Design and Development of Autonomous Soccer Humanoid Robot CU-legendary

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Abstract. Over the past decade the development of AI stimulated many application domains including robotics which combines multiple subjects and techniques. Humanoid robot becomes one of the research focuses because of its difficulty such as the limitation of cognition on environment and itself, the large number DOFs and the under-actuation. In fact there is still a long distance from its theoretical research to practical application. With regard of this, a state of the art autonomous soccer humanoid robot CU-legendary was designed and developed in this paper with the consideration of its mechanical optimal design, electrical system design, sensor configuration and software architecture design. The proposed robot team has taken first place on 2018 RoboCup China Open Competition, the goal of which is humanoid robots being able to win against the official human World Soccer Champion team by year of 2050.

1. Introduction

Being one of the ultimate research goals in robotics, humanoid has become the hot focus and preferred platform for artificial intelligent application [1] such as the RoboCup competition where a team consisting of fully autonomous humanoid robot soccer players is expected to beat the champion of the most recent World Cup under FIFA official rules by the mid-21st century [2]. Although many distinguished humanoid robots have been reported consecutively including Atlas [3], Hubo [4], HRP series [5], RoboCup competition requires the humanoid robot playing soccer game similar to human being especially from the point of view of the autonomous capability, the compliance with rules, the sensing system configuration as well as the whole-body structure. Hence many research teams have introduced their humanoids taking part in RoboCup annually [6, 7]. This paper proposed the design and development of RoboCup humanoid soccer robot with regard of its mechanical optimal design, electrical system design, sensor configuration, software architecture design with real-world realization by adopting the key technologies of FEA based optimal design and ADAMS simulation, simultaneous localization and mapping (SLAM), footprint planning and modeling, stable control and application, object recognition and tacking. The proposed team of robot has won the champion on 2018 RoboCup China Open Competition which indicates that our contribution can be prevailed to promote the progress of humanoid robot.
2. Outline of CU-Legendary Humanoid Robot

The technical indices of the proposed robot are listed in Table 1 where the size, weight, DOFs, walking speed, resolution, precision and identification distance are contained. A lot of breakthroughs in hardware and software system of the humanoid robot CU-Legendary were experienced during past years.

| Items               | Parameters | Items                      | Parameters       |
|---------------------|------------|----------------------------|------------------|
| Height              | 680mm      | Max. walking speed         | 35cm/s           |
| Wide                | 270mm      | Camera resolution          | 800*600, 30 frames/s |
| Weight              | <4.1Kg     | Positioning accuracy       | ±1cm             |
| Degrees of freedom  | 20         | Visual identification      | 4m               |
|                     |            | distance                   |                  |

Fig. 1 shows the robot's 3D design model (a) and dynamic simulation analysis (b) that indicates all the servos can bear the maximum impact force of corresponding joints during soccer game.

![3D design model and dynamic simulation analysis](image)

(a) 3D design model (b) dynamic simulation analysis process

**Figure 1.** Outline of CU-Legendary Humanoid Robot.

3. Mechanical Design of CU-Legendary Humanoid Robot

In accordance to RoboCup requirements, CU-legendary robot has two legs, two arms, one body and one head. The robot's hands and feet are made of carbon fiber while its arms, the legs and the trunk are of aluminum alloy. The firmware of the robot is designed through SolidWorks platform under Simulation environment where the finite element analysis (FEA) method is adopted to design each component optimally by von Mises yield criterion [8] toward the target of making the robot as light and flexible as possible with enough strength. In order to let the robot walk on 3cm height artificial grass ground, four anti-slip protruding parts are equipped at the corners under each foot of the robot to provide enough supporting force, which has been proved to work well. Servo is the most important mechanical driving part of the robot, so Dynamixel products of RX-106 and RX-64 are selected after ADAMS [9] dynamic analysis since they are well-designed for composition of humanoid. Each robot was driven by 20 servos: two for the head, three for each arm and six for each leg that ensure the robot acts flexible without hinder which is undoubtedly crucial for football player.
4. Electrical Design of CU-Legendary robot

4.1. Sensor Configuration
As for the humanoid soccer robots designed to participate in RoboCup competition, their sensors is required to be equivalent in human senses so as to make an unbiased equipment configuration between robots and man-players, camera becomes the most important external sensor for the robot where the IMU sensor containing gyroscope and accelerometer is usually fixed as internal sensors that helps the robot fulfilling self-localization.

