• GRAPHICAL SYSTEM DESIGN •

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ROBOTICS

Developing a Leg-Wheel Hybrid Mobile Robot Using LabVIEW and CompactRIO

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Products Used
LabVIEW
cRIO-9014
cRIO-9104
NI 9205
NI 9624
NI 9403
NI 9401

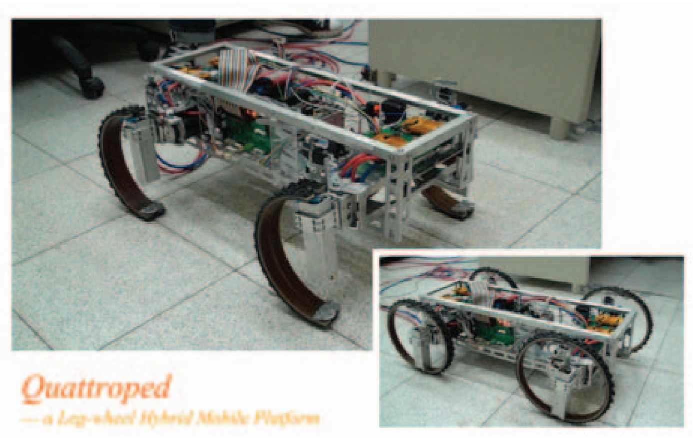

***Figure 1:** Quattroped in Legged and Wheeled Modes*

The Challenge
Developing an energy-efficient leg-wheel hybrid mobile robot that can drive quickly and smoothly on flat terrain and can stably negotiate natural or artificial, uneven terrain.

The Solution
Using NI LabVIEW software and CompactRIO hardware with various I/O modules to rapidly integrate the mechanical design, mechatronics, and programming into a functional robot prototype.

Motivation for the Project
Legs and wheels are two widely adopted methodologies used in ground locomotion platforms. The Bio-Inspired Robotic Laboratory (BioRoLa) team at National Taiwan University aimed to design a leg-wheel hybrid robot that combined the great mobility of wheels on flat ground and legs on rough terrain to provide an adequate mobile platform for general indoor and outdoor travel in both flat and rough environments.

Mechanism Design
Compared to most hybrid platforms, which have separate mechanisms and actuators for wheels and legs, our leg-wheel hybrid mobile robot, Quattroped, uses a "transformation mechanism" that deforms a specific portion of the body to act as a wheel or a leg. From a geometrical point of view, a wheel usually has a circular rim and a rotational axis located at the center of the rim. The rim contacts the ground and the rotational axis connects to the robot body at a point hereafter referred to as the "hip joint." In general, with wheeled locomotion on flat ground, the wheel rotates continuously and the ground-contact point of the wheel is located directly below the hip joint with a fixed distance. In contrast, in legged locomotion the leg moves in a periodic manner and there is no specific geometrical configuration between the hip joint and the ground-contact point; thereby, the relative position of the legs varies frequently and periodically during locomotion.

Based on this observation, shifting the hip joint out of the center of the circular rim and changing the continuous rotation motion to other motion patterns implies the locomotion switches from wheeled mode to legged mode. This motivated us to design a mechanism that directly controls the relative position of the circular rim with respect to the hip joint so it can generate both wheeled and legged motions. Because the circular rim is a 2D object, the most straightforward method to achieve this goal is to add a second degree of freedom (DOF) that can adjust the relative position of the hip joint to the center of the circular rim along the radial direction. The motions of the two DOFs are also orthogonal to each other. In addition, the same set of actuation power can be efficiently used in both wheeled and legged modes.

Mechatronics
The robot's computation is mainly powered by a 400 MHz NI cRIO-9014 real-time embedded control system operating at a loop rate of 1 kHz with an NI cRIO-9104 3M gate field-programmable gate array (FPGA) embedded chassis running at 10 kHz. In the former, the real-time microprocessor communicates to a remote-control PC laptop via standard IEEE 802.11 wireless protocols. In the latter, the FPGA directly connects to NI 9205 and NI 9264 analog I/O modules and NI 9401 and NI 9403 digital I/O modules, which further connect to various sensors and actuators on the robot.

The robot sensors include temperature sensors on the motors and power amplifier chips for health monitoring; voltage and current measurement sensors for power management; Hall effect sensors for leg-wheel configuration calibration; a 6-axis inertial measurement unit (IMU) and a 2-axis inclinometer for body state measurement; and three infrared (IR) distance sensors to measure ground clearance. Various sensors, such as GPS, vision, and laser ranger, are also used to improve the robot's perception ability. Actuators on the robot include eight DC brushed motors for driving the robot, two high-torque RC servos for front leg-wheel turning, and four small RC servos and four small DC brushed motors for leg-wheel switching.

