Team CHARLI: RoboCup 2012 Humanoid AdultSize League Winner

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Abstract. Autonomous soccer-playing humanoid robots have advanced significantly in the past few years. Skill sets elementary to humans such as omnidirectional bipedal walking, path planning, and gameplay strategy have matured enough to allow for dynamic and exciting games. In this paper team CHARLI, the two-time RoboCup Humanoid AdultSize League winner, describes the design and fabrication of essential components such as the spine and mechanical structure, then overviews the increase in performance resulting from recent mechanical upgrades. Finally, we detail the custom walking controller and gameplay module changes responsible for the outstanding performance of our self-constructed lightweight full-sized humanoid platform, CHARLI-2.

1 Introduction

Team CHARLI is a collaborative effort between Virginia Tech's Robotics and Mechanisms Laboratory (RoMeLa) and the University of Pennsylvania's GRASP lab. Stemming from the success of team DARwIn in the KidSize class, team CHARLI (Cognitive Humanoid Autonomous Robot with Learning Intelligence) has participated in the Humanoid AdultSize League since its debut at RoboCup 2010. Having demonstrated the reliability of the 2011 CHARLI-2 platform by winning the Louis Vuitton Best Humanoid Award – the first United States team to secure the trophy in RoboCup history – few modifications were necessary to comply with the 2012 rules. This paper details the design and fabrication issues of selected innovative features of the CHARLI-2 platform, and then overviews the hardware and software changes which steered team CHARLI to its second consecutive AdultSize victory.

2 Design and Fabrication Considerations

The main emphasis of the CHARLI-2 platform, shown in Figure 1, is on a lightweight design to reduce development cost, improve ease of handling, and ensure safe operation. The construction of a reliable full-sized humanoid robot requires several design considerations and manufacturing processes to create multi-purpose subsystems and minimize weight.

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Fig. 1. CHARLI-2 (left, right) and testing on a soccer field (center)

2.1 Spine

Some of the problems faced by full-sized humanoids are ease of handling, operator safety, and a lightweight design; many utilize a bulky handle near the shoulders or require multiple users to maneuver and position the robot. To address these issues, CHARLI employs a unique multifunctional spine design.

Two stainless steel rods are the only load-bearing components needed for the spine. However, an innovative design employing laser-cut acrylic disks resembling human vertebrae not only improves aesthetic appeal, but also allows for routing of wires through the center of the discs. The spine also functions as a comfortable handle well above the robot's center of gravity in an area free of pinch points, which ensures safe, stable, handling and eliminates the added weight of a conventional handle near the head or shoulders.

The base of the spine detaches from the waist, allowing us to separate CHARLI into upper and lower portions for easy transportation. The detachable spine base also permits changes to the waist and pelvis structure, so in the future we plan to implement a waist yaw joint to increase the upper body range of motion.

2.2 Speaker

Design considerations for the speaker system focused on power consumption, packaging, weight, and acoustics. To realize these design requirements a low-power Mylar cone was outfitted in the chest cavity, using the chest covers as a natural enclosure to enhance acoustic quality.

Though we typically use the speaker at demos to communicate and interact with the audience, it is also one of the most useful subsystems for code development and testing. Since it can be difficult to recognize errors in autonomous behavior during runtime, descriptive audio clips — such as *ball found*, *ball lost*, or *orbit right-forward* — were triggered by state machine transitions to provide cues regarding the robot's decision-making. This provides real-time monitoring of autonomous decisions made by the robot, increasing the efficiency with which we can debug the control software.

2.3 Mechanical Structure

Unlike the easily fabricated bent sheet metal components on the KidSize DARwIn-OP, the mechanical structure for CHARLI-2 requires more rigid components to sustain the increased dynamic loads associated with full-sized platforms. Thus, the fabrication of a CHARLI frame is a more involved process than its KidSize counterpart. Several manufacturing processes were considered for their ease of fabrication, time savings, and achievable tolerances, and CNC milling was determined to be the most effective.

The frame is primarily cut from aluminum alloy 6061 due to its machinability, strength-to-weight ratio, and low cost. Figure 2 depicts the procedure used to fabricate the CHARLI frame: we utilize CNC milling machines to cut the aluminum parts and a CAD-CAM program to generate the tool path and G-code required for CNC control. Once milled, parts are removed from the aluminum alloy sheets and post processed – cutting remaining features, threading holes, and removing sharp burrs – to complete fabrication. Using this manufacturing process, we can achieve intricate geometries with the precision and tolerances required for high-performance robotics applications.

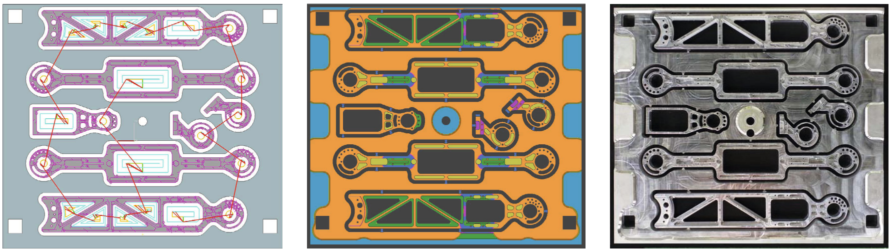

Fig. 2. Left: Designing a tool path. Center: Tool path simulation. Right: Resulting milled aluminum alloy sheet.

