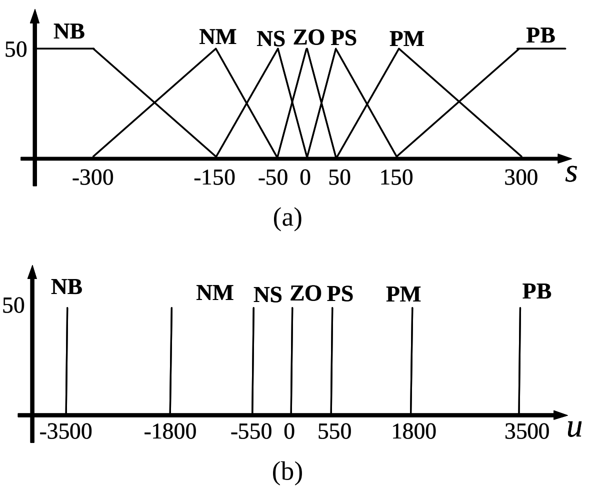

Fig. 4. Membership function of (a) IF-part and (b) THEN-part.

Table 1. The fuzzy rules of the motor control.

s	NB	NM	NS	ZO	PS	PM	PB
u	NB	NM	NS	ZO	PS	PM	PB

B. Game Artificial Intelligence

Connect four (also known as Captain's mistress, Four up, Plot four, Find four, Fourplay, Four in a row and four in a line) is a two-player game in which the players first choose a color and then take turns dropping colored discs from the top into a seven-column, six-row vertically-suspended grid. There are total 42 slots as shown in Fig. 5 on the board, and each player has 21 colored disks to use. The pieces fall straight down, occupying the next available space within the column. To win the game, the player must connect only four pieces together.

Artificial intelligence has been used in a wide range of fields including medical diagnosis, stock trading, robot control, law, scientific discovery and toys. Game artificial intelligence refers to techniques used in computer and video games to produce the illusion of intelligence in the behavior of non-player characters. The techniques used typically draw upon existing methods from the field of artificial intelligence [19].

The goal of the connect game is to have four disks of your color to connect each other, vertically, horizontally or diagonally before your opponent does. If all disks have been played and neither player has archived the goal, then the game is a draw. The proposed game artificial intelligence is to deploy a set of algorithms to implement an intelligent player. Algorithms and techniques used include game tree search and minimax algorithm to connect four.

There are total 42 slots on the game board, and there are 69 possible four-in-a-row winning combinations includes 24 combinations horizontally, 21 combinations vertically, 12 combinations diagonally with slope 1 and 12 combinations diagonally with slope -1. At any moment of the game, it should evaluate the current player's strength by looking at how close is it to archive a four-in-a-row at any of the 69 possible combinations.

Strength = Number of 3 in a row * 32 +
Number of 2 in a row * 4 +
Number of 1 in a Row (9)

where "*n* in a row" means there are *n* same color disks in a row. As shown Fig. 6, for board 1, the strength of black color disk is 11

Strength (black) = 0 * 32 + 1 * 4 + 7
= 11 (10)

and the strength of red color disk is

Strength (red) = 1 * 32 + 2 * 4 + 4
= 44 (11)

Clearly, the current board state is in favor of red player. Then, the game artificial intelligence player will make move according to minimax search result. Compute the score of the slots 1, 8, 15, 21, 25, 30 and 36.

Score = Strength (Player A) – Strength (Player B) (12)

Depends on the search tree level, min nodes or max node, both player can either be red or black color disks. Based on the analysis of the steps, it is proven that first player (black) should try to construct odd threats. And second player (red) should try to construct even threats.

Strength (black) = Number of 3 in a row odd * 32 +
Number of 3 in a row even * 16 +
Number of 2 in a row * 4 +
Number of 1 in a row (13)

and

Strength (red) = Number of 3 in a row even * 32 +
Number of 3 in a row odd * 16 +
Number of 2 in a row * 4 +
Number of 1 in a row (14)

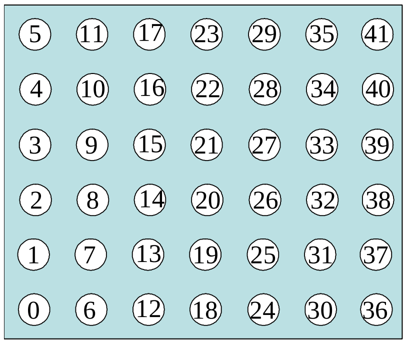

Fig. 5. Board layout.

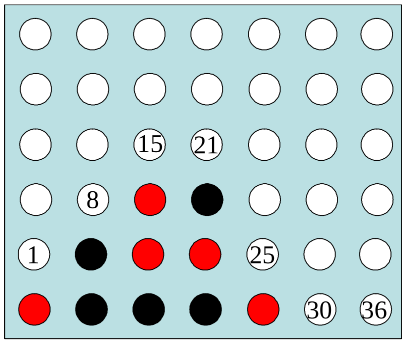

Fig. 6. Board 1.

