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mostly in coincident with input data points except those regarded as noise.

In this case the median filter results show better reduction in the volume error from average of 12.3% for raw data to average of 6.4% in processed data. These results are shown in Table 2. The other two NRFs has no significant effect on volume calculation error.

Table 2. Comparison of noise reduction filters on volume calculation accuracy for impulse flow wave

Volume Error (%)	Filtered and non-filtered data			
	raw data	*FIR*	*IIR*	*Median*
Impulse flow wave	12.3(2.1)*	12.1(1.1)	10.9(4.2)	6.4(2.5)

*Mean Value (Standard Deviation)

The same process for finding proper filter for a sinuous wave form was used. Figure 7 shows the result of a sample test for sinuous waveform. As it was seen in impulse wave test results, all three filters are capable of removing faulty peak values. But in this test, there is also another error caused by turbine inertia which happens on downhill segments of curve. On the resting phase of calibration system piston, the turbine does not fully stop because of the blade inertia, which causes another error in volume calculation.

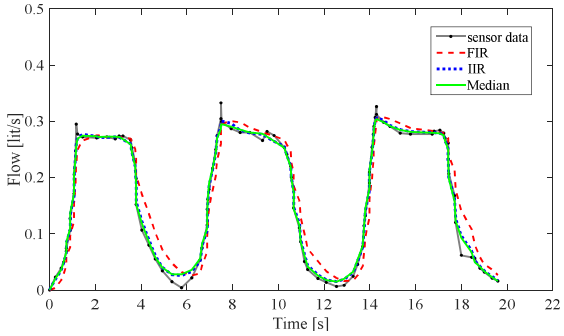

Figure 7. Effect of different NRF on a sinuous waveform

The results of 10 test show that although there are two causes of inertial error in this test, the error values are less than the previous test. This is because the error caused by a sudden flow incensement and peak value error is not as extreme as the one on the impulse wave test.

The results which are shown in Table 3 represent that in comparison to FIR filter that has a negative effect on improving system accuracy, using IIR and Median cause more reduction in volume calculation error and show better overall result.

Table 3. comparison of noise reduction filters on volume calculation accuracy for periodic flow wave

Volume Error (%)	Filtered and non-filtered data			
	raw data	*FIR*	*IIR*	*median*
Impulse flow wave	8.7(3)*	9.2(3.1)	6.9(2.5)	6.6(2.2)

*Mean Value (Standard Deviation)

For the last test the three cases where tested on an almost constant flow. In contrast to two previous tests the piston movement was powered by an electric rotor and a ball-screw system to increase the repeatability of test in comparison to a hand driven piston test.

The result shows that the raw data error for this test is lower in comparison to previous tests, but using noise reduction systems improve the accuracy significantly.

The example of a flow curve on this case and effect of each filter is shown in Figure 8.

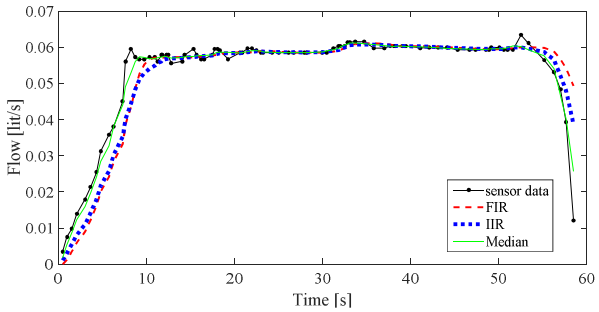

Figure 8. Effect of different NRF on impulsive blow

Volume calculation error for raw data in comparison to filtered data is shown in Table 4.

Table 4. comparison of noise reduction filters on volume calculation accuracy for periodic flow wave

Volume Error (%)	Filtered and non-filtered data			
	raw data	*IIR*	*FIR*	*Median*
Impulse flow wave	5.3(0.6)*	2.8(0.6)	3.1(0.2)	1.6(0.8)

*Mean Value (Standard Deviation)

Three filters show sufficient effect on error reduction for constant flow wave and that's because noisy data points amplitude in this form of flow are not as extreme as other forms of flow, where noises are mostly caused by mechanical and inertial causes and propeller behavior, compared to a constant flow rate where noises are mostly caused by sensing system defects.

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VI. Conclusion

The purpose of this paper was comparing three well-known noise reduction filter systems of FIR, IIR and Median to investigate effectiveness of each one for a flow-based turbine spirometer to improve its accuracy on calculation of lung volumes and reliability of performed Pulmonary Function Tests using this device.

Three modes of flow waves produced by an impulsive, a sinus and a constant movement of the cylinder's piston were investigated separately and the effectiveness of each NRF system was compared to find the most suitable filter to be permanently used on spirometer data processing software. Final results represent that Median filtration system do greater error reduction in comparison with FIR and IIR system in various types of flow patterns.

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