Fuzzy Controller Design for Quadruped Robot Posture Control

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Abstract

In this paper, motion patterns of a giant entertainment quadruped robot’s head, body and tail parts are analyzed and extracted. Then, a fuzzy controller is designed in order to obtain life-like motion. Motion data are derived using 3D animation during robot’s walking and an organization mechanism is produced to obtain this kind of data. This paper introduces a data extraction method using a 3D animation technique and a fuzzy controller used in real mechanisms.

Keywords: quadruped, fuzzy, life-like

1. Introduction

Research of quadruped robots is very lively in recent days. Quadruped robots execute walking patterns on various surfaces very securely [1, 2]. According to this research, the main topic during production of quadruped robots is an optimal leg mechanism production and walking control, which means imitating four-legged (quadruped) animal legs and make them walk steadily. So, research of quadruped robots is mostly focused on legs and walking. However, quadruped animals not only have legs but also head and tail. In most cases researchers have not paid more attention to the study of quadruped robots with other body parts because most quadruped robots are used in the industry and military. This kind of quadruped robots has a strong characteristic on moving specific objects to a target position.

Nevertheless, with the spread of quadruped robots in the entertainment market, research on motion of other body parts beside legs has become appealing. The first such robot was Aibo in 1999, which opened a new field of robotics research and now is widely underway. In addition, WWD-The Live Experience in Australia and Japan’s leading manufacturers, Kokoro and Kawada, are doing exhibitions and performances with quadruped robots [3, 4].

In this way, military and entertainment quadruped robots are both biomimetics but production and implementation focus have differences. This paper introduces an entertainment robot not only with legs but with head and tail as well. Research about walking pattern and mechanism of quadruped animals are studied by many scholars [5]. But studies about motion pattern analysis and control of quadruped animals with head, tail and body have not met much progress. Therefore, this paper describes these aspects.

This paper can be divided into two parts. Motion capture based on 3D animation is presented in the first part. And fuzzy control algorithms and experimental results are described in the second part.

2. Motion analysis

There are three typical methods among many data extraction methods. The first method uses motion capture camera, the second uses video capture, and the last method uses 3D graphic animation. The first two methods apply to live subjects (camera, video), and analysis of motion data of virtual subjects or extinct subjects cannot be performed. To analyze these, the subject is modeled in 3D via some 3D graphic tool then diverse motions are performed (homoplasy taken into account). This method is commonly applied in character animation such as those of dinosaurs[6]. We choose the 3D graphic method where the subject is modeled in 3D Max and data is extracted through a self-developed scripter (Fig.1).
2.1. Motion data

The walking leg pattern is shown in Fig. 2. As it can be seen from the figure, results do not show big differences according to existing walking patterns, which is a walking type with a slight overlap between each leg. Walking sequence is followed closely to the line of \textit{Left Front (LF) \rightarrow Right Hind (RH) \rightarrow Right Front (RF) \rightarrow Left Hind (LH)}.

Motion of body, head, tail and other body parts is analyzed according to the leg motion pattern. First is analysis of the body. Data analysis is shown in Fig. 3(a). As it is known, the body moves horizontally and vertically in actual walking. While the body moves up and down, as shown in Fig. 3(a), if two kinds of motion happen, the vertical movement can be seen to change significantly. Firstly to implement the swing motion of each leg, the left hind leg and left foreleg could be deemed to be a pair, while the right hind leg and right foreleg could be deemed to be another pair. The body goes up during the swing of each pair. Second, it can be observed that the body goes down during the motion transition period of each pair. This phenomenon can be easily observed; however, in order to implement a life-like motion by extracting and proving the data above, the controller design plays an important role.

Motion of the tail is also associated with the walking pattern. As mentioned earlier, the leg pattern is separated into two pairs, while the right-left side motion of the tail goes according to one pair of the leg motion as shown in the Fig. 3(b). As it can be seen from the figure, the right-left side moving appearance of the tail due to one pair of legs is an arching shape, and the motion direction of head and tail is the same. So far, motion of the head, body and tail has been analyzed according to the leg walking pattern. Compared with the accurate actual speed and position data, these data focus more on an overall pattern. In order to apply these patterns to real algorithms in the future, the expression using math and language is very important.

3. Mechanism

The mechanism for applying motion data is shown in Fig. 4. It is a 7 meter-long quadruped robot including neck, body and tail. The characteristic of this system is that the legs do not actually make contact with the ground. In fact, it is a mechanism that uses wheels instead of legs to walk. The robot
can be moved using wheels while the walking pattern shape can be displayed by four legs. In other words, the four legs just play a role in showing the walking appearance, but in fact they have no practical effect. In addition, the giant quadruped robot is supported by a mobile cart, to give more emphasis to natural movement and helps solve the stability issue. This method is the most suitable for giant quadruped robots used in entertainment. The head is combined with three cylinders that can perform roll, pitch and yaw, while the body is designed with one cylinder to perform up and down motion. A four-bar linkage mechanism is used for the tail, which has one cylinder and three joints to allow movement from different angles. Verifying each body part through kinematics and inverse kinematics, a controller could be easily designed.

