HYDRAULOBS

Define a task that reconstructs the internal state of a hydraulic actuator from measurements of displacement.

HYDRAULOBS *(<in_displacement>, <in_command>, <model>, <gains>, <out_pipe>)*

Parameters

<in_displacment>
Input data pipe with current measurement of actuator position.
WORD PIPE

<in_command>
Input data pipe with current command level as sent to hydraulic positioning servo.
WORD PIPE

<model>
Vector containing parameters modeling behavior of the actuator.
FLOAT VECTOR

<gains>
Observer gains established in advance by the observer design.
FLOAT VECTOR

<out_pipe>
Output data pipe with multiplexed estimates of actuator state variables.
FLOAT PIPE

Description

The **HYDRAULOBS** command monitors the control input *<in_command>* and the measured position state *<in_displacement>* of a hydraulic actuator. The **HYDRAULOBS** command applies these measurements to a model determined by parameter vector *<model>*, with error correction dynamics tuned by vector *<gains>*, reconstructing the current values of all internal state variables. The updated state estimates are placed into *<out_pipe>*. Sampling rates are fixed at 100 microsecond intervals, that is, 10 kilohertz.

The actuator reference model is a fourth order linearized system described by the differential equation set

$$\begin{bmatrix} \dot{x} \\ \dot{v} \\ \dot{m} \\ \dot{d} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -kx/M & 0 & km/M & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & -1/Td \end{bmatrix} \begin{bmatrix} x \\ v \\ m \\ d \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1/Td \end{bmatrix} u$$

where the four state variables are

x	Displacement distance of piston and attached mass M.
v	Velocity of piston travel.
m	The normalized hydraulic fluid transfer driving the piston displacement.
d	Drive signal after high-gain servo lag.

and u is the input drive signal.

The equation set is completely specified by the following parameters:

kx	Piston displacement coefficient.
km	Fluid transfer coefficient.
M	Intertial loading, including the combined mass of the piston and attached objects.
Td	Time constant of servo-amplifier stage.

The kx parameter represents compressibility, force per unit of travel. It can be measured by valving off the fluid supply sources and observing the displacement of the piston under controlled external force loading applied to the piston. The km parameter represents fluid injection. Given known constant command level u and unconstrained load, servo drive level d will track its input u, and hold the fluid injection at a known constant rate. Given the known constant fluid injection rate, the known kx parameter, and the observed rate of position change over time, the km parameter can be adjusted to balance the velocity derivative at zero. The time constant Td for the servo amplifier can be obtained from manufacturer specifications. The combined mass of the piston and attached load can be measured independently.

In addition to the model equation parameters, there are two signal scaling factors.

x_scale	Scaling factor for A/D converter measurements of displacement.
u_scale	Scaling factor for A/D converter value of command signal.

To convert to physical units, the values from the input signal pipes are divided by the corresponding scaling factors. The *<model>* vector consists of the four model parameters and the two signal scaling parameters in the order described.

The *<gains>* vector specifies four observer tuning variables, established by the observer design to assure reliable convergence of state estimate corrections.

λx	Observer correction coefficient for displacement state.
λv	Observer correction coefficient for travel velocity state.
λm	Observer correction coefficient for fluid displacement state.
λd	Observer correction coefficient for servo drive state.

After incorporating the observer gains into the system model, the observer equations become

$$\begin{bmatrix} \dot{x} \\ \dot{v} \\ \dot{m} \\ \dot{d} \end{bmatrix} = \begin{bmatrix} -\lambda x & 1 & 0 & 0 \\ -\lambda v & 0 & km/M & 0 \\ -\lambda m & 0 & 0 & 1 \\ -\lambda d & 0 & 0 & -1/Td \end{bmatrix} \begin{bmatrix} x \\ v \\ m \\ d \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1/Td \end{bmatrix} u + \begin{bmatrix} \lambda x \\ \lambda v - kx/M \\ \lambda m \\ \lambda d \end{bmatrix} X$$

where the variable X is the measured input value of the piston and load displacement, not the observer estimate.

Warning

Considerable care must be use when applying state estimates from this command in control applications. Be sure to perform many experiments to verify that the state estimates produced by the observer match the actual behaviors of the actuator to an acceptable degree. The cost of being wrong about a gain setting or safety limit could be very high. The observer is based on linearizing assumptions that are broadly true, but given the fact that hydraulic actuators are severely nonlinear systems, a linear model cannot possibly model all actuator behaviors under all operating conditions.

Examples

```
HYDRAULOBS (PX,PU,VPARM,VGAIN,PSTATE)
CONTROL(PSTATE,PU)
```

Read input and output data from pipes `PX` and `PU`, using these values to compute estimates of the current internal states of the actuator based on the device model parameters in vector `VPARM` and the pre-computed observer gains in vector `VGAIN`. Receive the sets of state variable estimates from pipe `PSTATE`. Compute a feedback control signal for driving the actuator position in a custom command using the observed states for the control decision.