Software
Three computation cores (PC, real time, and FPGA) running LabVIEW 8.6 are responsible for different tasks. A remote-control PC operated by the user exchanges only essential information with the microprocessor of the real-time CompactRIO controller, such as high-level commands to drive the robot in different modes, passing back crucial motor and electronic status for health monitoring and logging state data.

Most computation is executed within the onboard real-time processor. Some algorithms that require high-speed signal exchanges are compiled within the FPGA, such as proportional-integral-derivative (PID) control for the DC motors, encoder readings, and PWM-based RC servo commands. The robot is programmed with various state machines and each state represents one of the robot's particular operating behaviors.

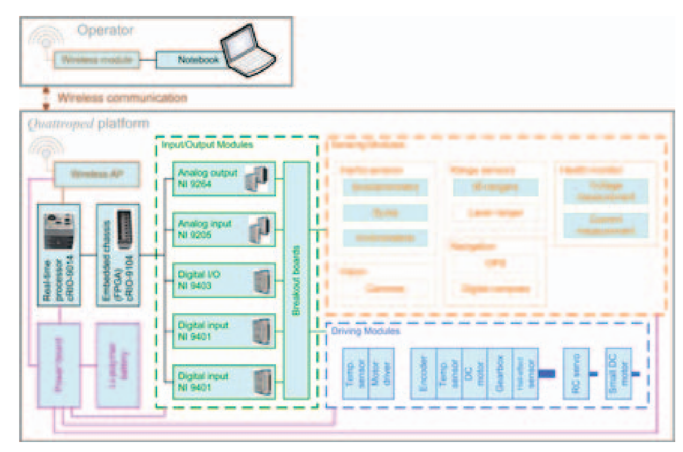

***Figure 2:** Quattroped Platform Architecture*

After the robot is powered on, we must calibrate the motors to define the absolute geometric configurations of the two active DOFs on each leg-wheel with respect to the robot. Calibration is achieved by matching the relative position between Hall effect sensors installed on the body and magnets mounted within the leg-wheel. The calibrated robot can be operated either in legged mode or in wheeled mode, depending on the current rim configurations (that is, wheel or half-circle leg). Otherwise, we can also perform leg-wheel switching to transform the leg-wheel configuration. Three behaviors are provided when the robot is operated in wheeled mode, including standing, driving, and sitting. Standing and sitting are two transient states to bridge the initial on-the-ground configuration and the driving behavior. In the driving behavior, the forward speed and turning rate are continuously adjustable. Similarly, when the robot is operated in legged mode, standing and sitting behaviors are also included for transient states. After the robot stands up, it can perform various behaviors, including walking, trotting, step crossing, bar crossing, and stair climbing.

Benefits of NI Hardware and Software
Robots, in general, are high-DOF complex systems. The successful development of a robot requires time and effort to properly integrate various mechanical, electrical, and computer systems. For the BioRoLa team at National Taiwan University, which is mainly composed of students with mechanical engineering backgrounds, a reliable, modular, easy-to-use, and well-integrated mechatronic system suitable for rapid prototyping played a vital role in the robot development process.

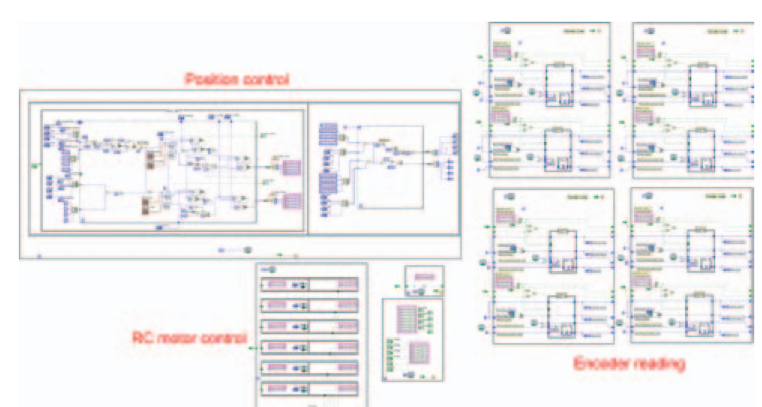

***Figure 3:** Quattroped Control FPGA Block Diagram*

After an extensive survey, we found NI products to be the best solution for our application. The LabVIEW graphical programming interface makes it easy for students to construct logic flow followed by coding and to understand the programs created by other developers. The compact, durable, and modular CompactRIO system is extremely suitable for mobile robot development in academic institutions where the size, weight, performance, and learning time are important factors. Moreover, well-defined integration between LabVIEW and NI hardware significantly reduces the time and efforts of developers in performing system integration.

Future Plans
On the hardware side, we are in the process of integrating various sensors into the current mechatronic system to improve the perception capabilities of the robot. On the behavioral side, we are refining and developing legged behaviors with a closed-loop feature to improve the mobility of the robot on various challenging terrains and to explore dynamic legged gaits.

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