IMPLEMENTATION OF KALMAN FILTER USING TDC AND PLL FOR OBJECT DETECTION AND TRACKING IN SIGNAL PROCESSING

[a]Sharat Chandra Jampa, [b]Dr Noor Mahammad SK, [c]Ravindra T
[a]*PG student, Dept. of ECE, Gayatri Vidya Parishad College of Engineering (Autonomous), Visakhapatnam, India*
[b]*Associate professor, Dept. of CSE, IIITDM, Kancheepuram, India*
[c]*Assistant Professor, Dept. of ECE, Gayatri Vidya Parishad College of Engineering (Autonomous), Visakhapatnam, India*
[a]21131d7705@gvpce.ac.in, [b]noor@iiitdm.ac.in, [c]ravindra@gvpce.ac.in

***Abstract*—In GPS receivers, the measurement uncertainty depends on many external factors such as thermal noise, atmospheric effects and slight changes in satellite positions, receiver clock precision, and many more. One of the biggest challenges of tracking and control systems is providing an accurate and precise estimation of the hidden states in the presence of uncertainty. The Kalman Filter is one of the most important and common estimation algorithms. It produces estimates of hidden variables based on inaccurate and uncertain measurements. Also, it predicts the future system state based on past estimations. This research introduces an innovative blend of the Kalman filter with Phase-Locked Loop (PLL) and Time-to-Digital Converter (TDC) techniques, aiming to elevate object detection and tracking capabilities within signal processing. By combining the precision of PLL and TDC methodologies with the predictive nature of the Kalman filter, this approach seeks to significantly improve the accuracy and consistency of localizing and tracking objects. Leveraging PLL's phase coherence maintenance and TDC's precise time measurements complements the Kalman filter's predictive strengths, forming a comprehensive framework for robust object detection and tracking. This blend of methods proposes a promising solution to tackle the challenges in accurately detecting and tracking objects. It offers a practical approach suitable for real- world applications that require precision, reliability, and quick responses. This research establishes a strong starting point for further investigation and practical use, advancing the methodologies for detecting and tracking objects in signal processing.**

***Index Terms*—Kalman Filter, Phase-Locked Loop (PLL), Time-to-Digital Converter (TDC), object detection, tracking, measurement uncertainty, Digital signal Processing.**

I. INTRODUCTION

The filter is named after Rudolf E. Kalman,during the year 1960; he published his famous paper describing a recursive solution for linear filtering problem for discrete data. The first application of kalman filter was in the 1960s in the Apollo mission, and the filter aim was to estimate the trajectory of space craft. Later it is found to be useful for other applications. Kalman filter is an algorithm that takes data inputs from multiple sources and estimates unknown variables, the kalman filter has the advantage of being able to predict unknown values more accurately. It is like a smart filter that takes into account both predictions and measurements to give us a better understanding of what's really happening, even if there's some noise messing things up. It keeps updating its estimate as it gets more data, making it more accurate and reliable. Think of it as a noise-cancelling filter for real-world data.

A. KALMAN FILTER PROCESS

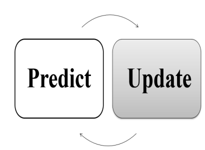

Fig. 1. Kalman filtering

Prediction of range = initial range + initial velocity * time interval

Gain=predicted error/measured error + predicted error

Calculation of current estimation velocity = velocity+ gain *(measured data-new total range/time interval)

II. FUNCTIONAL REQUIREMENTS AND ASSUMPTIONS

TDC(Time-to-Digital Converter) Implementation (Verilog in Vivado), The TDC module should accurately measure the time delay between transmitted and received signals. **PLL (Phase-Locked Loop)** Implementation (Verilog in Vivado), Implement a PLL to synchronize the received signal with the local oscillator. **Radar Formulas (Python)**, Implement radar signal processing algorithms for extracting target information. Output reliable target position and velocity estimates for Kalman filtering. **Kalman Filter Implementation (Python)**, Implement a Kalman filter algorithm for object detection and tracking. The filter should fuse information from TDC, PLL, and radar measurements. **Integration of Modules** between TDC, PLL, radar, and Kalman filter modules. **Graph Plotting (Python)** graphs illustrating the tracked object's position and velocity. **Hardware Assumptions** The hardware platform supports the implementation of Verilog modules in Vivado. **Python Environment** Python environment includes necessary libraries (e.g., NumPy, Matplotlib) for signal processing and graph plotting.

