Design & Rapid Prototyping of Robust Fault-Tolerant Embedded Control Systems Using Field Programmable Gate Arrays (FPGAs)

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Overview:

The use of rapid prototyping tools such as MATLAB, Simulink, and Xilinx' System Generator becomes increasingly important as the design requirements for real-world real-time embedded systems become more demanding and complex. The ability to quickly and directly realize a control system design as a real-time embedded system greatly facilitates the design process.

Due to the ever increasing complexity of modern control systems, an easily scalable platform is needed for design, prototyping, and built in redundancy. The use of multiple FPGA chips in a control system implementation is investigated.

Motivation & Issues

- Technological Advances (i.e. computing)
- Systems Growing in Complexity
- Move Stringent Performance Specifications
- Operating in Uncertain Environments
  - Spacecraft (i.e. Crew Exploration Vehicles)
  - Robotic Exploration Systems (i.e. Mars Rover)
  - Uninhabited Combat Aerial Vehicles (UCAVs)

Rapid Prototyping Tools

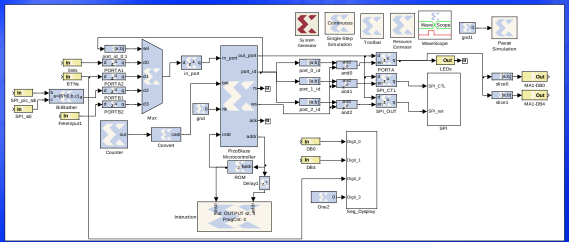
Tools:

- MathWork's MATLAB and Simulink
- Xilinx' System Generator Toolbox
- JTAG configurable FPGA board (Such as the Spartan-3 Starter Board)

Features:

- Ultra high speed
- Parallel execution
- High level Mathworks design tools
- NO VHDL programming
- NO C++ programming
- NO assembly programming

Spartan-3 Starter Board operation with System Generator



Sponsors: NSF, GEM, IBM, WAESO, Microchip Technology, and Xilinx

Problem Statement:

How can we do each of the following;

1. Rapid Prototyping
   - Rapidly implement algorithms?
   - Design algorithms as Real-Time Embedded Systems?
   - Use Systems to make suitable Real-Time decisions (Control Actions) and maintain high performance standards?
2. Scaling Across Multiple FPGA's
   - Accommodate increasingly complex control systems?
   - Easily increase available resources by scaling across multiple FPGA's?

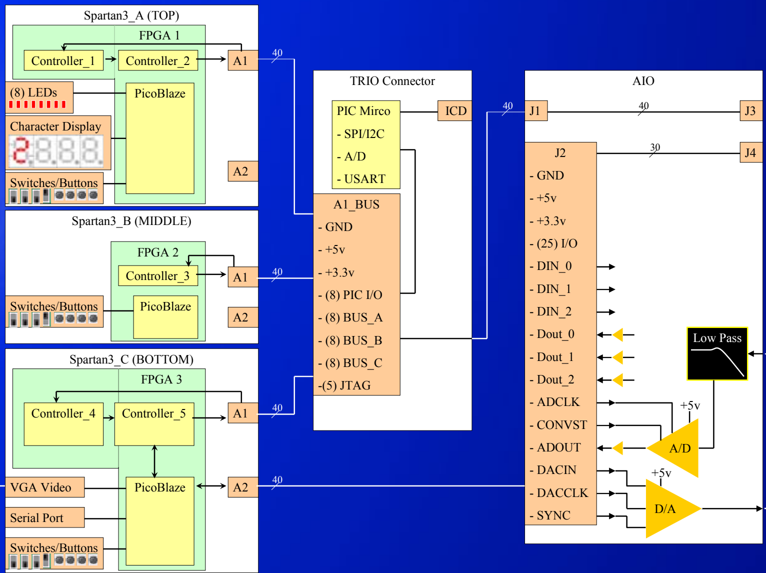
3 FPGA Control System

Three Spartan-3 FPGA development boards are stacked and networked via the Trio interconnect board.

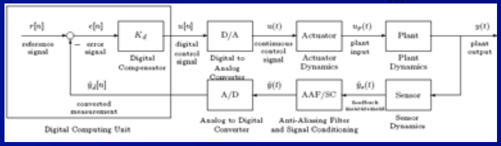
Features:

- 600K system gates
- LED, Button/Switch, VGA and Serial Port User Interface
- Pre-Filtered A/D & D/A Analog Interface
- External PIC Microcontroller

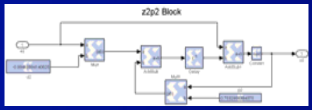
3 FPGA Control System Schematic



Fixed-Rate Sampled Data Negative Feedback System



Simple Example

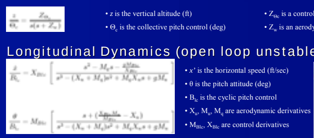


$$K_d(z) = \frac{(1 - Z_z z^{-1})}{(1 - P_z z^{-1})}$$

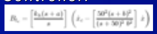
Simple example of a pole – zero transfer function implementation using System Generator

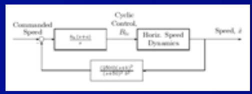
Helicopter Application:

- Model:
  - Vertical Dynamics
  - Longitudinal Dynamics (open loop unstable)

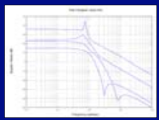


- Controller:





Single Helicopter Horizontal Speed-Hold Controller



Summary and Future Direction

Summary

- Method for Rapid Prototyping Control System Design
- Investigation of scaling across multiple FPGA's

Future Directions

- Further development into a comprehensive design methodology.
- More Complex Robust Fault-Tolerant Control Design Algorithms