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DATE: June 3, 2003

TO: The John Deere Company  
Derek Eagles, Scott Hendron, Bob Tyler, Dan Radke, Mark Evans, David Klas, Paul Meyer, David Holm, David Knight, Brian Rauch

FROM: Joe Frankel, Matthew Kontz, Dr. Wayne Book

SUBJECT: **Proposal for development of the Robotic Backhoe with Haptic Display**

Dear Derek, Scott, Bob, Dan, Mark, David, Paul, David, David, and Brian:

Below is our proposed plan for the haptically-controlled backhoe. If you have any input on this project, please respond at your earliest convenience.

**Summary**

The John Deere Company has expressed interest in developing haptic controls for their earthmoving equipment. The overall purpose of the project will be to develop a testbed for evaluating various haptic feedback control schemes as applied to a hydraulic backhoe, to be used as a tool in the development of haptic user interfaces for John Deere.

The project will involve two phases. In the first phase, haptic control will be applied to a single cylinder/degree of freedom on the backhoe, utilizing position feedback from a sensor mounted to the backhoe and controlled by the PHANTOM manipulator. Once the concept has been proven on one cylinder, the project will progress to the second phase, to include feedback and control of all four of the backhoe's links.

## **Project Description**

This proposal outlines the planned development of the Robotic Backhoe with Haptic Display at the Georgia Institute of Technology, Fluid Power and Motion Control Center. This plan has been formulated based upon the meeting at the John Deere Research Center in Dubuque, Iowa on May 29, 2003.

### ***Objectives***

Based upon the meeting, the objectives of the project are:

- Build a testbed for evaluating haptic control techniques of hydraulic backhoes
- Use existing off-the-shelf components
- Use low-cost proportional valves without spool feedback
- Create a virtual spring connection between the haptic joystick and backhoe links
- Start with dipperstick control, then apply to all cylinders later
- Allow for easily adjustable haptic forces
- Test, evaluate, and document the improvements to traditional backhoe control using feedback from expert operators

### ***Valve Selection***

The Parker-Hannifin D1FT Electrohydraulic (EH) Proportional Solenoid valve will be used for the initial setup. This is a 3-position, 4-way, single stage valve with on-board driving electronics, and capable of flows up to 10 gpm and 5000 psi maximum pressure. This is an open-loop valve without spool feedback, quoted at \$760/ea for a 1-2 valve order. More information on this valve can be found in at <http://www.parker.com>. Some of the hookup details have yet to be determined, and an unloading valve may be required to divert flow back to tank while the EH valve is closed.

## *Sensor Selection*

Research thus far has indicated that in the mobile fluid power industry, articulated link position sensing techniques have yet to be perfected. Table 1 summarizes some of the potential position sensing techniques that have been identified, along with their perceived strengths and weaknesses.

Table 1: Position Sensor Type Comparison

Type	Low Cost	Robustness	Accuracy	Resolution	Ease of implementation	Score
<i>String Pot</i>	5	1	3	2	5	<b>16</b>
<i>Linear Pot</i>	3	2	3	3	3	<b>14</b>
<i>Rotary Pot</i>	4	3	3	2	3	<b>15</b>
<i>Magnetostrictive (Temposonics)</i>	5	2	3	3	4	<b>17</b>
<i>Linear LVDT</i>	2	2	4	3	3	<b>14</b>
<i>Hall-effect</i>	3	3	3	3	3	<b>15</b>
<i>2-axis accelerometer</i>	5	5	3	3	2	<b>18</b>
<i>Angle encoder</i>	1	2	5	3	3	<b>14</b>

Since the IMDL at Georgia Tech is already in possession of a suitable magnetostrictive sensor from Temposonics, this sensor will be used for the initial setup of the backhoe. The Temposonics sensor will serve temporarily to generate a feedback signal and should be simple to mount to the dipperstick cylinder. However, it is not robust against impact, vibration, or bending, and a better solution will need to be found as the project evolves.