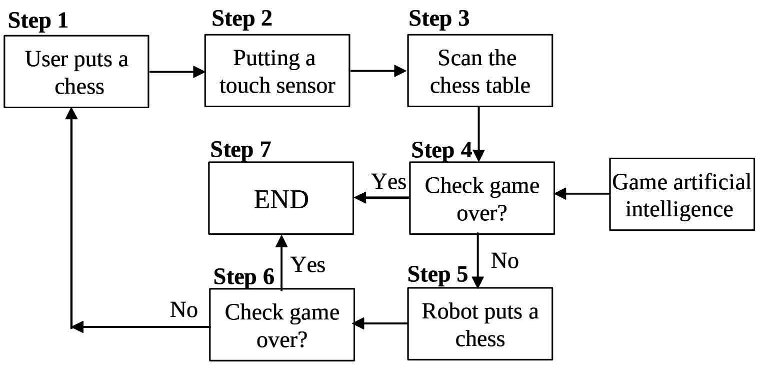

Fig. 7. The software flowchart.

IV. Experimental Results

The Stellaris family offers efficient performance and extensive integration, favorably positioning the device into cost-conscious applications requiring significant control-processing and connectivity capabilities. The Stellaris LM3S1000 series extends the Stellaris family with larger on-chip memories, enhanced power management, and expanded I/O and control capabilities. All members of the Stellaris product family, including the LM3S1138 microcontroller, are designed around an ARM Cortex-M3 processor core. The ARM Cortex-M3 processor provides the core for a high-performance and low-cost platform that meets the needs of minimal memory implementation, reduced pin count, and low-power consumption, while delivering outstanding computational performance and exceptional system response to interrupts. The software flowchart of the control algorithm is shown in Fig. 7. Figure 8 is the photograph of the sequence of the experiments.

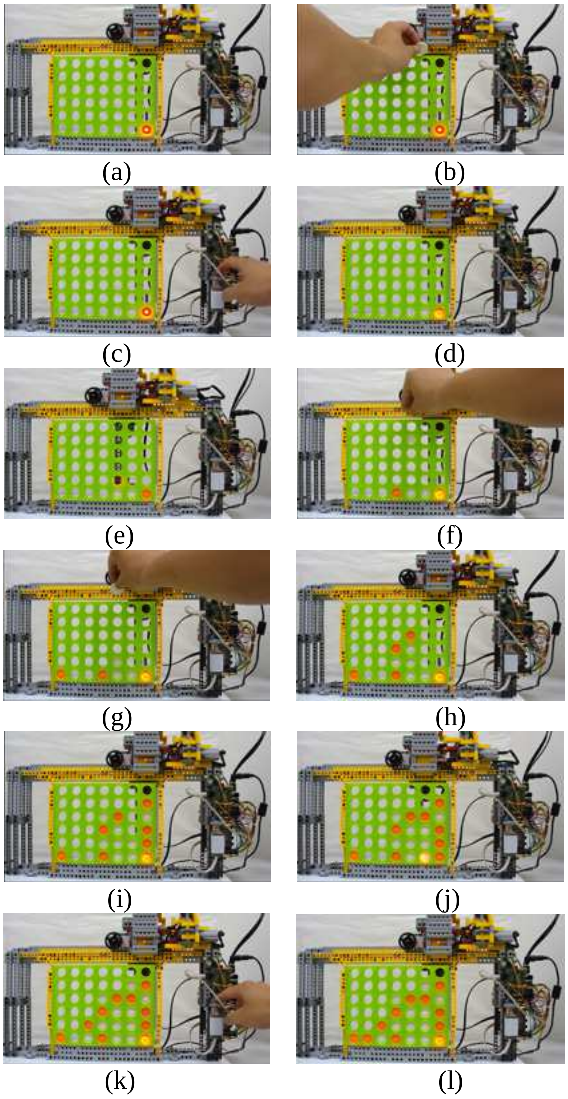

Fig. 8. Sequence of the experiments.

V. Conclusions

The concept of the connect four game is to get four chips in a row either diagonally, vertically and horizontally before your opponent. This paper proposes a low-cost high-performance interactive robot for a connect four game. An ARM Cortex-M3 microcontroller (LM3S1138) is used to develop the game artificial intelligence to produce the illusion of intelligence in the behavior of non-player characters. The proposed game artificial intelligence is to deploy a set of algorithms to implement an intelligent player. Through the user pressing the touch switch module, it indicates that the user has completed the colored disks action, and it is the robot turn to play colored disks. Experimental results show that the proposed interactive robot can reach the goal to enhance entertainment.

VI. Acknowledgment

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