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Students and researchers in the School of Mechanical Engineering at the University of Adelaide have developed a so-called diwheel that allows a driver to travel in a conventional upright position and, for the more adventurous, in an upside down position. A dSPACE MicroAutoBox was used as the development and control platform.

Down Under: Diwheel Defies Gravity

Australian students developed an upside down vehicle.

Figure 1: The Electric Diwheel With Active Rotation Damping (EDWARD) developed at the University of Adelaide.

Free Rotation Fun

Commencing in March 2009, honors students in the School of Mechanical Engineering at the University of Adelaide designed, built and tested an electric diwheel called EDWARD (Electric Diwheel With Active Rotation Damping).

Diwheels, like their more popular cousins the monowheel, have been around for almost one and a half centuries. A diwheel is a vehicle that consists of two large coaxial wheels that completely encompass an inner frame containing a driver (Figure 1). The inner frame, suspended between the wheels, can rotate freely. The physical arrangement of a diwheel shares many similarities with two-wheeled inverted pendulum systems such as the Segway.

In fact the dynamics of the two systems are almost identical, the only difference being that the frame (pendulum arm) of a diwheel is smaller than the radius of the wheels, enabling the frame to completely rotate without striking the ground.

Overhead Locomotion

The outer wheels are driven from the inner frame and forward motion

> "EDWARD not only rocks (literally) but it's green too. It's fully electric, and employs regenerative braking, so energy is recovered when slowing down. The MicroAutoBox has saved us so much time compared to programming an embedded micro controller. Connection of all the I/O was simple and it has allowed us to rapidly try alternative control strategies. And using ControlDesk to develop the HMI was a breeze."

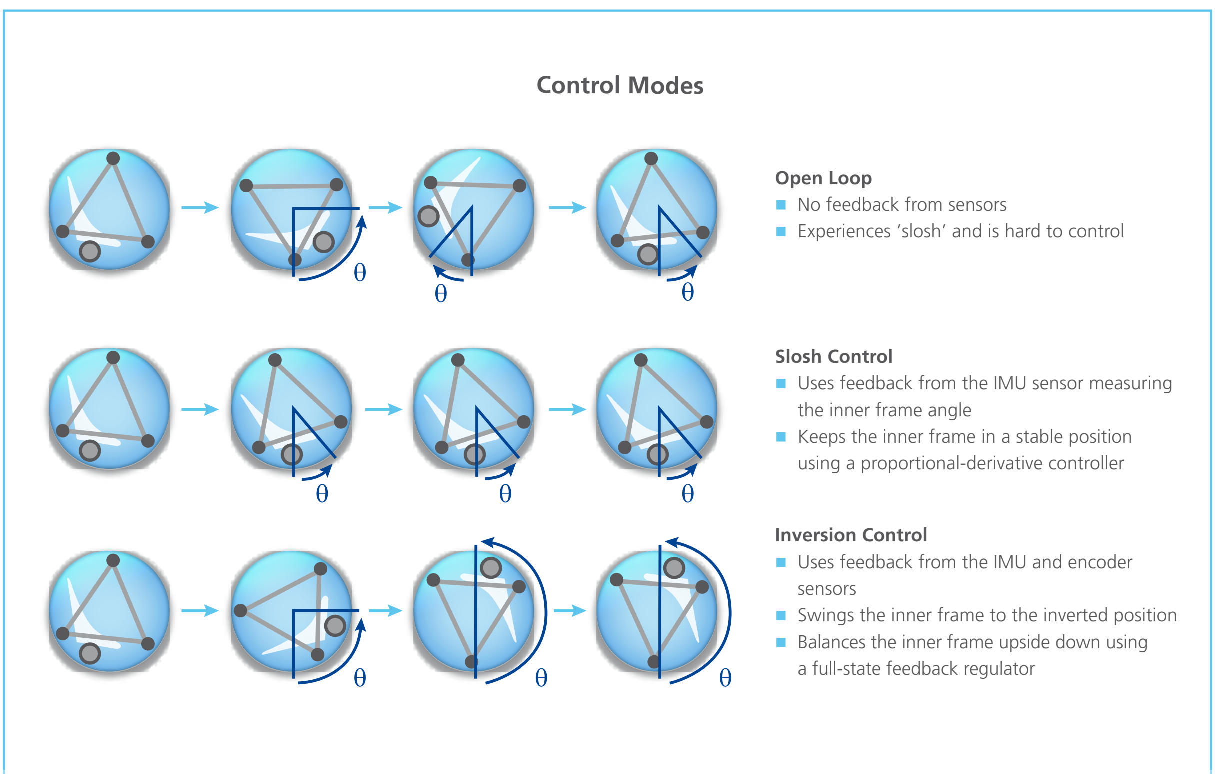
Jack Parsons, Student of The University of Adelaide

is achieved through a reaction torque generated by the eccentricity of the centre of gravity of the inner frame. During operation, diwheels experience slosh (when the inner frame oscillates) and tumbling (also known as gerbiling, when the inner frame completes a revolution). This can make driving the vehicle extremely difficult and has impeded the development and commercial success of diwheels in the past.

The Inner Frame and the Outer Rolling Wheels

The outer wheels are rolled and welded stainless steel tubes with a rubber strip bonded to the outer rolling surface. The driver, who is held in place by a five-point harness, is supported by the inner frame which runs on the outer wheels. The outer wheels have three nylon idler wheels each and are coupled to the inner frame by suspension arms, which act to provide some suspension and also maintain a constant contact force between the idlers and the wheel.