### *PHASE 1: Single Degree of Freedom Haptic Control*

The initial phase of the project will be to validate the performance of a haptic controller applied to a single degree of freedom on the backhoe. This will require one EH proportional solenoid valve which will be set up to control the dipperstick cylinder, one Temposonics magnetostrictive position sensor mounted to the cap and rod ends of the dipperstick cylinder, the PHANTOM haptic joystick, a control computer, DC power supply, and amplifier.

Figure 1: Single-DOF Haptic Control

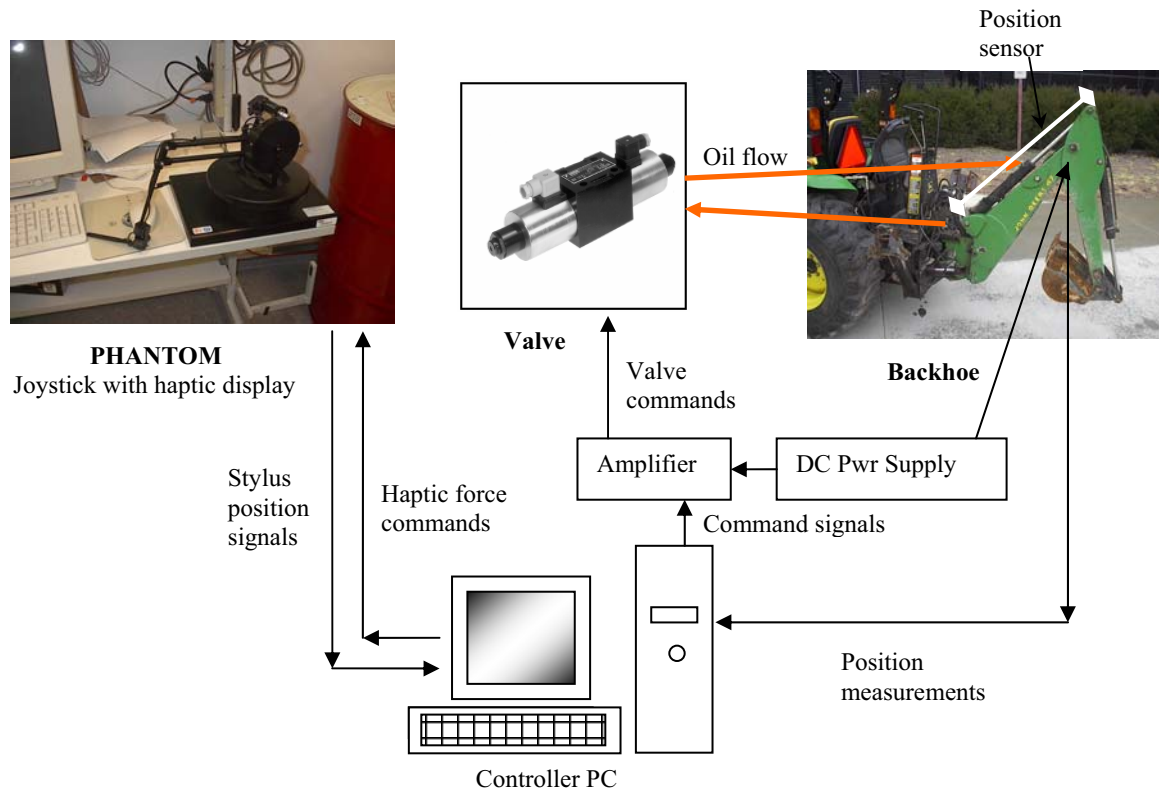


Figure 1 illustrates the proposed single-dof haptic control system for the backhoe. The haptic joystick will be programmed such that an adjustable virtual spring connects the stylus of the joystick with the dipperstick on the backhoe. During Phase 1, the computer, sensor, joystick, and valve will be powered externally and put on a stand not attached to the backhoe other than by hydraulic lines. The valve's supply and return ports will be connected to the backhoe's existing Power Beyond fittings, and the A & B ports of the valve will be spliced into the dipperstick cylinder lines.