C930e WEBCAMI of Logitech is employed as image sensor which configures HD lens, 1920*1080 pixel, 20-step auto focus, automatic correction of light insufficient and high-speed USB3.0 port that directly connect to up-level computer where the robot conducting visual recognition.

IMU ADIS 16405 is fixed firmly on the trunk of the robot thereby the 3-axis gyroscope can accurately measure the robot trunk angular velocity and send it to the control system to adjust the robot's posture and maintain its balance while the 3-axis accelerometer helps the robot knowing when it is fallen down so that it can raise-up autonomously.

4.2. Electrical System Configuration
Elaborate design of the electrical system is an essential guarantee for the normal work of robots. Based on sufficient analysis and demonstration, we designed and developed an electrical control system which is composed of an up-level computer, a low-level controller and a power supply board. The lower controller is designed by integration of three embedded microcontrollers driving different servo buses of servos and an IMU sensor while the camera is connected to up-level computer through USB port. Such simply design ensure effective utilization of the interior space of the robot. Apart from transferring power from the battery to up-level computer and low-level controller, the power supply board acts as a hot plug switch that ensures uninterruptible power supply if the battery needs to be changed when the robot are working.

5. Software Architecture Design for CU-Legendary
Robot playing football on the field is highly complex intelligent system that requires intact collection, timely delivery and effective usage of information. We adopted the software architecture of the blackboard structure [10] shown in Fig. 2 to ensure the real-time sharing of various information which includes data blackboard, solution model blackboard, behaviour decision-making blackboard, execution driving blackboard and action executive blackboard.

The data blackboard contains camera data, sensor data, servo data, and control box instructions, internal and external instructions. Among them, the camera data being taken by the robot on field with the speed of 30 frames per sec is used to generate field image data, which is used for the target recognition. Sensor data contains the measurements form gyroscopes, accelerometers and potentiometer, helping the robot's positioning and posture judgments. The servo data present the state of each motor for their security including temperature, torque, etc. Robot must obey external instruction comes from the field network. The internal instruction is delivered among field robots while the external instruction is used during technical challenge competition.

Both data and instructions are delivered to the model blackboard, which contains Data calibration model, Robot role model, Robot gait model, Robot self-positioning model and Robot target recognition model. Data calibration model normalize the robot data collected by the data blackboard and calibrate them according to the deviation of actual information and that generated from model of library so as to ensure that the results of the model meet the robot in field under actual conditions. The robot role model sets different roles for the robot according to the internal instruction. The robot gait model adopts the D-H kinematics [11] representation method to establish the mathematical expression of the robot’s gait and solves it on basis of the sensor data. The robot self-positioning model is built by employing particle filter (PF) [12] algorithm. In detail, a set of weighted particles are generated by a posteriori probability density function to indicate the probability of the robot on certain position. The probability of every weighted particle is calculated iteratively based on the value of the observation model of the robot. After times of recursive and iterative calculation, the final collection of particles
with largest weight represents the most probable position of the robot [13]. Based on SLAM [14] and deep-learning [15] technique, the object recognition model identifies the field soccer [16], goal, mark line, opponents and partner, while marking their position.

Figure 2. Software scheme of CU-Legendary humanoid robot based on blackboard architecture.

Behavior decision blackboard obtains the states of both robot and field through the information of model solution blackboard. Also the features in field are extracted to be matched with the feature library so that the robot knows what to do next. For example, if the robot is set to be a striker, it can know where he should go at what speed. If it acts as a goalkeeper, it knows how to treat with the coming ball.

Actuator blackboard gives instructions to operation blackboard under different boundary conditions. These instructions mean what the robot should do to fulfill the decision from behavior decision blackboard, such as go forward, go back, raise-up from front, raise-up from back, left kick, right kick, turn left and turn right. Once the robot needs to change a position, a path planning model [17] based on A* algorithm is triggered to give a set of optimized footprints that the humanoid should complied with especially during object tracking.

Operation blackboard converts the expected action of the robot to executive instruction to the servos, that is when the motor should start to rotate and when stop plus rotation speed. All these data are stored and used in real time. Meanwhile the decision-making instructions are sent to all the cooperative robot players on field so that they can help each other to win the game.

6. Conclusion
In this paper we presented the overall design and development of autonomous humanoid robot CU-legendary by considering the mechanical optimal design, electrical system design, sensor configuration and software architecture design. The robot team of CU-legendary can fulfill soccer game without human control by virtue of its high intelligence that integrating the methods of D-H
kinematics functions, particle filter, SLAM and deep-learning. The robot team of CU-legendary performed well and won the champion on 2018 RoboCup competition China Open.

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