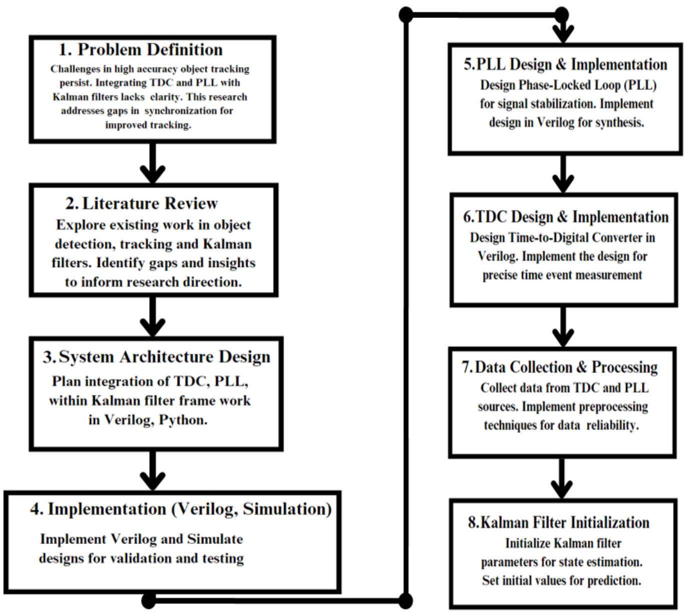

Fig. 2. WORKFLOW OF THE THESIS

III. TIME TO DIGITAL CONVERSION-(TDC)

Counts the number of clock cycles between the leading edge of the TX pulse (Start) and (Stop) reflected pulse. TDC measures the time difference between the two events It uses digital counter to perform the counting operations. The precision depends upon the clock frequency and counter resolution.

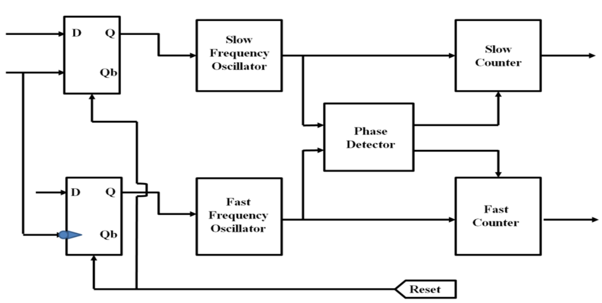

Fig. 3. Block diagram of TDC

IV. PHASE LOCKED LOOP-(PLL)

PLL is a circuit, synchronizing an output signal (generated by an oscillator) with a reference or input signal in the frequency as well as in phase Phase locked loop is mechanism may be implemented as either analog and digital circuits. Both implementations use the same basic structure. Both analog and digital pll circuits include these basic elements: (a) Phase frequency detector (b) Loop filter (c) Digital Controlled Oscillator

