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Lab 7: Kalman Filters on FPGAs

ECEN 689-600: FPGA Information Processing Systems
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FPGA Outputs

The terminal outputs for the Kalman filter can be seen in Figure 1. We can observe that as required, the first ten outputs have errors whose absolute values fall within 1.5; specifically, the first 11 filtered data outputs meet the criterion. (Sampling interval of 20 clock cycles is used since 20 states were defined in the code.) The errors notably increase in magnitude with respect to time; this may be due to using the * operator instead of a multiplier module for scalar multiplication. Additionally, how the code responds to new inputs may be inconsistent from the top module.

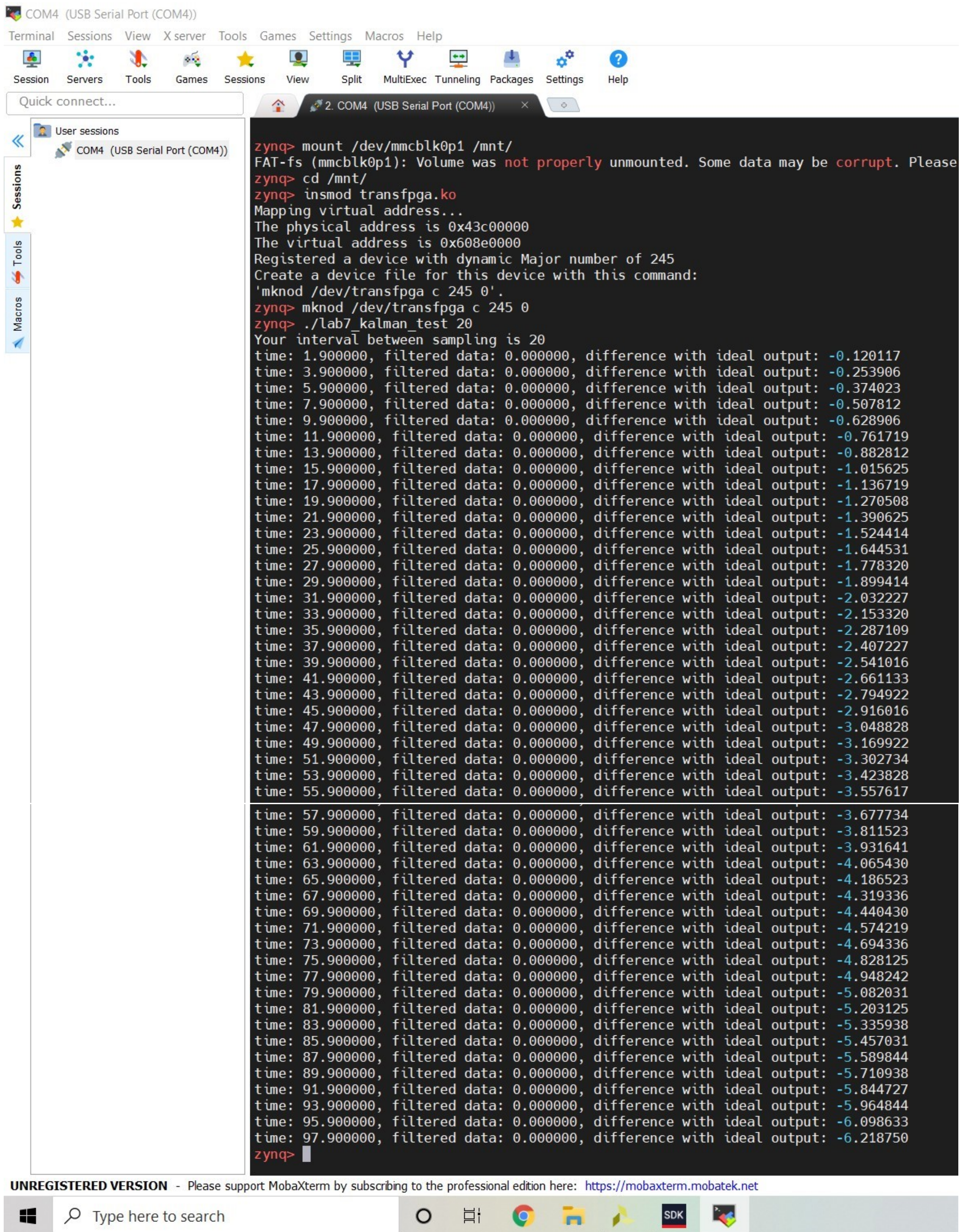
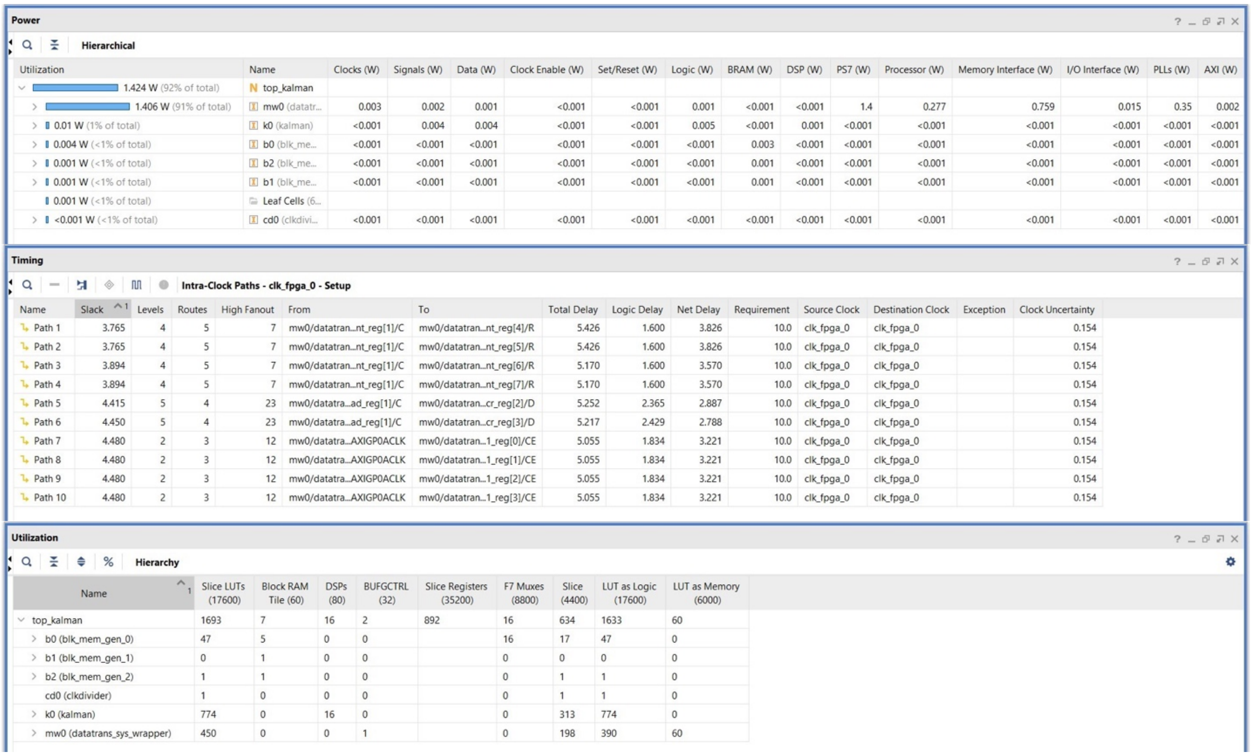