4. Fuzzy controller design for head, body, and tail motion

Motion data for each body part were extracted as shown in the above section. For a robot to deliver life-like motion of all body parts, understanding motion pattern becomes more important. However, it cannot be considered perfect because it is very subjective and there is almost no method to make it a quantitative mathematical model. Therefore, a fuzzy controller is needed to get a design for motion data tracking.

Fuzzy logic provides the means of handling vague, ambiguous, incomplete or imprecise information [7]. It is applied in a variety of applications such as data classification, decision analysis,robotics, pattern recognition and automatic control [8]. Fig. 5(a) illustrates the flow of data through a fuzzy system. Basically, a fuzzy logic controller consists of four components as shown in Fig. 5(a), which is the fuzzification interface, knowledge base, fuzzy inference and defuzzification interface. The fuzzification interface scales and maps the measured variables to suitable linguistic variables. The membership function of a fuzzy set is a generalization of the indicator function in classical sets. The above linguistic quantification will be used to specify a base of set rules that captures the expert's knowledge about controlling the plant. The rule-base is the biggest impact on control performance. These control rules are shown in linguistic variables to connect input and output using if-then structures.

In this paper, a multiple-input-multiple-output system is used. Mamdani’s max-min method is used as synthetic. Through this process, a degree of membership can be obtained. In many practical
applications, a control command is given as a crisp value. Therefore it is needed to defuzzify the result of the fuzzy inference. A defuzzification is a process to get a non-fuzzy control action that best represents the possibility distribution of an inferred fuzzy control action. The defuzzification method used is known as center of gravity. Practical outputs in this paper are body, head and tail while input is the leg walking pattern (Fig. 5(b)). Thus, four inputs and three outputs consist of the following:

-Inputs: FLL (Front Left Leg), FRL (Front Right Leg), RLL (Rear Left Leg), RRL (Rear Right Leg)
-Outputs: Neck (Left/Right), Body (Up/Down), Tail (Left/Right)

Fig. 6 below shows the membership function according to the inputs. The membership function is selected to be Gaussian. According to the change of leg step, five fuzzy sets are defined for each leg, which are the Large Back, Middle Back, Small Back, Zero, and Large Forward. Leg length is between +400 and -400 mm. Fig. 7 shows the membership function for outputs, which are the head, body and tail. The head and tail move from side to side driven by a straight cylinder. The head is available for right-left side movements by two cylinders. Under this condition, two cylinder displacements are possible to gain one angle valve using inverse kinematics. The head could move between +15 and -15 degrees. Five fuzzy sets are involved depending on each region, which are the Large Neck Right (LNR), Middle Neck Right (MNR), Zero, Middle Neck Left (MNL), and Large Neck Left (LNL). Both the tail and body are built using one cylinder, and the tail moves right and left while the body moves up and down. Tail displacement is -20 ~ 20 mm, while the body is -80~80 mm. Five fuzzy sets are considered for both the tail and body, which are the Large Tail Right (LTR), Middle Tail Right (MTR), Zero, Large Tail Left (LTL), Middle Tail Left (MTL) for tail, and Large Up (LU), Middle Up (MU), Zero, Large Down (LD), Middle Down (MD) for the body.

According to leg walking, a rule base for each body pattern is introduced. In this paper, five rule bases are used as follows.

-Inputs: FLL (Front Left Leg), FRL (Front Right Leg), RLL (Rear Left Leg), RRL (Rear Right Leg)
-Outputs: Neck (Left/Right), Body (Up/Down), Tail (Left/Right)

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5. Fuzzy control simulation

Fig. 9 shown below is the control algorithm flowchart using a fuzzy controller. The fuzzy controller can change the leg position information to adaptive output for head, tail and body. Then, we compare

Figure 9. Fuzzy control flowchart
the running data between the fuzzy controller and the PID controller.

Simulation results shown in Fig. 10 are similar to the actual animation appearance even though these results do not perfectly match with the motion capture data, they could be considered to be a very similar pattern. In order to match perfectly, several trial and error steps to get the value of membership function have been done, and then that could get almost identical results. Changes in head and tail motion could be seen as the legs are crossing over.

6. Conclusion

This paper introduces a quadruped robot used for entertainment purposes with legs, body, tail and head. Before producing the quadruped robot, motion data is extracted using an animation data extraction method according to the quadruped animal’s body motion pattern. These motion data are defined as life-like motion data. This kind of life-like motion entertainment robots is widely used in many fields, and will be positioned as a new research field. In this paper, life-like motion data were applied to a real driver and a designed fuzzy controller. Fuzzy control is widely used in subjective systems that are and difficult to make a quantitative mathematical model of. The extracted motion data have some parts that are difficult to express mathematically, so a fuzzy controller was applied to a real system. Even though results until now do not perfectly match with the captured motion data, a very similar pattern could be found after using fuzzy controller. By tuning the membership function and rule base, a perfect shape will be implemented in the future. In addition, with the performance improvement of fuzzy and PID controllers, vibration and hydraulic control problems on the giant organization mechanism will be resolved on this issue.

7. References