The advantage of dual blade cylinders is that this arrangement creates a wide, open space between the blade's arm structure. The cylinders are placed directly above the two "arms" of the blade, thus creating an open space in the middle. This allows debris to fall through much easier.

With a single, center mounted blade cylinder, the location of the cylinder has a tendency to restrict material from falling through this area. Explains Connor, "It's like holding three fingers out and dumping dirt on top of them. If you were to retract the center finger, material will pass through much easier."

The dual blade arrangement also provides protection for the bottom side of the blade cylinders. If the operator were to lower the blade down in rocky conditions, the blade's "arm" structure will contact the rocks, thus protecting the bottom side of the blade cylinder from damage.

Other improvements

Hydraulic hoses are routed within the width of the arm of the 430 to improve protection from snagging and other damage. This means more reliable operation and more productive up-time.

The 430 excavator is powered by a Kubota 43-hp direct injection, liquid-cooled engine. Compared to the indirect injection engines found on most other compact excavators, this engine is more fuel efficient, starts better in cold weather, and runs cooler, Connor reports.

By using a hydraulically-driven cooling fan instead of a belt-driven unit, Bobcat engineers have been able to install the radiator cooling assembly on the side of the machine, where it can draw in air that is cool and clean. A thermostatically controlled fan matches air flow to the cooling requirements for reduced noise and improved fuel efficiency.

Haptics gets a feel for the job at Georgia Tech

Haptic Backhoe initial trials — with student team leader Joe Frankel — focus on developing heavy equipment interfaces for the "Nintendo Generation."

Haptics is a new, but increasingly important, word in operator interfaces for fluid power. It refers to the feel of the lever, joystick, wheel, or other operator control — the tactile sensations and force felt in response to motion of the device. Although the word is new, haptics itself has always been with us. Spring centering of a lever, detents in a knob or switch, and the feel of a brake pedal or steering wheel are common examples. So why this new word?

The word reflects the new means of providing the feel to the operator. A new generation of input devices is capable of sophisticated programming, to create a feel that not only informs the operator of their input, but the response of the equipment to this input and the relevant environment of the device. If a backhoe operator could be provided with the sensations as if he were using a hand shovel, fewer utilities would be breeched during excavations. Since the feel can be made extremely relevant to the task underway, it is intuitive, less prone to operator mistakes, and requires less mental processing, and consequent, delay in response.

The increased use of electrohydraulics and "X by wire" (where X = drive, brake, dig, operate…) interfaces makes fertile ground for new haptic interfaces. The tactile sensations experienced with old manual operation can be replaced with more relevant tactile queries that are well-suited for operators more accustomed to computer games than machine operation. The trend toward equipment rental by temporary operators further encourages an emphasis on intuitive machine response and haptic feedback.

What sensation will help an operator do a better job? One essential sensation is force that indicates the lag or error between command and response. The needed error signal is readily available if the motion is under feedback control. Virtual constraints on the operator's inputs can assist a forklift operator to pick up loads without collisions. It can assist a backhoe operator to dig a flat-bottomed trench. It can indicate known obstacles (utilities) or unstable configurations of massive booms. To assist with the implementation of virtual sensations, we have new, less expensive sensors and cheap, fast computers connected by digital networks to haptic interfaces and electro-hydraulic actuators. The cost of an error with heavy equipment can be large, and haptic enhancements can help avoid mistakes.

Haptic interfaces have found their way into luxury cars and are under consideration by various equipment manufacturers. Researchers in universities and industry now must demonstrate the practical merit of such controls, so that additional engineering effort and cost can be justified. Exploration of this type captures the imagination of today's students as well, giving fluid power a more progressive image and encouraging students to master both technologies.

Consider four projects underway at Georgia Tech that incorporate fluid devices and haptics: forklift haptic enhancement, backhoe haptic enhancement, digital clay surface haptics, and passive trajectory enhancing robots.

A laboratory version forklift (two degrees of freedom, constrained to a track for safety) was created to educate Georgia Tech students in the dynamics of realistic hydraulic systems. This device, dubbed HAL (hydraulically actuated lifter), has wheel-driven horizontal motion and a cylinder actuated vertical duplex mast. It differs from industrial forklifts in that it uses electrohydraulic servovalves for fluid control. Thus, it can be controlled over the Internet commanded through a haptic interface. For versatility, a commercially available, electrically actuated haptic interface device with good supporting software is used. With proximity sensors at the front of HAL to trigger the feel of a wall, gentle engagement of a load is easy.