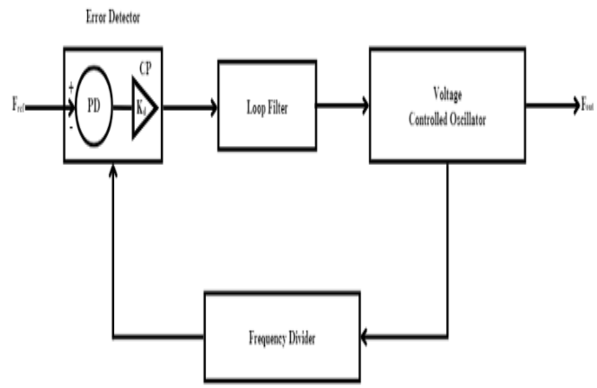

Fig. 4. Analog Phase Locked Loop

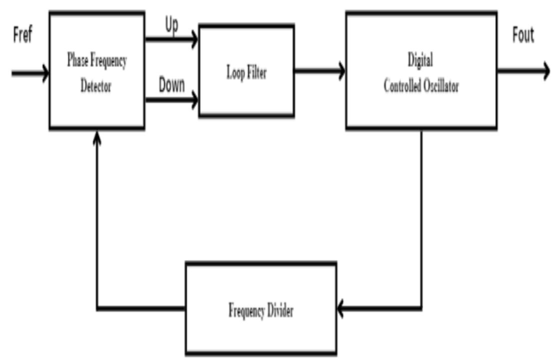

Fig. 5. Digital Phase Locked Loop

V. PHASE FREQUENCY DETECTOR

A phase detector is basically a comparator that compares the input frequency with feedback frequency. The phase detectors receives two digital signals, one from the input, the other from feedback from the output. The loop is locked when these two signals are of the same frequency and have fixed phase difference.

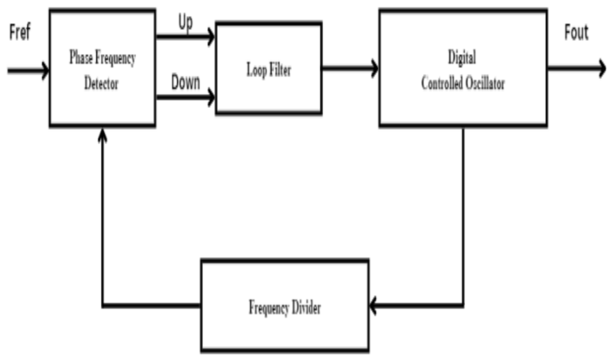

Fig. 6. PHASE FREQUENCY DETECTOR

A. LOOP FILTER

Loop filter is used to remove high frequency components and noise from the output of the phase detector. Loop filter provides a steady dc level voltage which becomes the input of digital controlled oscillator.

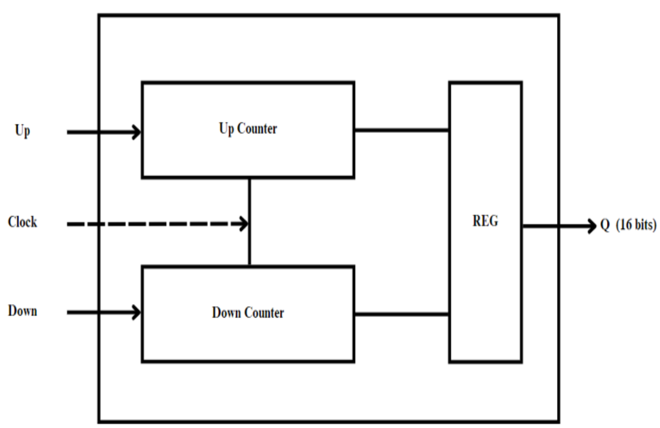

Fig. 7. LOOP FILTER

B. DIGITAL CONTROL OSCILLATOR

Digital control oscillator generates frequency controlled by the input voltage. The dc level output of Loop filter is applied as controlled signal to the digital control oscillator. The digital control oscillator frequency is adjusted till is becomes equal to the frequency of the input signal. During this adjustment the phase locked loop undergoes three stages – free running, capture range, lock range.

