A Segway-based Human-Robot Soccer Team

Botond Szatmáry, Jason Fleischer, Donald Hutson, Douglas Moore,
James Snook, Gerald M. Edelman, Jeffrey Krichmar
The Neurosciences Institute
10640 John Jay Hopkins Drive
San Diego, California 92121
E-mail: szatmary, fleischer, hutson, moore, snook, edelman, krichmar@nsi.edu

***Abstract*— A new RoboCup soccer league is being developed, focussing on human-robot interaction. In this league each team consists of both human players, mounted on Segway HT scooters, and a robotic version of the Segway; both human and robot players must cooperate to score goals. This paper presents details of the physical design of our autonomous Segway Soccer robot and the modified Segway scooter that is ridden by the human teammate. Our approach was demonstrated in a series of a Segway Soccer exhibition games at the 2005 RoboCup American Open in Atlanta, Georgia.**

I. Introduction

RoboCup [1] is an organization dedicated to fostering robotics research by providing a standard problem, robot soccer. The stated goal is to develop, by 2050, a team of fully autonomous humanoid robots that can win against the human world soccer champion team. However, all current RoboCup leagues involve only robots playing other robots. A new RoboCup league, Segway Soccer [2], [3], is under development where humans and robots will interact on the playing field. We hope that this new league will be as useful to the field of human-robot interaction as previous RoboCup leagues have been to the field of multi-agent coordination.

This poster presents the electromechanical design of both our autonomous robot and the modified Segway scooter ridden by the robot's human teammate. We also describe how our team, which consisted of an autonomous robot and a human, worked together to play a game of Segway Soccer. For more details on the behavior and control of the robot, please refer to our ICRA paper [4] and on-line videos [5].

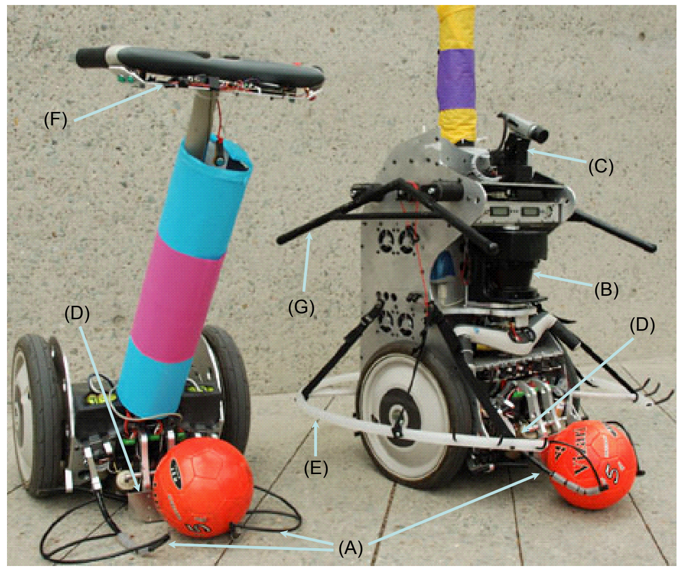

Fig. 1. Our Segway Soccer devices. On left the modified Segway HT scooter for the human player, which gives the rider the same active ball-handling and kicking capabilities as the SS-BBD on the right. (A) active capture devices, (B) laser rangefinder, (C) pan-tilt unit and camera, (D) kicking assembly, (E) passive capture ring, (F) voice command module, (G) crash bars.

II. Segway Soccer Game

Segway Soccer is relatively new, and the rules [3] are still under development. The object of this league is to have both human players and robots cooperate and compete with each other, in a game on an equal footing.

The most important features of the game are:

- Games may be two-a-side or more, up to 11 on a team. At least half of the team members must be robots.
- For safety reasons, the players are not allowed within one meter to each other.
- As in other RoboCup leagues [1], color markers are used to help the robots' object recognition ability: the ball is orange, the goals have separate colors, and each team has its own color which has to be announced to the opponent team 20 minutes before the game.
- Dribbling and travelling is not allowed. The player (either human or robot) who has the possession of the ball may turn in place, but must not move forward or backward, and has 30 seconds to pass to his teammate or shoot. If ball possession exceeds the maximum allowed possession time, the ball is given to the other team.
- When a team gains control of the ball, both a human and a robot must have touched the ball before a goal can be scored. This rule ensures human-robot cooperation must take place before scoring. To further increase the robots' dominance on the field, at the recent 2005 US Open [1] only robots were allowed to shoot on goal.
- Human players are not allowed to mark robots. That is, a human player cannot closely follow a robot player with the intent of preventing its movement or intercepting a ball passed to it.
- Games consist of two 20 minute halves with 10 minutes halftime break.