Figure 2: Phase 1 Hydraulic Circuit

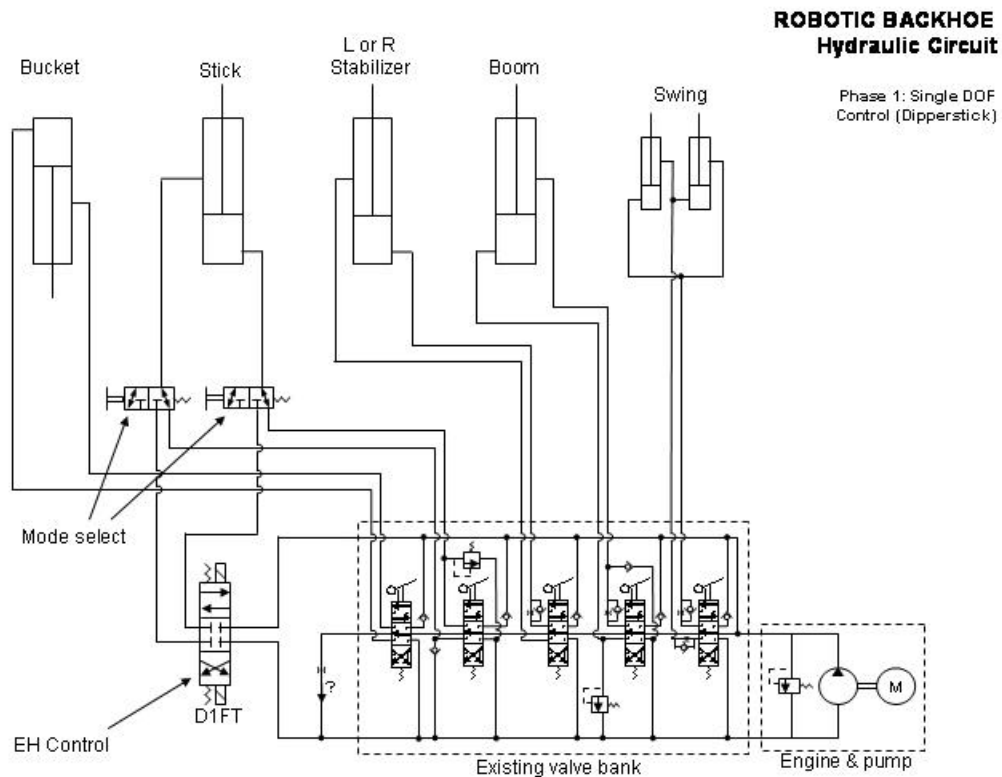


Figure 2 illustrates the proposed hydraulic circuit. This circuit is virtually the same as the stock backhoe, with the addition of the proportional solenoid valve and two 3-way direction control valves connected to the Power Beyond ports and spliced into the dipperstick lines.

The setup illustrated in Figures 1 and 2 will be primarily used for familiarization with the system, verifying valve performance, and developing position sensing techniques. The results of Phase 1 will be used for design decisions before proceeding to Phase 2.

### ***PHASE 2: 4 Degree of Freedom Haptic Control***

Phase 2 will involve adding three additional position sensors and three additional valves to the system, and programming the PHANTOM for control and force feedback in 3-D space. The valves will be installed into a manifold fixture, mounted to the backhoe,

and connected to the Power Beyond supply and return ports. All hydraulic lines between the manifold and cylinders will be spliced into existing lines, preserving the manual control functionality so that demonstrations may be performed operating the backhoe in both manual and robotic modes.