Figure 1. FPGA output for the Kalman filter, with the terminal displaying filtered data and their respective errors.

Implementation Summary

Figure 2 shows the power, timing, and utilization summaries for the implementation of the Kalman filter.



Power — Hierarchical

Utilization	Name	Clocks (W)	Signals (W)	Data (W)	Clock Enable (W)	Set/Reset (W)	Logic (W)	BRAM (W)	DSP (W)	PS7 (W)	Processor (W)	Memory Interface (W)	I/O Interface (W)	PLLs (W)	AXI (W)
1.424 W (92% of total)	top_kalman														
1.406 W (91% of total)	mw0 (datatr...	0.003	0.002	0.001	<0.001	<0.001	0.001	<0.001	<0.001	1.4	0.277	0.759	0.015	0.35	0.002
0.01 W (1% of total)	k0 (kalman)	<0.001	0.004	0.004	<0.001	<0.001	0.005	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
0.004 W (<1% of total)	b0 (blk_me...	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
0.001 W (<1% of total)	b2 (blk_me...	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
0.001 W (<1% of total)	b1 (blk_me...	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
0.001 W (<1% of total)	Leaf Cells (6...														
<0.001 W (<1% of total)	cd0 (clkdivi...	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Timing — Intra-Clock Paths - clk_fpga_0 - Setup

