

# HAPTICALLY ENHANCED ROBOTIC EXCAVATOR

a.k.a. "HEnRE"

Modeling, Design, and Construction

by Joe Frankel



and

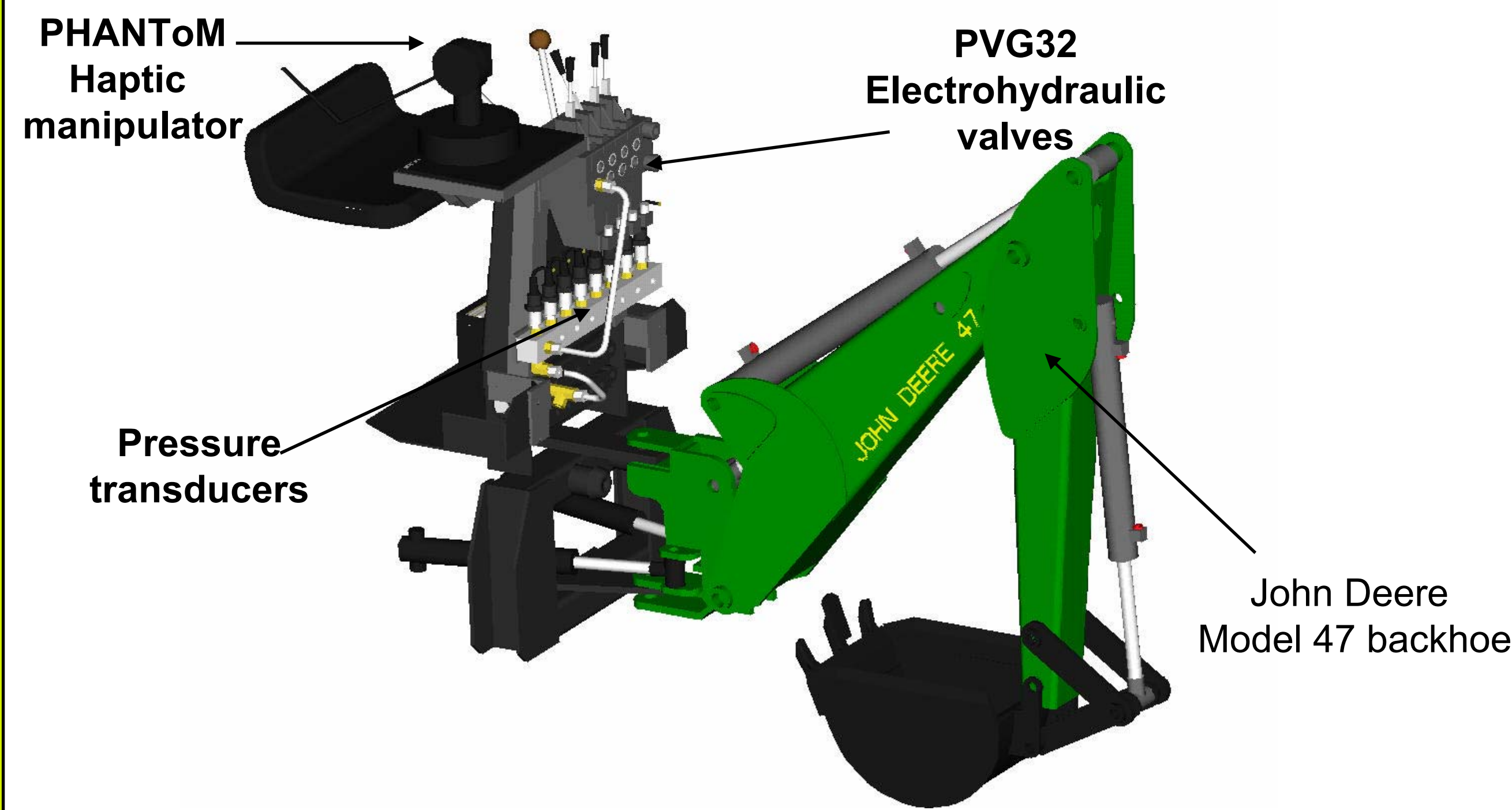
Matt Kontz



Haptic backhoe under construction

## Project Goal:

Develop a testbed for haptic control algorithms on a John Deere model 47 backhoe



## Modeling

Valve model

$$\frac{Q(s)}{U_s(s)} = \frac{Kp_1\omega_n^2 e^{-T_d s}}{(s+p_1)(s^2+2\zeta\omega_n s+\omega_n^2)}$$