Figure 2: 4 Degree of Freedom Haptic Control

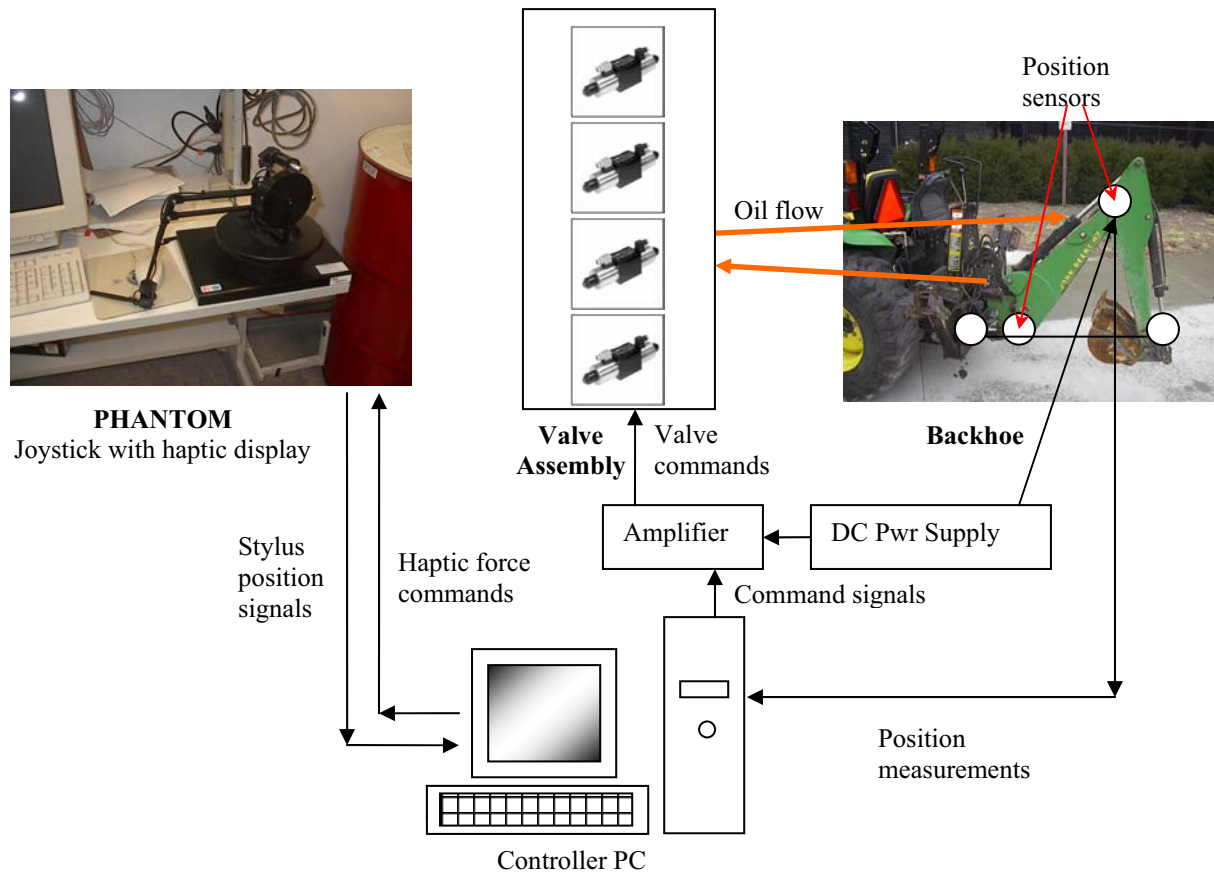


Figure 2 illustrates the main components of the 4-dof haptically controlled backhoe. Once the 4-dof system is assembled and working, the system will be tested for performance evaluation using human subjects, to include expert backhoe operators, intermediate operators, and novices.

Beyond the scope of the current proposal, the project will allow for future exploration as suggested below.

***PHASE 3: Variable Joystick Configurations***

The next step beyond 4-dof control with the PHANTOM may be to explore various joystick configurations. This may include comparing position control versus rate control, or exploring alternatives to the current stylus which is pencil-type, such as a mounting the pivot points above the user's hand or a more typical armrest and pistol grip shape.

***PHASE 4: Upgrade joystick robustness***

It is expected that the PHANTOM haptic joystick will be replaced with a more robust, industrial grade user interface. This may come from either an outside supplier or designed in-house.

***PHASE 5: Connect to on-board electrical system***

The joystick and control computer may be mounted to the tractor and wired into the on-board electrical system.

***PHASE 6: GPS earth referencing***

A GPS receiver may be installed to earth reference the vehicle in conjunction with kinematic positioning of the backhoe relative to the vehicle, for predefined digging contours or underground obstacle avoidance.

***PHASE 7: Remote excavation control***

***PHASE 8: Remote navigation control***

***PHASE 9+: Future work and further modifications will be anticipated***