Conradt J, Cook M, Berner R, Lichtsteiner P, Douglas RJ, Delbruck T:
Live Demonstration: A Pencil Balancing Robot using a Pair of AER Dynamic Vision Sensors. In ISCAS 2009: 2009:781-785.

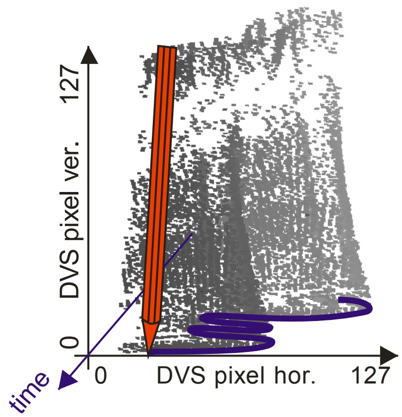

Figure 4. Space-time plot of 54k events (dots) reported from one DVS sensor during balancing in a time window of 640ms. The pencil's base over time and the last tracked position are shown in blue and red. The lower density of events close to the top reflects lower contrast of the pencil's rubber holder in silver-metallic.

Fig. 5 shows recorded control data from our system during 2 seconds of operation. For clarity, we display data of a single dimension only. The top panel shows raw unfiltered data whereas the bottom panel shows the same data processed by a low-pass filter for clarity. The blue trace shows the estimated position of the pencil (X) over time; the red trace a 100-fold amplification of the pencil's slope (α_X). Both these signals are obtained based on spiking visual input only. The green trace shows the desired position of the cart, as computed in section VI. The blue position trace follows the green desired position trace with an average delay of about 50ms. This delay is probably dominant in limiting the possible object length that can be balanced.

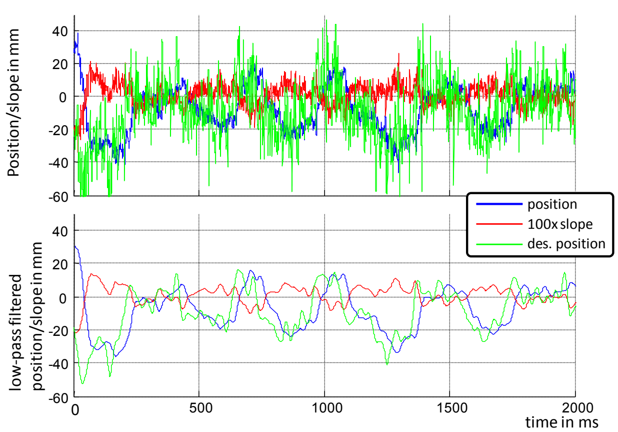

Figure 5. Recorded traces of position, slope and desired position during a 2s time window. Upper graph: raw data; lower graph: same data filtered in 3rd order Butterworth filter (-3dB cutoff frequency set to 30Hz) for clarity.

Fig. 6 is a histogram of X, Y-positions visited by the table during balancing. The plot clearly shows that the cart typically stays close to the center of the table, but occasionally needs much of the available motion space. The center of balancing is shifted relative to the table's origin, indicating an offset between the centers of the two DVS and the center of the table. In fact, we never properly calibrated the visual system with the actuated table.

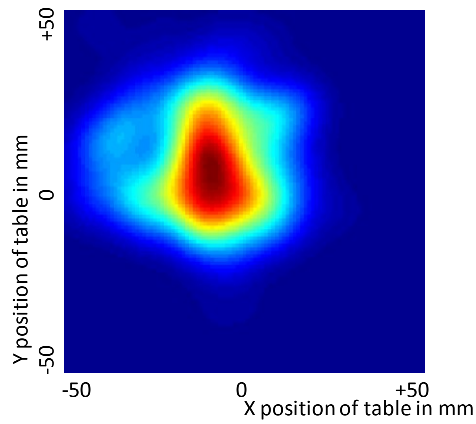

Figure 6. Histogram of relative occurrances of true table positions, red denoting areas often visited.

VIII. Conclusions

This paper describes a balancer demonstration that uses spike-based vision sensors coupled to a standard PC running a standard preemptive OS. The low latency and sparse output of the sensors enable a straightforward solution to this balancing problem, which challenges conventional imaging based systems. A solution to balancing small objects using standard image sensors requires running at >1 KHz frame rate. Even at the relatively low spatial resolution of 128x128 = 16k-pixels of the DVS sensors, image analysis requires processing pixels at a rate of 2·16k·1k=32M pixels/second for data acquisition, which would saturate a USB2.0 hub. Log conversion for temporal contrast extraction and subtraction against stored values to obtain event-like equivalents to the DVS output would require several hundred MIPs of processing before the remaining processing described here. Quantization noise at the low end of the conversion scale would limit low light performance severely, as would the 1ms exposure times, necessitating bright and uniform lighting. The use of AER sensors and event-driven methods for computation has simplified and reduced the cost of implementing this demonstration, and has shown the advantages of the event-driven style of computation used in brains.

Acknowledgment

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