Oil, hose, and cylinder compliance:

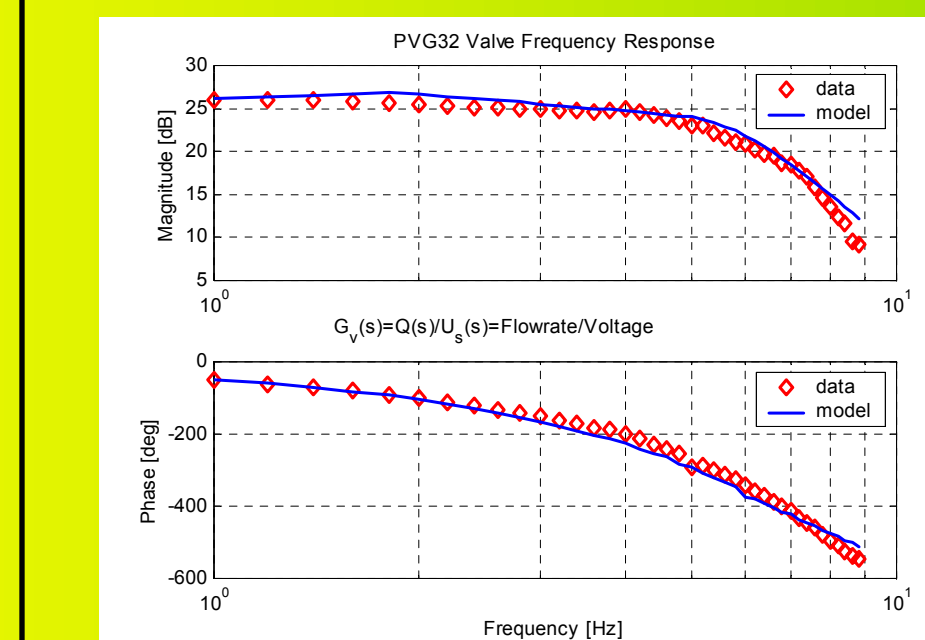
$$p_c = \frac{\int Q_c dt - \int Q_{rc} dt - (y_c - y_c(0))A_c}{C_c} + p_c(0)$$

Kinematic transforms between vector spaces

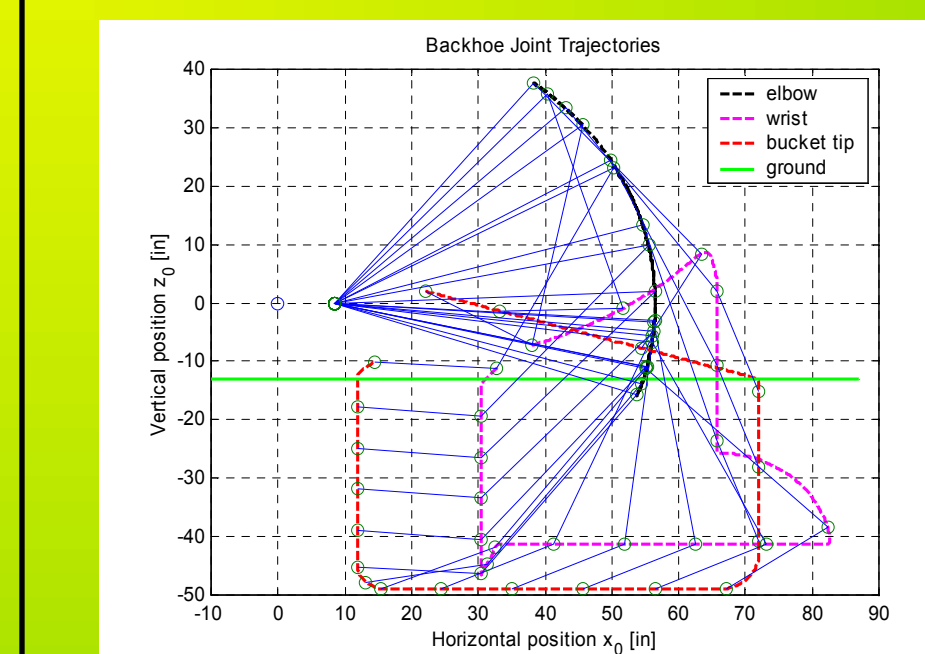
$$y_c = \begin{bmatrix} y_{c1} \\ y_{c2} \\ y_{c3} \\ y_{c4} \\ y_{c5} \end{bmatrix} \text{ Cylinder space} \quad \theta = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \end{bmatrix} \text{ Joint space} \quad y_b = \begin{bmatrix} x_b \\ y_b \\ z_b \end{bmatrix} \text{ Cartesian space}$$

