EE345: Modeling and Simulation

Homework 1

The title of the book for this course is *Discrete-Event System Simulation*, and the focus of the course is going to be on discrete-event and discrete-time systems.

In the 1950s and 1960s, before digital computers were as readily available, as fast, and as inexpensive as they are today, continuous-time system simulations were often performed using analog computers. Systems were modeled with integral and differential equations, using (vacuum tube) operational amplifiers and R-C circuits to create integrators and differentiators. Simulation parameters were often set by adjusting variable resistors, e.g., to set gain or cutoff frequencies. Aircraft, weapon ballistic trajectories, and much of the early US space program navigation simulations were performed on these platforms.

Today, essentially all simulations are discrete-time/discrete-event simulations, despite the fact that most physical systems are really continuous-time.

(1) Identify at least one problem where you think digital, discrete event simulation might not be appropriate and describe why this might be so.

(2) Identify at least one problem where you think analog, continuous-time simulation might not be appropriate and describe why this might be so.

Analog computers suffer from parameter drift over time and temperature. The changing, non-infinite gain of a real op-amp, the variation and imprecision in R-C values, etc., can drastically change the results of a simulation erroneously. In addition, noise in the analog circuits can influence the results of the simulation. Further, with feedback paths in the simulation, oscillation and instability of the simulation can lead to an incorrect modeling of system behavior. Finally, non-linearities in the simulation can cause unexpected results. In addition, real non-linearities in the system performance are hard to model. Dynamic range limitations of analog computations can create difficulties in simulating real systems.

Digital computers do not suffer from most of these problems. However, discrete-time sampling of continuous-time data can lead to problems if the system dynamics change faster than the discrete-time simulation can track. Finite-precision representation of data in a digital computer creates non-linear effects that are not present in analog computers. This can be especially problematic if there are feedback loops in the system implementation. Quantized, sampled, systems can exhibit oscillations, known as “limit-cycles” which are not present in the real system or in an analog, continuous time simulation.

For a complex system, each differential equation, representing a part of the system operation, requires separate hardware, leading to very complicated simulation hardware. The same digital computer CPU can sequentially process separate simulation steps. The high-speed CPU can allow complex simulations to be performed at high speeds, sometimes faster than “real-time.”

Finally, while both simulation techniques can allow observability of the internal operation of the system, recording a large number of continuous-time signals can be cumbersome, and repeatability of a simulation is problematic. A digital, discrete-time simulation can often be replayed from a fixed internal state with all the details of the simulation recorded.

(1) With a sufficiently fine time scale and the precise representation of signal levels that is possible with a high-speed, long word size digital computer, there are few inherently continuous time problems that cannot be adequately simulated on a discrete-time platform. One area where continuous-time analog simulation retains an advantage is for simulation of a simple, low-speed

physical system where system parameters may be physically tied to real user inputs. For instance, a control system for a physical plant process that could be represented as a linear first or second order differential equation could be examined with a simple continuous time simulation. User (or system) actuated potentiometers could be used to adjust simulation parameters, allowing the user to gain immediate insight into system behavior. On the other hand, with increasingly sophisticated graphical user interfaces (e.g., the control knobs and slider controls provided in Matlab® and Simulink®) and powerful I/O (e.g., wave devices, D/A interfaces, etc.), discrete time simulations are beginning to eliminate these advantages.

(2) Continuous-time simulation would generally not be appropriate for a long running, complex simulation with large dynamic range signals. The long run time is likely to exacerbate the drift inherent in analog components. The complexity of the system being simulated is likely to make the analog implemention unwieldy. Finally, a large signal dynamic range is likely to stress signal-to-noise performance of the analog components. Any example that highlights several of these issues would be appropriate. One such example would be the simulation of a high-speed data communications network, e.g., a broadband wireless system. To gain meaningful information about the system performance, we would often want to simulate operations over an extreme range of channel conditions, suggesting the need for a long-running simulation. It is not unusual in such systems to consider signal dynamic ranges of 60 – 90 dB. Finally, with gain control loops, frequency offset tracking loops, and signal timing loops, not to mention the basic demodulation functions, the complexity of the simulation would require realization of a large number of differential equations. In addition, there might be functions in these systems that cannot be directly realized in an analog continuous time simulation: e.g., forward error correction and other forms of channel coding.