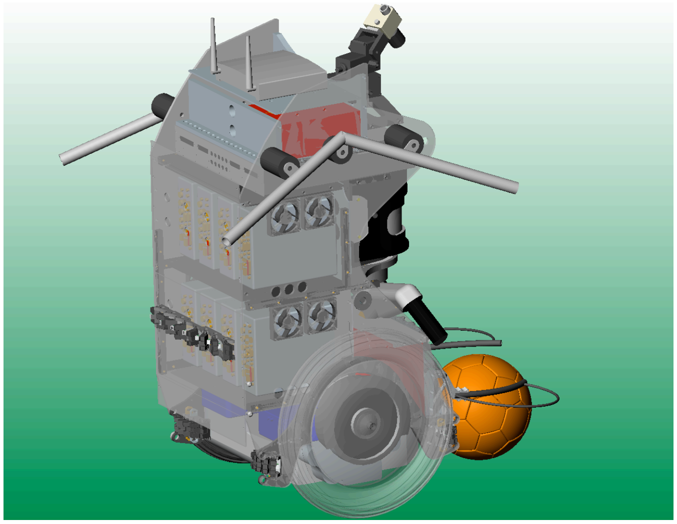

Fig. 2. A CAD model showing the rear of the SS-BBD. Transparent rendering of some structural elements shows the arrangement of the compact on-board PCs (grey boxes with golden connectors on the back; 8 are shown, but only 7 are installed), and the lead-acid batteries that power them (red boxes both above and below the PCs). The kicker/catcher NiCd batteries are shown in blue underneath the PCs. Also note the IR sensor banks, the lower ones detect soccer balls and the upper ones obstacles.

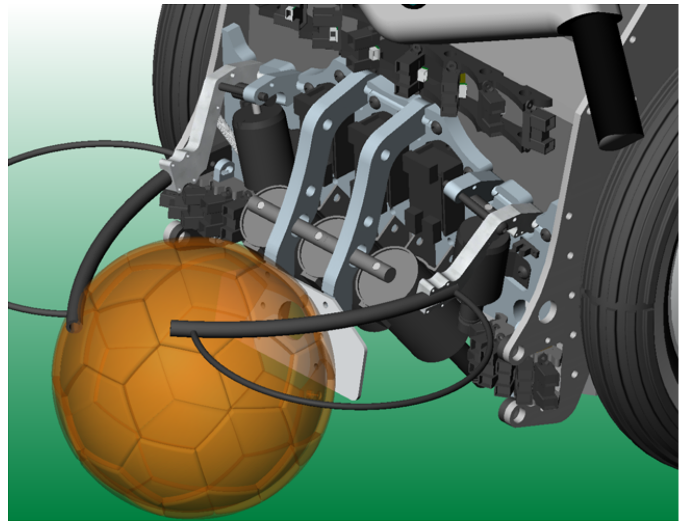

Fig. 3. A CAD model close-up of the solenoid driven kicking and ball-catching actuators. Note the banks of IR sensors mounted just outboard of the catcher solenoids, and also above the entire ball-handling assembly. The lower IRs detect balls, the upper obstacles.

III. The Segway Robot

The robotic member of the team is known as the Segway Soccer Brain-Based Device (SS-BBD), a name that reflects that its design follows the Brain-Based Device methodology [6]. Brain-based devices are a class of neurally-controlled robots, which are based on features of vertebrate neuroanatomy and neurophysiology, emphasizing the organism's interaction with the environment. Further details about the control system and the neuroscience behind its design can be found in our ICRA paper [4]. This poster, however, will present details of the electromechanical design of the SS-BBD that allow it to play Segway Soccer.

The SS-BBD is based on the Segway Robotic Mobility Platform (RMP) (Fig. 1 and 2), a commercially-available robotic version of the popular Segway HT scooter [7]. The Segway RMP is capable of traveling at speeds of up to $13km/h$ for about $16km$. An aluminum chassis has been added to the robot base, that houses sensors, ball-handling devices, computers, and batteries. The high-heat conductance of the aluminum helps cool the electronics inside. The complete SS-BBD is $90cm$ tall (without the plastic mast on top that holds the team color marker), $55cm$ wide, and weighs about $135kg$.

A. Sensors

The SS-BBD possesses a variety of sensors: a color camera, a laser rangefinder, banks of infra-red distance measurement sensors.

The CCD camera (Sony DFW-V300) sends 640x480 pixel images at 30 frames per second via Firewire to one of the on-board PCs. The camera is mounted on a pan-tilt unit (Directed Perception, Inc. PTU-D46-70) that allows the camera to view the entire front arc of the robot and to look downwards at a ball directly in front of it.

The laser rangefinder (SICK LMS-200) measures distances to obstacles in the front $180°$ arc of the robot, up to 20 meters away, with a one degree angular resolution. It provides about 70 scans of the front arc per second to one of the on-board PCs via an RS-422 connection.

The IR distance measurement sensors (Sharp GP2Y0A02YK0F) detect objects up to 1.5 meters way. IR sensors are arranged in banks of eight, each bank having its own controller that communicates via RS-232 with one of the on-board PCs. There are eight such banks: four banks are mounted low in order to detect soccer balls (two banks in front, two in the rear) and four banks mounted higher up for detecting other obstacles (also two front, two rear).