Backhoe dynamics

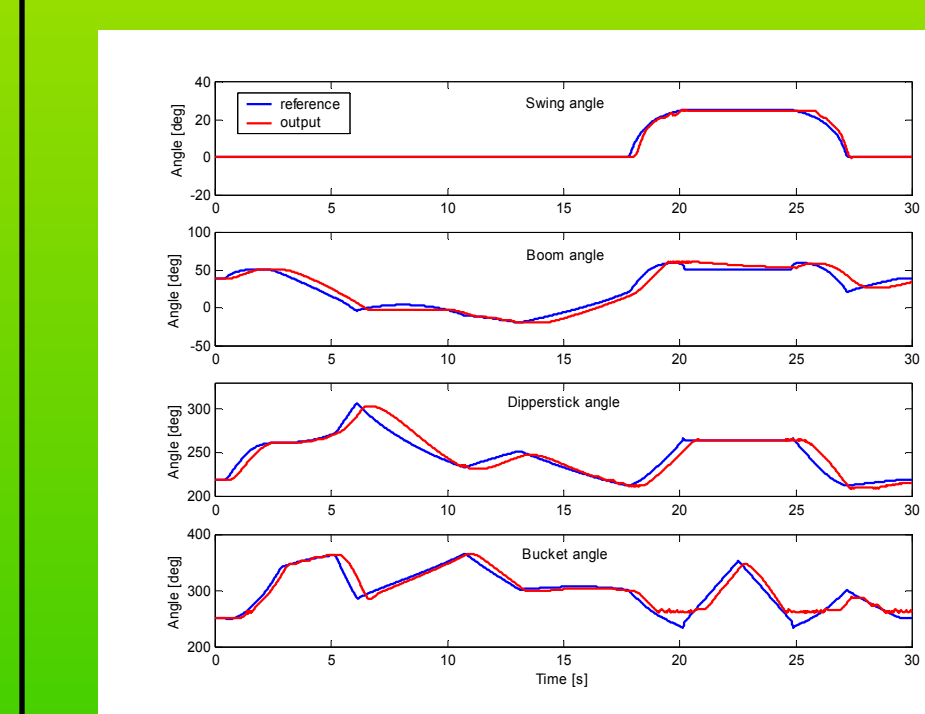
$$M(\theta)\ddot{\theta} + V(\theta, \dot{\theta}) + G(\theta) = \tau$$



Valve system identification



Trenching simulation



Joint angle tracking

Potential algorithms to explore:

1. Position / position control
2. Position / rate control
3. Position / force control
4. Force / force control
5. Impedance control
6. Optimal control
7. Input shaping
8. Gain scheduling
9. Kalman filtering
10. many more...



