HOMEWORK PROJECT 4, Due 5 pm, Wednesday, December 12, 2007

During project 4, you will assess overall functionality of the “degraded” machine with faults of project 3, and the healthy machine of projects 1 and 2. Recall for the degraded machine, ME 392Q students had at least 2 faults, ME 348C students, 1 fault. In this final project, you will assess functionality by estimating the channel capacity for your system, both healthy and degraded, and comparing this to the task that the machine is to do. For this task, the class notes entitled “InfoTheoryDiagnostics.pdf”.

1. Review the healthy machine of projects 1 and 2. Describe the machine and how it works, present the system physics (this could come from project 1 or the proposal), give the most up to date bond graph and state equations, and the measurements of project 2.

2. Review the degraded machine of project 3 with faults. Describe each fault(s), the physics of the fault(s), how these affect or alter transmission of signal through the system (adding noise or changing the system response), and how and why you modeled them as you did. Also supply the degraded machine bond graph model, the state equations, and the data taken during project 3.

3. Produce and present Bode plots or step response data for both healthy and degraded systems, for the simulated and measured system (if you were able to measure Bode plots). Make clear what were the inputs and outputs for these plots.

4. Calculate the channel capacity

\[
C = \int_{0}^{W} \log\left(1 + \frac{S(f)}{N(f)}\right) df
= \int_{0}^{W} \log\left(\frac{S(f) + N(f)}{N(f)}\right) df
= \int_{0}^{W} \log\left(\frac{S(f)}{N(f)}\right) df
\]

for both healthy and degraded machines. You will probably have to estimate this integral numerically. Upper band frequency \(W\) (hz) you will guess-estimate based on your Bode plots: how high do you need to go before the system has severely attenuated the frequencies, permitting a truncation error on the integral of less than say 1 to 5%? Note that signal power spectral density \(S(f) = |Y(f)|^2\), is the square of the frequency magnitude (which you plotted in decibels in the Bode magnitude plots). The noise power spectral density \(N(f)\) is computed in a similar manner. Note that noise \(n(t) = y(t) - y_i(t)\) is the difference between the signal \(y(t)\) from the (degraded) system and the signal \(y_i(t)\) from the (perfectly healthy) system. This noise could
emanate from parameter changes between the perfectly healthy and degraded systems, or from noise sources chosen to the model specific faults. How do these values compare?

5. For step response data $x(t)$ in the time domain, you will need to estimate $S(f) = |X(f)|^2$ and the noise $N(f)$ in the frequency domain. Note that noise $n(t) = x(t) - x_i(t)$ is the difference between the step response $x(t)$ from the (degraded) system and the step response $x_i(t)$ from the (perfectly healthy) system. You probably calculated $x(t)$ and $x_i(t)$ via numerical simulations. If so, you can produce the fourier transform $X(f)$ of this data with a Fast Fourier Transform (FFT) found in most math packages (Matlab, Mathcad, Maple, Mathematica, etc.). To insure a reliable, smooth FFT in the frequency domain, your simulations in the time domain should have MANY points, which can be had via a short time step in the numerical simulations. Your data must be consistent with the sampling theorem. For most systems, you probably want the time step to be smaller than about $10^{-4}$ seconds.

6. Calculate the rate of information $R = w_o \log \frac{S_i}{N_i}$ or $R = \int_0^{w_o} \log \frac{S(f)}{N_i(f)} df$ for a typical task for your system. Here $S_i$ is the power from the signal produced by the perfectly healthy system, and $N_i$ describes the maximum permissible error, or tolerance. A convenient way to estimate $R$ is to specify a tolerance on the ratio $S_i/N_i$. Most mechanical devices can tolerate large errors (viewed here as noise), with $N_i$ of the order of 10 to 50% of $S_i$. After estimating $R$, compare $R$ to $C$, for both healthy and degraded systems.

Your report should overview the system, its fault(s), present the bond graph models, the data from projects 2 and 3, and then discuss the functionality of the system with respect to items 5 and 6 above.