2.4 Covers

Covers are a critical robot component, as they improve the safety and reliability of the system and define the basic appearance of the robot. Covers provide an essential barrier between the user and the vital internal circuitry to prevent injury or electronic shorts. We considered several methods of fabricating covers, each with distinct advantages and disadvantages: injection molding is only advantageous for mass production due to its high start-up cost, CNC milling a cover from a large block of stock is extremely time-consuming, and carbon fiber lay ups have low material costs but can result in weakened mechanical properties due to uneven resin distribution.

Instead, fabrication of CHARLI's lightweight covers is accomplished through the cost-efficient, repeatable vacuum forming process depicted in Figure 3 [1]. Molds are carefully designed to avoid overstretching and webbing of the plastic, and are then cut on CNC mills similar to the aluminum parts. Next, thin clear plastic covers are shaped over the molds through vacuum forming. Post processing of the covers involves trimming excess plastic and painting the interior, resulting in the appealing glossy finish characteristic to CHARLI's appearance.

Fig. 3. (Left to right) Cover molds, vacuum formed covers, and post processed covers

3 Mechanical Platform Upgrades

The only major mechanical change to the CHARLI-2 platform from 2011 to 2012 was an upgrade from Robotis's Dynamixel EX-106+ actuators in the legs to the new MX-106 actuators. The MX-series boosts performance over the previous EX-series without a change in actuator cost or dimensions.

A contactless absolute encoder permits 360° rotation of the motors, a 40% increase from the magnetic encoder [2], permitting CHARLI to utilize a larger range of motion. Furthermore, the new actuators require a lower nominal operating voltage, allowing the use of lower voltage leg batteries to reduce weight.

Another new feature is the ability to receive bulk feedback data from the actuators including the actual position, velocity, voltage, and/or current draw. By monitoring the consumed current for each leg actuator, power consumption was analyzed for various walking speeds and trajectories [1].

Despite the increased maximum torque, one tradeoff to using the MX-106 actuators is a 35% reduction in maximum speed inherent to the reduced gear ratio [2], but we did not find this to inhibit walking performance.

4 Codebase Upgrades

One major RoboCup 2012 rule change was a 50% size increase of the AdultSize field, presenting exciting challenges for AdultSize teams. Team CHARLI was able to directly port the majority of the cross-platform software architecture employed by team DARwIn for the KidSize competition [3]. However, CHARLI's custom walking controller and dedicated gameplay module required innovative changes in order to complete the Dribble-and-Kick competition within the effectively reduced timeframe.

4.1 Custom Walking Controller

CHARLI can walk at speeds of up to 0.4 m/s, but this speed was never attained during matches in 2011 due to the inherent reduction in stability at maximum walking velocity. Adapting to the larger field size this year required a faster stable walking gait to minimize the time required to traverse the field. To enhance the ZMP-based walking controller [1],[4] we conducted extensive testing to further understand the multifaceted effects of the walking algorithm parameters on the speed and stability of the gait.

The walking controller is tuned using a number of intuitive parameters such the step period time, double stance phase ratio, and peak foot height. By reducing the step period time and double stance phase ratio, we created a faster, more dynamic walking gait which which was more robust to disturbances. Increasing the proportional feedback gains for the hip and ankle roll and pitch joints provided the stability necessary to maintain balance at higher speeds. Secondary walking controller parameters were then adjusted to fine-tune the walk for various surfaces.

The increased stability of the walking gait improved performance of turning and side-stepping, allowing us to more effectively implement the omnidirectional path planning included in the cross-robot software architecture and improve the aiming accuracy during attacks.

4.2 Gameplay Module

We made several upgrades to the high-level gameplay module to futher reduce the time required to complete each challenge. Ball dribbling was improved by utilizing the side-step to adjust foot alignment during the approach. We also implemented a range of kick speeds to provide more accurate ball placement across the field.

We modified the 2011 goal-scoring algorithm to combine the robot's angle of approach to the ball with an adjustable gain to determine where to aim the kick within the goal. As opposed to consistently kicking towards goal center, this approach can reduce the number of blocked goals; however, shooting accuracy was more sensitive to errors in localization prior to the kick, which can result in missed goals.

Finally, we created a goalie module unprecedented in the AdultSize League. Conventional AdultSize goalkeepers typically remain stationary at the center of the goalie box or, range of motion permitting, temporarily squat with arms extended to block the kick. Inspired by basic human goalie tactics, CHARLI advances within the goalie box toward the incoming attacker in order to block off the angle of attack available to the striker.

5 Conclusions

CHARLI was featured at the 2012 World Expo in South Korea, walking on stage and interacting with the audience 12 hours per day for three months, demonstrating the durability of the CHARLI-2 platform. Team CHARLI is committed to introducing reliable innovative platforms to the humanoid community, and is currently developing a new platform utilizing linear series-elastic actuators and an impedance control walking algoritm capable of safe falling and recovery.

Recognizing the booming success of DARwIn-OP and the unified humanoid robotics codebase, we also have aspirations of releasing an open platform version of CHARLI. We believe this is the most effective method of advancing the field of humanoid robotics and contributes toward the ultimate RoboCup goal of playing soccer with humans.

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