B. Ball-handling

There are active and passive ball-manipulators on the SS-BBD (Fig. 3). The active devices catch, hold, and kick the ball using solenoids for actuation. The passive device consists of a large plastic hoop suspended from straps so that it is parallel to the ground and at roughly ball-height. The hoop covers the sides and back of the robot, i.e. all areas outside that covered by the ball catcher/kicker. When an incoming soccer ball hits the hoop, the force of the impact makes the hoop ride up over the top of the ball, absorbing much of the kinetic energy. In most cases, the ball is trapped between the hoop and the robot's chassis, allowing the SS-BBD to pivot in place until the ball comes underneath the ball catcher/kicker assembly, so that it can be firmly trapped and kicked away again when necessary.

Two jaw-like solenoid-driven catchers pinch the ball against the front of the robot where the kicker assembly lies. The catcher solenoids (Trombetta Q610-B1V24), one on each side of the kicker, drive a flexible plastic arm that raises up above the ball-level when the solenoid is powered.

Once the arm has been driven to a raised position it engages a limit-switch that causes the solenoid's controller to turn off the main driving coil and engage a low-power holding coil that is rated for continuous duty. This holding coil enables the SS-BBD to hold its catchers in the raised position as long as battery power lasts, something that would not be possible with normal solenoids. The raised holding position allows the SS-BBD to trap a ball more quickly than if it had to first raise the catchers before dropping them to trap the ball.

The solenoids are spring-loaded so that when neither coil is powered the catcher-arms fall to the down, ball-trapped position. This spring is essential to the functioning of the catcher assembly; if a ball is slightly misaligned during the capture it makes the catcher arms compliant enough that small turn of the wheels will fix the problem and bring the ball in firmly against the kicker.

The kicker is driven by three solenoids (Trombetta Q613-B1V12) connected in parallel to a kicking plate that, when the solenoids are unpowered, lie flat against the front of the SS-BBD. The solenoids are mounted so that they push the plate against the ball imparting velocity and forward spin. Each kicking solenoid is driven simultaneously at $24V$ (although they are rated for only $12V$), $\sim 80A$ for a brief instant to produce the kick. After the power is turned off, the solenoids are driven by a spring to retract, therefore pulling the kicking arm back down.

We have experienced only 6 solenoid failures in approximately 400 hours of soccer game time, resulting in a mean time between failures of approximately 66 hours. This is more than sufficient for the purposes of playing a game that lasts only 40 minutes.

C. Electronics and Power

There are seven Pentium IV-based compact PCs (EZGo PC) on-board the robot. These PCs are being operated as a Beowulf cluster using $v1.2$ of the MPICH library for message-passing between computers. Most of the cluster's computational power is used for the simulated nervous system (approximately $60,000$ neuronal units having 1.6×10^6 synapses, which are updated every $30ms$) that processes sensory input and controls motor actions [4]. The PCs are connected with each other through Gigabit Ethernet and with the outside world through an 802.11g wireless connection. The SS-BBD is completely autonomous computationally, this external wireless link is used only to allow off-field observers to view the state of the robot in real-time or to execute a remote emergency stop.

The SS-BBD is also autonomous in power. There are three separate battery systems on-board: those for driving the wheels of the Segway RMP, those that power the PCs and other electronics, and those that provide the power to the ball-handling apparatus. The separate power systems are necessary to ensure that the electronics are always supplied with the correct voltage even when the actuators are demanding large loads of current. The Segway RMP's wheel and electronics are driven by the same set of batteries it came with from the factory. The computers are supplied by $37kg$ worth of lead-acid, deep-discharge batteries with a capacity of $42A \cdot h$ at $24V$. The kickers are supplied by Ni-Cd packs that deliver a total of $7.2A \cdot h$ at $24V$.

IV. The Human Scooter

The Segway scooter ridden by our human player is a modified i-series Segway HT (Fig. 1). It has the similar solenoid-driven ball catcher/kicker apparatus as on the SS-BBD. The actuators are controlled by a set of toggle switches on the scooter's handlebars.

The control software on the SS-BBD responds to voice commands from its human teammate. The Segway HT scooter ridden by the human has a voice recognition board (Sensory, Inc. Voice Extreme^{tm} Toolkit), connected to a microphone, that can recognize about a dozen discrete short phrases. These short phrases, such as 'run downfield' or 'mark the opponent', are code names for various plays in the SS-BBD's repertoire, and for each such phrase a corresponding command is transmitted wirelessly to the SS-BBD. See [4] for more details.

V. Segway Soccer Exhibition

At the 2005 RoboCup American Open in Atlanta, Georgia, a set of Segway Soccer demonstration games were held to promote this new RoboCup league. The demonstration was a great success; two different institutions (The Neurosciences Institute and Carnegie Mellon University [2]) were able to field teams consisting of a human and a robot player. Both of the teams on the field in Atlanta were able to demonstrate safe human-robot interaction in a competitive situation. Both teams showed that they could take control of the ball, move it around the field through human-robot cooperation, and score. However, we should like to modestly point out that we won all five demonstration games. Videos and details of the event can be found on-line [5].

Acknowledgment

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