Other haptic sensations inform the operator how closely the axes are following the commands, and the proximity of the limits of travel. The operator can command the velocity as conventional or alternatively the position of the axes. MS student Jonathan Beckwith has been systematically evaluating the effectiveness of haptics in comparison to more traditional controls without haptics and with various levels of vision displays. Former students have participated in designing, building, and controlling HAL. Interaction and support from Komatsu Forklift has helped make this a more realistic project.

The **haptic backhoe interface** moves closer to a full-up industrial haptic application. Tech students have also moved out of the laboratory to retrofit a small John Deere 47 backhoe donated by Deere with compatible open-centered proportional valves donated by Sauer Danfoss. Balluff has donated the necessary position sensors, installed by Georgia Hydraulic Cylinders. WIKA and Hydac donations of sensors and other components make the project financially viable when coupled with funds from the National Fluid Power Association, HUSCO, Ford Motor Co. and other companies supporting Georgia Tech's Center for Fluid Power and Motion Control (FPMC).

Prof. Wayne J. Book of the FPMC says, "We use the same user control interface as the fork lift for user interaction through which all four axes of the backhoe will be commanded electronically. However, bucket curl will not generate haptic feedback force for the user. The backhoe project has not used servo valves due to their high cost. We believe haptics can be even more valuable if lower cost components can be used."

Objectives of the research are not only improved operator proficiency, particularly for occasional users, but implementation of methods to avoid damaging utility lines during excavation. Team leader and MS student Joe Frankel has created an excellent Web page if you want to track this project: www.imdl.gatech.edu/jfrankel/

"More exotic combinations of fluid power and haptics are found in our **Digital Clay project**," continues Book. Sponsored by the National Science Foundation, and involving six faculty and up to 20 students, Digital Clay is conceived to be a haptic surface for computer input and display of surface shape and feel. What would be more suited to provide actuation with relatively high forces and moderate speeds and distributed over scores of actuators than fluid power? Pulse width modulation of the current tiny solenoid valves is intended to

HAL, the laboratory forklift imitation, is shown with Ph.D. student Matthew Kontz. Matt and MS student Jonathan Beckwith are documenting the improvements possible with haptic controls.

carry over to MEMS (microelectromechanical systems) valves when the valves, under development, are perfected. Numerous challenges remain to be overcome, but the project has already led to novel kinematic structures, controls, and human interface solutions."

High forces and fairly high velocities are hallmarks of hydraulics, but when applied to exercise machines, they can lead to fearsome safety concerns. Similarly for mechanical surgical assistants, assembly aids, and other devices that the user must come into direct physical contact with. **Passive devices** can provide high forces and high velocities in contact with a human in total safety. However, the human must put in all the energy to move the device. The device only guides and constrains the user's motion to avoid sensed or known obstacles or provide highly safe exercise for training or rehabilitation. The Georgia Tech device is called a PTER: Passive Trajectory Enhancing Robot, and two implementations currently exist.

The fluid used by MS student Matthew Reed for this device is a Magneto Rheological (MR) fluid that can transition from a liquid to a solid with various shear strengths on the application of a magnetic field. The MR fluid serves as a clutch at joints in a mechanism that can selectively nudge the user in the right direction under computer control with impressive success. Tech students are studying its use as a machine control stick for teleoperation as well as a more general haptic display in situations where the safety of operation is most crucial. Again, industry assistance is crucial in the form of funds from FPMC companies and equipment, this time from National Instruments.

In all these projects, the sense of touch addressed by haptics is a more natural and effective way to display the consequences of past motion and encourage appropriate future motions. Universities do not operate in a vacuum, and companies, perhaps yours, can provide a valuable lifeline of equipment, experience, and financial support, whether for fluid power, haptics, or other innovative and inspiring projects that bring students to your industry, as clients and as prospective employees. Either individually or through the NFPA's educational and research initiatives, you can help give university students, undergraduate and graduate, a feel for your industry and perhaps a future job. And with haptic operator controls, the phrase "get a feel for the job" may have an entirely new meaning.

For more information, contact Prof. Wayne Book, Georgia Tech's HUSCO/Ramirez Chair of Fluid Power and Motion Control, at (404) 894-3247 or wayne.book@me.gatech.edu.

Circle **XXX**