## Sponsors

Special thanks go out to the many generous sponsors of this project:

**The John Deere Company**

tractor & backhoe

**Sauer-Danfoss**

EH valves

**Balluff**

position sensors

**Georgia Hydraulic Cylinders**

cylinders

**Wika**

pressure transducers

**Daman Manifolds**

manifold

**Hydac**

manual valves

**Brennan Industries**

hydraulic fittings

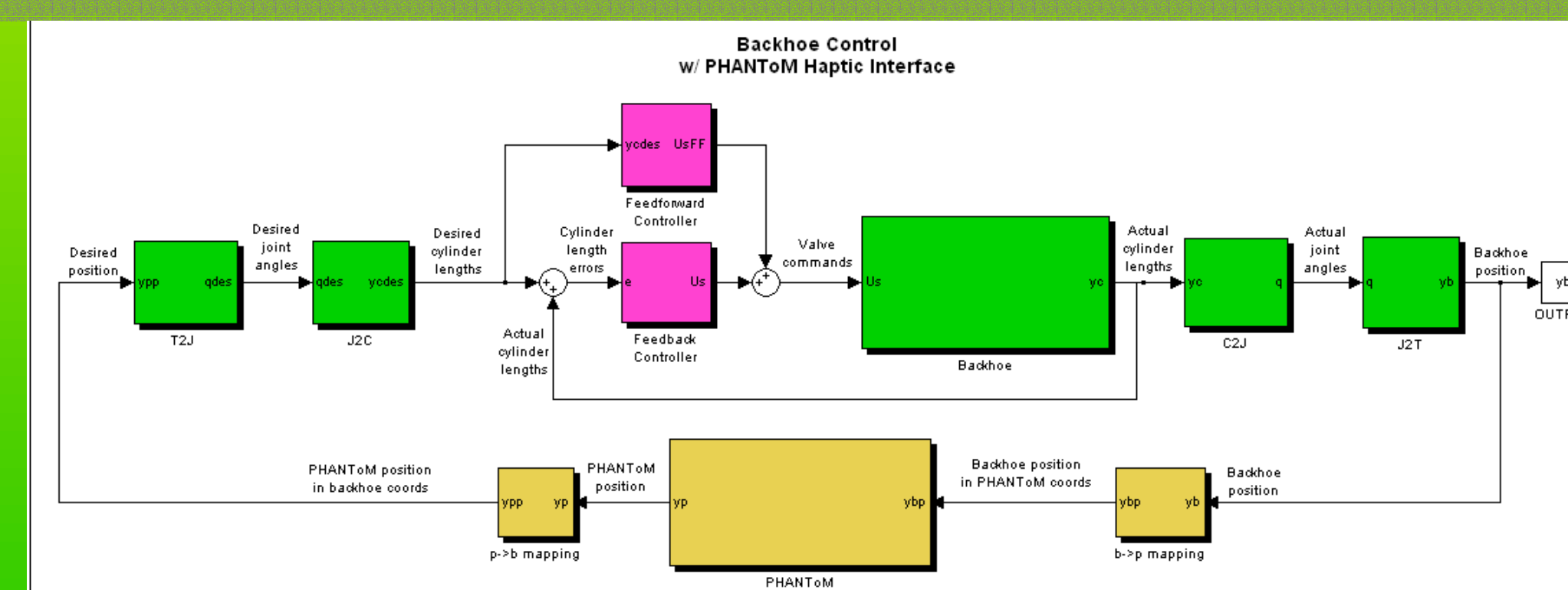
## Abstract

The advent of a new generation of haptic input devices has opened up new possibilities for the fluid power industry. Previously, extensive training and experience have been required before someone can become an effective backhoe operator. It takes time to acquire a "feel" for the non-intuitive lever motions necessary to load a truck or dig a trench efficiently. Even more difficult is the ability to sense the forces experienced between the bucket and the environment due to the lack of force feedback.

However, by replacing the manual controls with a haptic joystick, electrohydraulic valves, and feedback sensors, three significant improvements result over the original system. First, kinematic transformations are handled by a computer so that the operator thinks and works solely in Cartesian space. Second, forces experienced by the end-effector can be displayed to the user's hand via the active nature of the haptic interface. Third, controls can be physically separated from the equipment and teleoperated if desired.