Name	Slack	Levels	Routes	High Fanout	From	To	Total Delay	Logic Delay	Net Delay	Requirement	Source Clock	Destination Clock	Exception	Clock Uncertainty
Path 1	3.765	4	5	7	mw0/datatran...nt_reg[1]/C	mw0/datatran...nt_reg[4]/R	5.426	1.600	3.826	10.0	clk_fpga_0	clk_fpga_0		0.154
Path 2	3.765	4	5	7	mw0/datatran...nt_reg[1]/C	mw0/datatran...nt_reg[5]/R	5.426	1.600	3.826	10.0	clk_fpga_0	clk_fpga_0		0.154
Path 3	3.894	4	5	7	mw0/datatran...nt_reg[1]/C	mw0/datatran...nt_reg[6]/R	5.170	1.600	3.570	10.0	clk_fpga_0	clk_fpga_0		0.154
Path 4	3.894	4	5	7	mw0/datatran...nt_reg[1]/C	mw0/datatran...nt_reg[7]/R	5.170	1.600	3.570	10.0	clk_fpga_0	clk_fpga_0		0.154
Path 5	4.415	5	4	23	mw0/datatra...ad_reg[1]/C	mw0/datatran...cr_reg[2]/D	5.252	2.365	2.887	10.0	clk_fpga_0	clk_fpga_0		0.154
Path 6	4.450	5	4	23	mw0/datatra...ad_reg[1]/C	mw0/datatran...cr_reg[3]/D	5.217	2.429	2.788	10.0	clk_fpga_0	clk_fpga_0		0.154
Path 7	4.480	2	3	12	mw0/datatra...AXIGP0ACLK	mw0/datatran...1_reg[0]/CE	5.055	1.834	3.221	10.0	clk_fpga_0	clk_fpga_0		0.154
Path 8	4.480	2	3	12	mw0/datatra...AXIGP0ACLK	mw0/datatran...1_reg[1]/CE	5.055	1.834	3.221	10.0	clk_fpga_0	clk_fpga_0		0.154
Path 9	4.480	2	3	12	mw0/datatra...AXIGP0ACLK	mw0/datatran...1_reg[2]/CE	5.055	1.834	3.221	10.0	clk_fpga_0	clk_fpga_0		0.154
Path 10	4.480	2	3	12	mw0/datatra...AXIGP0ACLK	mw0/datatran...1_reg[3]/CE	5.055	1.834	3.221	10.0	clk_fpga_0	clk_fpga_0		0.154

Utilization — Hierarchy

Name	Slice LUTs (17600)	Block RAM Tile (60)	DSPs (80)	BUFGCTRL (32)	Slice Registers (35200)	F7 Muxes (8800)	Slice (4400)	LUT as Logic (17600)	LUT as Memory (6000)
top_kalman	1693	7	16	2	892	16	634	1633	60
b0 (blk_mem_gen_0)	47	5	0	0		16	17	47	0
b1 (blk_mem_gen_1)	0	1	0	0		0	0	0	0
b2 (blk_mem_gen_2)	1	1	0	0		0	1	1	0
cd0 (clkdivider)	1	0	0	0		0	1	1	0
k0 (kalman)	774	0	16	0		0	313	774	0
mw0 (datatrans_sys_wrapper)	450	0	0	1		0	198	390	60

Figure 2. Implementation summary for the Kalman filter: power (top), timing (middle), and utilization (bottom).

Questions

1. **What are the factors that affect the performance of a Kalman filter? Why?**

Statistical noise for the state and measurement processes can affect the Kalman gain and thus the performance of the Kalman filter; the noisy values are carried out throughout the prediction and update steps. Therefore, we also need an optimal choice of matrices R and Q. One way to rectify this is to apply some sort of smoothing filter such as a moving average filter or Savitzky-Golay filter before applying the Kalman filter.

Additionally, there may be unmodelled dynamics that are not observable by the model (i.e., the filter cannot distinguish between measurement noise and unmodelled dynamics) but can still be changed by the controller (which in this case is a controller for the vehicle).