C. FREQUENCY DIVIDER

In a Phase-Locked Loop (PLL), a frequency divider is a crucial component that divides the input frequency to generate a lower frequency output signal, which is compared to a reference frequency. This comparison helps the PLL adjust

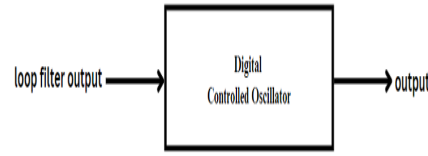

Fig. 8. DIGITAL CONTROL OSCILLATOR

and maintain the output frequency in sync with the reference. The frequency divider essentially allows the PLL to lock onto and synchronize with the input signal.

VI. RESULTS

The working of the proposed design depends on the transmitted signal and the received signal from the object. On the Outlook when the received signal arrives the PLL is used to stabilize the signal to acquire it's frequency giving the velocity of the moving object. Then this synthesized received signal and transmitted signal are given to XOR phase detector where the output is given to TDC for calculating the time difference between the received and transmitted signal. This output is used for range estimation This is the process used for calculating the range and velocity of the moving object

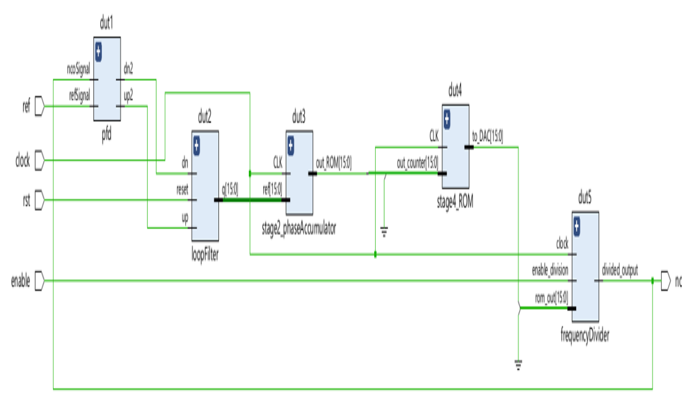

Fig. 9. PLL-TOOL SCHEMATIC

VII. CONCLUSION

In conclusion, our proposed design successfully integrates a Kalman Filter for object detection and tracking, implemented in both Verilog Hardware Description and Python. The Verilog implementation includes a Phase-Locked Loop and a Time-to-Digital Converter, addressing challenges in stabilized frequency generation and precise range calculation. However, limitations arise in Verilog's handling of floating-point operations, necessitating the use of Python for enhanced accuracy. The designed system showcases promising capabilities in object tracking, but further improvements and optimizations are