To prove this concept, a haptically operated backhoe has been developed for testing and evaluating haptic control algorithms on hydraulic equipment. The master is the PHANToM 1.0 haptic interface and the slave is a John Deere model 47 backhoe. Control is implemented with host and target computers running Matlab/Simulink/xPC Target. Electrohydraulic valves, pressure sensors, and custom cylinders with integrated position sensors have also been retrofitted to the backhoe.

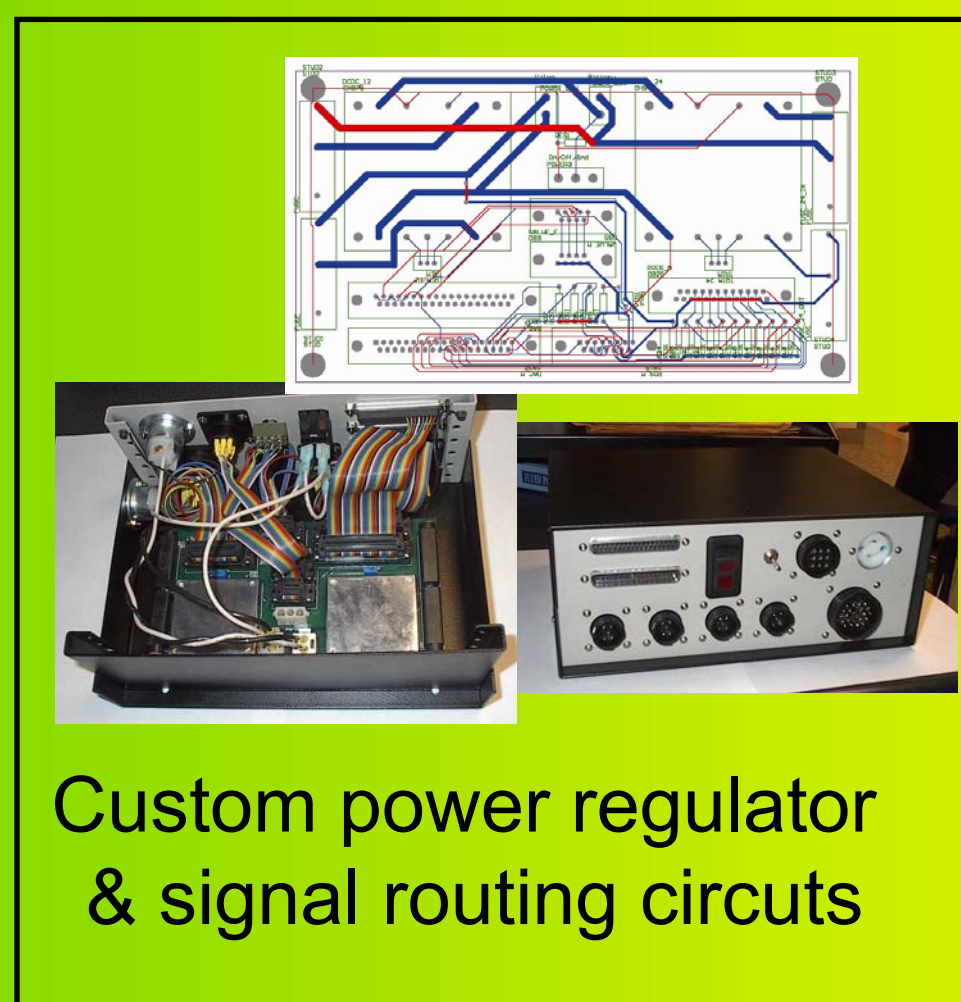
Dubbed the Haptically Enhanced Robotic Excavator (HEnRE), the resulting system is a platform suitable for ongoing haptics-for-hydraulics research.



