Application Report: 8715 characters, 1353 words, 5 images

Stability and Dynamics – and this all on a Ball?

An interdisciplinary team of students has impressively brought to reality what sounds, at first, kind of crazy and appears to contradict most basic laws of physics. Their Ballbot[1] "Rezero" accomplishes not only a balancing act on the ball, but equally impresses by its convincing technical solutions, unprecedented agility and appealing design.

Figure 1 Rezero in Action

As a focus project of the Swiss Federal Institute of Technology Zurich (ETHZ), students of the Autonomous System Lab (ASL) along with their fellow colleagues at the Zurich University of Applied Sciences (ZHAW) and the Zurich University of the Arts (ZHdK) have formed a cooperation of a special kind. The result of this collaboration is named Rezero, being the first Ballbot that not only perfectly masters balancing on a ball. It also exploits its movement potential and shows that a robot can look appealing without bystanders needing to overcome their inhibition threshold. As tour guide, servant, assistant or as toy, Rezero feels comfortable when space is limited or in crowded places. It is a most-talented artiste and entertainer, it impresses, unfolds emotions and interacts with persons standing nearby in a very impressive way.

[1] Category of robots capable to balance and move on a ball.

The Ballbot Principle

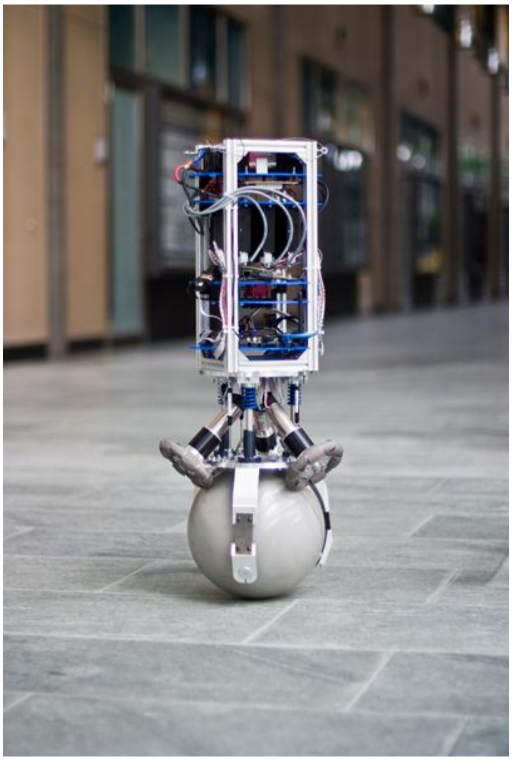

Figure 2 Rezero "in the Nude"

One obvious attribute of a Ballbot is the „ball“ on which it stands. Its contact area to level ground is actually a single point, making the robot generally instable by design and highly at risk to keel over. On the other hand, this fact enables free movement in any direction as well as the rotation around its own axis.

Another aspect: Rolling in a particular direction produces counter torque – the tilt of the robot in opposition to the direction of motion – in turn, would actually make it tumble. But, a Ballbot makes use of this fact as it slightly leans in the opposite direction to, quasi, chase behind its center of gravity. To further accelerate, the Ballbot lets itself fall even further in direction of travel. For deceleration however, additional acceleration is required to first “out-compete” its center of gravity before coming to a synchronized standstill in the fully upright position. Yet; total “standstill is the Ballbot’s death“. Even when appearing standing erect, it equilibrates by continuously slightly revolving the ball underneath its center of gravity.

An obstacle to be overcome is the actuation of the ball itself: A „normal“ wheel rotates radially around its own axis, either forward or backward. Yet, a movement in the wheel’s axial direction can only be achieved by overcoming the friction.

Figure 3 Omniwheel in Pieces

Applied to the drive of a ball it means that, when moving in one direction, at least one of the drive wheels will radially jam. This fact requires the employment of a multi-directional drive system. Thereby, so called omniwheels[2] take care of load transmission in one direction, while simultaneously providing free-wheeling in the other direction.

The Rezero Solution

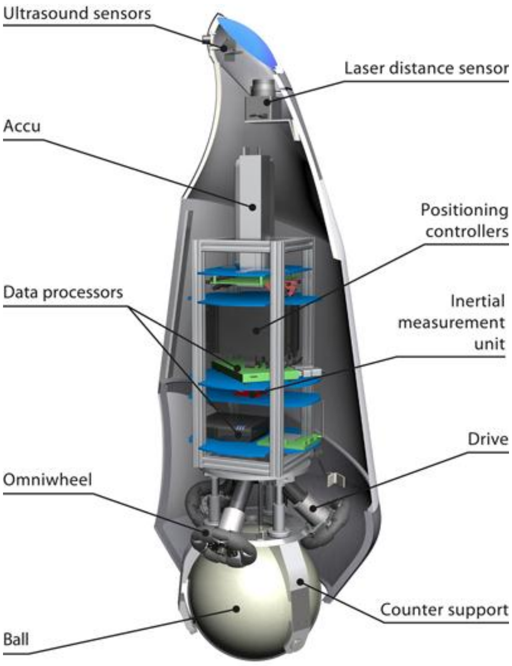

Figure 4 Rezero's Structure

[2] Multi-directional wheels that work like "normal" wheels, being capable to transmit force in radial direction. In axial direction, they feature self-rotating elements capable to freely turn under axial load.

“Ball”

The ball is a project-own design that distinctly differentiates from other approaches. Its structure and the consequently required manufacturing process have been made-up in collaboration with an industrial partner.

