Hardware Acceleration Implementation of Kalman filter with Memristor

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Kalman filter provides a powerful means to perform signal preprocessing on high-dimensional data and has been widely used in many automatic systems. An intelligent robot, as a control system, needs to manage both decisions making and motion control to accomplish various tasks. Previously, many researchers worked on algorithms to achieve these goals. As the tasks are becoming more complex and challenging, the time consuming of running the perception algorithms is increasing. Therefore, the acceleration of motion control computation is needed. Traditionally, in an intelligent robotic system (Figure 1), the analog signal is converted to digital using analog to digital circuits and transported via communication bus. Then the Kalman filter is used as the sensor fusion algorithm and the signal is processed by digital circuits. For example, in the two wheels self-balancing robot using MPU6050 and K60 MCU, it takes about 1.8ms to get the estimated signal, which is too long for a control system and causes instability in certain conditions. Thus, it will limit the performance of the robotic system. Here, we propose to use the memristor based analog signal processing circuit to precisely run the sensor fusion algorithm and motion control. This method enables the parallel computing of the system. Thus, it will shorten the control period and save more time for running high-level perception algorithm.

The electrical characteristics are shown in Figure 2. Al_2O_3 was chosen as the switching layer to achieve linear I-V characteristic. Meanwhile, multiple conductance states (Figure 2b) have been demonstrated using different compliance current during setting process. The device was set to more than 50 conductance levels (more than 5 bits) with DC sweep by controlling the compliance current from 1μA to 110μA.

Here, we analyzed and designed an analog circuit based Kalman filter (Figure 3a). The Kalman gain parameter converges to a certain value after several iterations and this value may vary with different environment or sensors. Therefore, traditional analog circuits with fixed parameters cannot totally solve this problem. However, the memristor, simply as a non-volatile variable resistor, can be implemented in this circuit. And the conductance value can be determined by the optimization method to realize the optimal performance of data processing (Figure 3b). Compared to digital circuits, the above method will significantly accelerate the sensor fusion algorithm, reduce the control time period, separate the motion control algorithm and thus save more computing power to perception algorithm. Meanwhile, the inaccuracy of analog circuits won't affect the control performance because of the robustness of the system in the robotics application.

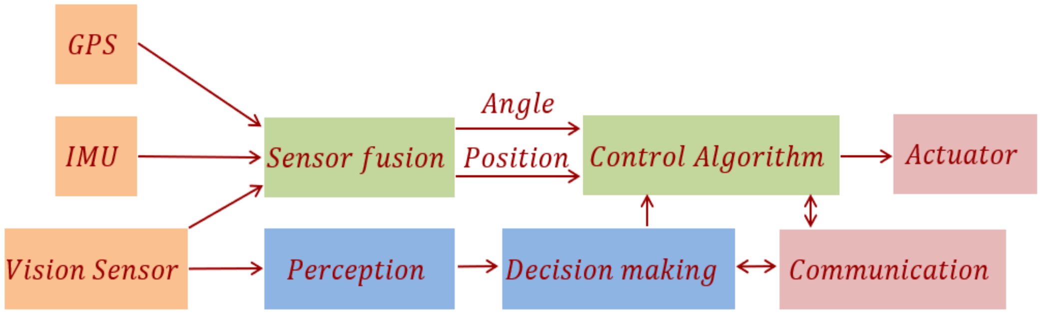

Figure 1: Typical System flowchart of an intelligent robot.

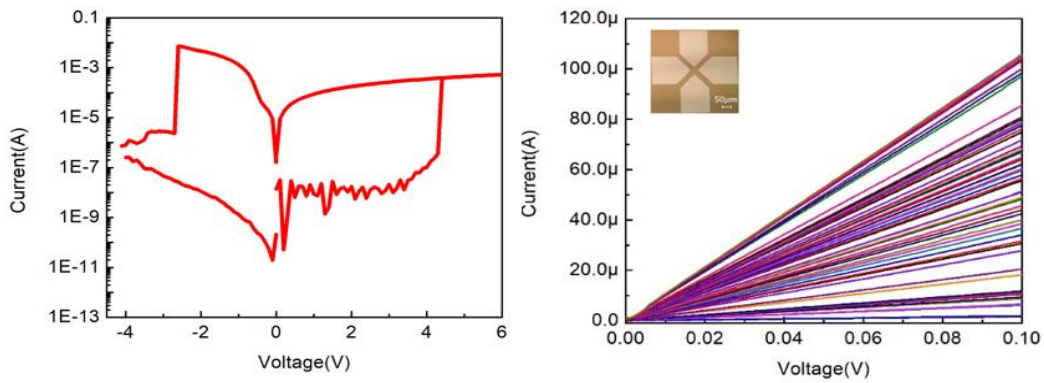

Figure 2: (a)Typical I-V curve memristor. (b)Typical I-V curve of multiple conductance states of single device.

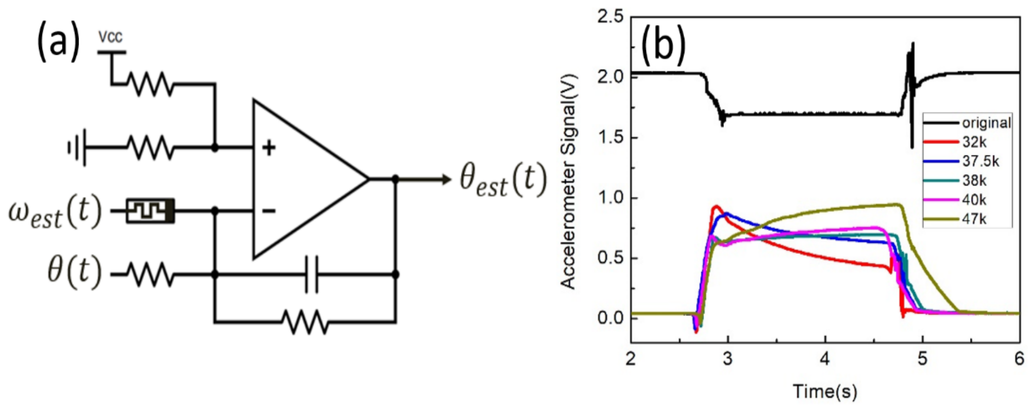

Figure 3: (a)Simplified continuous Kalman filter circuit. (b)Original signal from accelerometer (upper curve) and estimated signal using different Kalman gain values (lower curve). The Kalman gain is at optimal when the memristor is set at 38 kΩ.