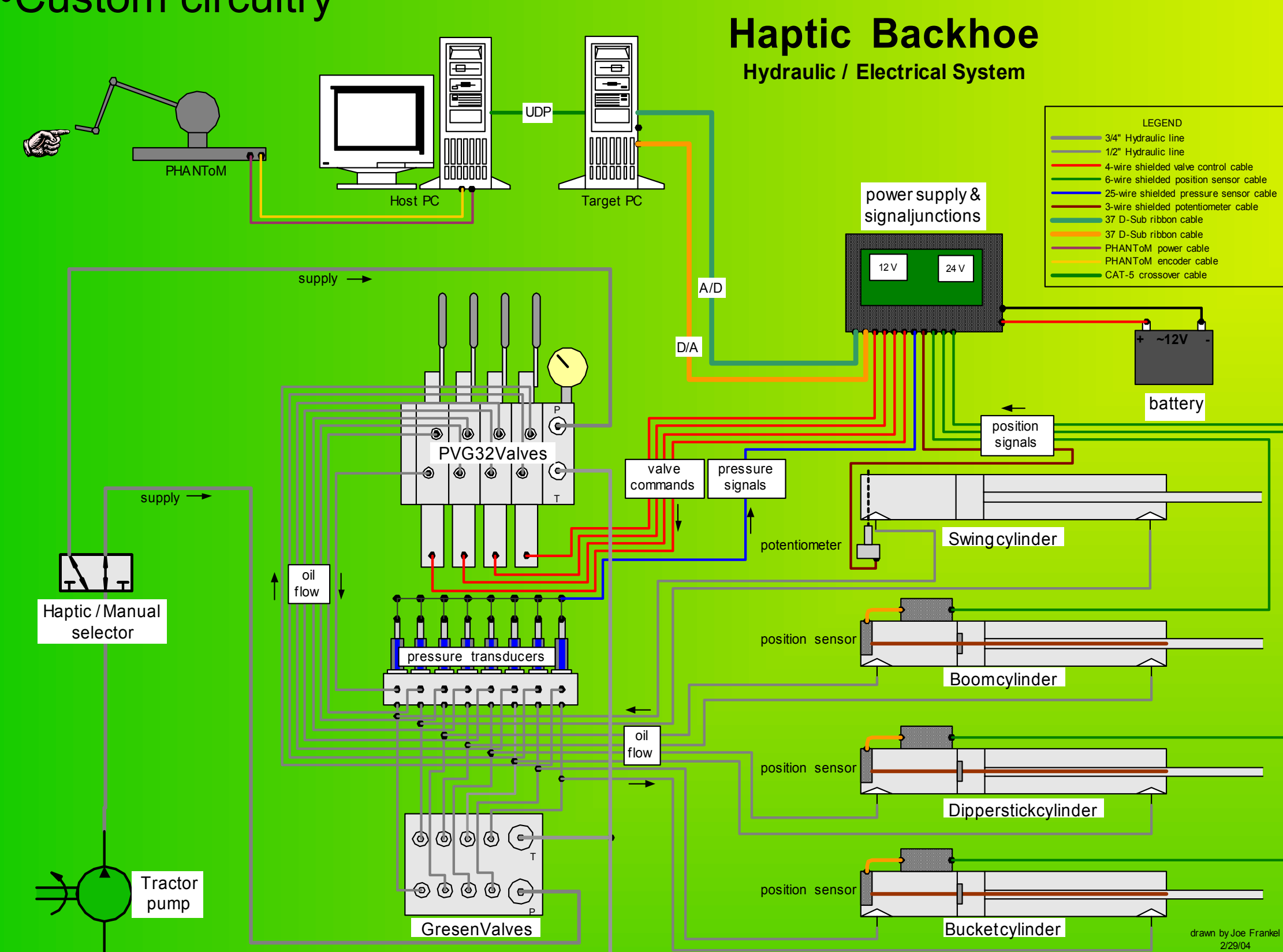
Simulink control software

## Features

- PHANToM haptic interface
- PVG32 EH Proportional Valves
- Magnetostrictive position feedback
- Pressure feedback
- Matlab Host/Target control system
- Custom circuitry



Custom power regulator & signal routing circuits



Electric / Hydraulic system



Intelligent Machine Dynamics Laboratory

Email: [gto389j@mail.gatech.edu](mailto:gto389j@mail.gatech.edu)

website: <http://www.imdl.gatech.edu/jfrankel/backhoe.htm>

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