It is based on a geometrically highly accurate aluminum hollow sphere covered by a 4 mm thick rubberized, low-wear surface providing a very high coefficient of static friction. Both factors, precise spherical shape and high friction result in supremely quite running, extreme dynamic acceleration capability, and high velocity of up to 3.5 m/s (almost 13 km/h, that is close to 8 mph!).Most other known Ballbots travel somewhat “out of the true” and seem to stand out rather by their sluggishness and slowness.

Drive System

Figure 5 Drive System: Motor EC-4pole 30, Planetary Gearhead GP 42 C, Angular Encoder HEDL 5540, Omniwheel

Another in-house development are the three omniwheels which are arranged in 120° angles around the ball’s circumference. This in particular, since available standard solutions could not satisfy the requirement of an entirely encapsulated outer shape .Their complex geometry, low-loss design of the individual components and load transmission-optimized surface all contribute to the exceptionally high-grade construction design. The wheels are driven by a motor/gearhead combination made by maxon motor. They compose of a maxon EC-4pole 30[3], a planetary gearhead GP 42 C[4] and an angular encoder HEDL 5540[5]. The drives’ suspension is designed that the ball remains ideally positioned underneath the three omniwheels to provide continuous traction. The drives are regulated by maxon EPOS 70/10 positioning controllers[6] in

[3] Compact, brushless, electronically commutated high performance motor delivering 200 W power output, Ø30 mm, efficiency above 85%, speed/torque gradient approximately 5 rpm/mNm

[4] 2-staged planetary gearhead with ceramics axes, Ø42 mm, gear reduction 26:1, torque (continuous/max) 7.5/11.3 Nm, efficiency 81%

[5] 3 channel encoder with Line Driver, 500 impulse

[6] Positioning controller with 700 W power output, operating voltage 11…70 VDC, output current (continuous/max) 10/25 A, slave within CANopen network

current control mode, being addressed as slaves within the CAN network. The three drives are being coordinated by the real time low-level computer.

The drive system impresses by its remarkable maximum dynamics during acceleration and deceleration, high velocities and, at the same time, high-precision positioning and quite running.

Control, Position Monitoring and Sensor Technology

In control are two data processors; a real time low-level computer for fast, accurate equilibration and position monitoring, and a high-level processor in Linux running the Robot Operating System (ROS) which takes care of interaction with the surroundings. Rezero can be controlled by various input methods, such as joystick or trajectory planning via MATLAB. Additionally, Rezero features a “game mode” by which, within preset parameters (such as, for example, maximum speed, acceleration, range of movement), a group of people can take control by jostling and tapping it.

The Inertial Measurement Unit (IMU) represents one of the robot’s core components. The system measures translative and rotatory accelerations, as well as spatial tilt angles and features a compass. Data are being smoothened by an internal Kalman filter and transmitted to the low-level computer. The unit operates at a frequency of 160 Hz and represents the clocking link within the regulation chain.

To perceive its surrounding, Rezero is equipped with various laser and ultrasonic detectors. Their arrangement allows full 360° detection of objects within a range of approximately 6.5 m (21 feet). Depending on the selected mode, detected objects are assessed as obstacles, or they can be incorporated in the robot’s behavior. Thus, for example, allowing Rezero “to take chase”. The sensory capabilities are being enhanced by surround microphones, whereby their signals can also be integrated into the robot’s actions.

Casing

Kids (and not just small ones!) can hardly resist the temptation to touch the robot, to play with it or to bring it to heel. Not just due to its incredibly organic movements, but also because of its very friendly, inviting appearance. The kinetic behavior reflects also in its exterior packaging; curved, nicely shaped, of strong character, dynamic and elegant.

Technical Data

Description	Value	(Equivalent)
Gross weight (including casing)	19.5 kg	(43 lbs)
Weight (operational, without casing)	14.5 kg	(32 lbs)
Motor output	3 x 200 W	–
Velocity (max.)	3.5 m/s	(12.6 km/h) (7.8 mph)
Acceleration (max.)	3 m/s^2	(0-100 km/h in 9.3 s) (0-60mph in 8.9 s)
Inclination angle (max.)	20°	–
Autonomy	5 h	–

The Result

Rezero it the first Ballbot that not only perfectly commands the act of balance, but also outbids the moving capabilities of a Ballbot in an incomparable manner. The project team's well-elaborated concept impresses: The successful in-house development of the mechatronic elements, the high grade design and the interdisciplinary total package solution make Rezero an outstanding eye catcher.

Hence, it does not come as a surprise that Rezero has attracted the attention of renowned companies in the film and entertainment industry. In the near future, Rezero for sure can be admired by a large audience when performing at its best.

Author: maxon motor ag / Martin Rüegg

For further information, please contact…

maxon motor ag
Brünigstrasse 220
P.O. Box 263
CH-6072 Sachseln

Phone +41 41 666 15 00
Fax +41 41 666 16 50
Web www.maxonmotor.com

ETH Zurich
Project Rezero
Autonomous Systems Lab
CLA E 15.2
Tannenstrasse 3
CH-8092 Zurich

Phone +41 44 632 71 68
Web www.rezero.ethz.ch

Captions and Picture Credits

Figure 1 *Rezero in Action*

Figure 2 *Rezero "in the Nude"*

Figure 3 *Omniwheel in Pieces*

Figure 4 *Rezero's Structure*

Figure 5 *Drive System: Motor EC-4pole 30, Planetary Gearhead GP 42 C, Angular Encoder HEDL 5540, Omniwheel*