Figure 2: Schematic illustrating different control modes: Open Loop, Slosh Control and Swing-up/Inversion Control.



> "We often get asked why build it? Why build a roller coaster? 'Cause it's fun! Apart from the incredible exhilaration of driving EDWARD, there are some serious pedagogical reasons to build such a device. It teaches engineering students about modern system design and control techniques – the very methods they will use when working as graduate engineers."

Dr. Ben Cazzolato, Associate Professor of The University of Adelaide

MicroAutoBox-Developed Control Platform

Via sprockets and chain, two 4kW brushed DC motors each drive a small motorcycle drive-wheel which contacts the inner radius of the outer wheel. Thus the vehicle can be driven forwards and backwards using a collective voltage applied to the motors, and yaw is achieved when the motors are differentially driven. The vehicle is drive-by-wire, with the driver controlling the vehicle via a joystick. A mechanical hand brake operates callipers on the drive-wheels for safety in case of electrical failure. There are three sensing systems onboard; an Inertial Measurement Unit (IMU) comprised of a solid state gyroscope for measuring pitch rate, a solid-state DC coupled accelerometer for state estimation of pitch angle and two incremental encoders on each of the two drive-wheels that measure the difference in angular rate between the inner frame and the wheels. A dSPACE MicroAutoBox provides the development and control platform.

A touch screen mounted in front of the driver provides feedback on the states of the vehicle (such as pitch angle, forward speed, battery charge) as well as allowing the driver to change the control modes.

From Simulation to Real-Time Control System

The fully-coupled differential equations of a generic diwheel were derived in order to allow the dynamics of the plant and control system to be simulated in MathWorks' Simulink®. Once the control laws were developed and performed well in simulations, the controller was ported to a dSPACE MicroAutoBox via MathWorks' Real-Time Workshop® for real-time control of the physical system.

Figure 3 illustrates the signal flow for the functional operation of the EDWARD platform, which employs

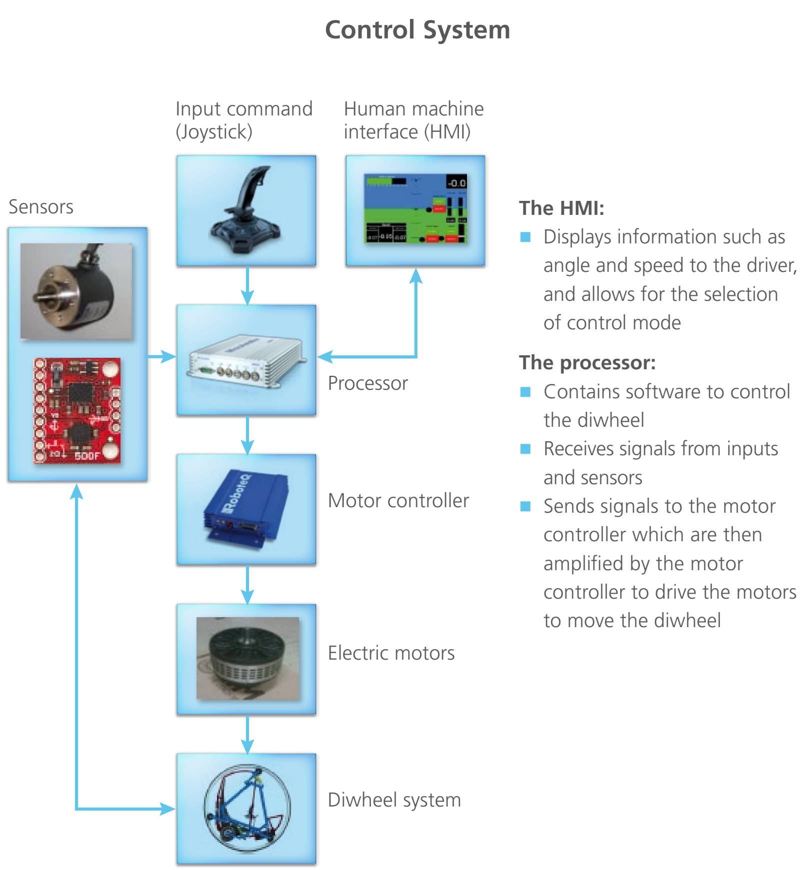


Figure 3: Schematic illustrating the electronic control system and HMI.

drive-by-wire technology and control theory to aid the driver in piloting the vehicle. Such technology prevents the inner frame from rotating (sloshing back and forth) during operation (Figure 2), an inherent property that has limited the drivability of previous diwheels.
And for the thrill seeker, the unique dynamics of the vehicle can be exploited to invert the inner frame, so it is possible for the diwheel to be driven while the driver is upside down (Figure 4).

What About The Future?

The driver can be orientated in any direction, and held in by a racing seat and harness, allowing for intense accelerations of several G's. For the first time a complete mathematical model of a diwheel has been derived, which will enable extreme maneuvers and tricks to be performed at the press of a button. These tricks are to be coded in software by future honors students in 2011. ■

Dr. Ben Cazzolato
The University of Adelaide

Scan here to see the Diwheel in action.

Dr. Ben Cazzolato
Ben Cazzolato is Associate Professor at The University of Adelaide, teaching and researching in the fields of dynamics and control.

Figure 4: Feedback control allows honors student Jack Parsons to drive around upside down.