Fig. 10. PLL-TOOL WAVEFORM

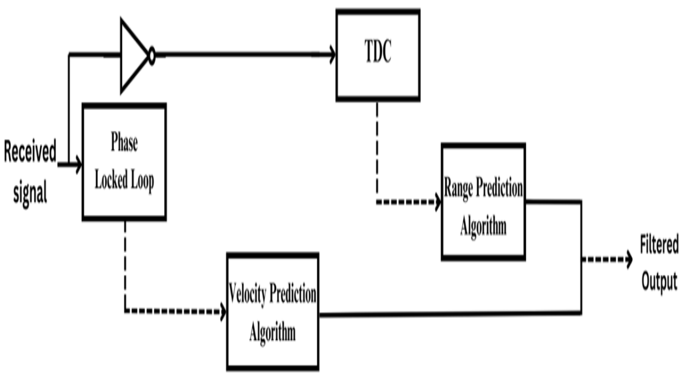

Fig. 11. TDC AND PLL BASED KALMAN FILTER

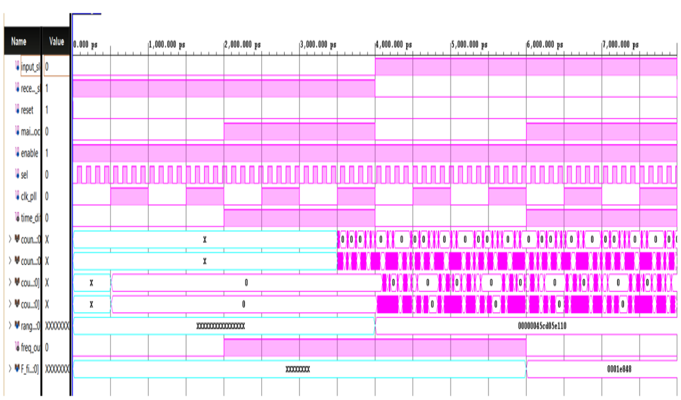

Fig. 12. OBJECT DETECTION AND TRACKING WAVEFORM

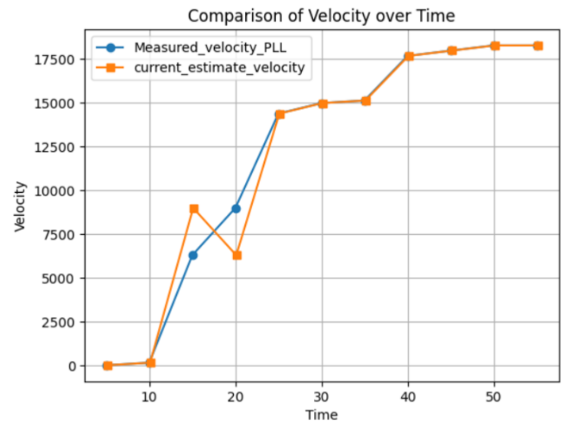

Fig. 13. Graphical representation of Velocity calculation

Input frequency(hz)	Received Frequency(hz)	Measured velocity_PLL(m/s)	Current Estimate velocity (m/s)	Error
50000	50000	0	-1.191	1.191
50000	50000.05	149.8962	148.8235	1.0727
50000	50002.3	6295.642	6294.859	0.783
50000	50003	8993.774	8992.447	1.327
50000	50004.8	14390.04	14388.56	1.48
50000	50005	14989.62	14987.98	1.64
50000	50005.05	15139.52	15136.98	2.54
50000	50005.9	17687.76	17686.88	0.88
50000	50006	17987.55	17986.58	0.97
50000	50006.1	18287.34	18285.5	1.84
50000	50006.1	18287.34	18286.63	0.71

Fig. 14. Measured and current estimate velocity values of the moving object

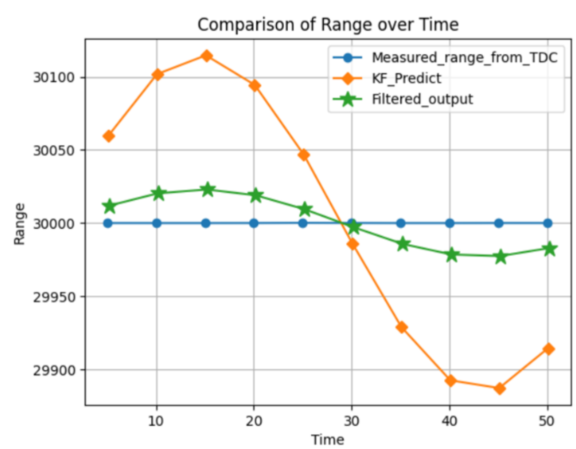

Fig. 15. Graphical Representation of Estimation of Kalman Filter

Time (in seconds)	ΔT value from TDC (ns)	Measured value (in meters)	Predicted value (in meters)	Kalman Filter Estimate value (in meters)
5	20000.01	30000.02	30059.52	30011.903
10	20000	30000	30101.82	30020.3638
15	20000.12	30000	30114.69	30022.962
20	20000.02	30000.03	30094.43	30019.006
25	20000.1	30000.15	30046.93	30009.433
30	20000.04	30000.06	29985.88	29997.176
35	20000	30000	29928.93	29985.786
40	20000	30000	29892.53	29978.542
45	20000.03	30000.05	29887.2	29977.465
50	20000.02	30000.03	29914.48	29982.909

Fig. 16. Measured, Predicted and Kalman Estimated Values

needed to overcome the challenges associated with Verilog's limitations.

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