Whirlwind I Hardware Vector Interface

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To connect a Whirlwind I (WWI) machine (emulated or simulated) to a physical CRT not in raster, but in X-Y-Z-mode, a hardware interface supports drawing of vectors. Single points are drawn as zero-length vectors.

The board has a dual 12-Bit D/A converter (MCP 4822) controlled by SPI, and two digital inputs to set the starting point and to draw a (short) vector with a given velocity.

As a vector is drawn by setting the direction and velocity, the destination point is not defined by its absoulte coordinates. Although the analog hardware is quite precise, the vector size is limited to a fraction of the sceen. Thus, long vectors must be composed from shorter ones, as to restart at a known location.

The board can handel two CRT's and lightguns.

The design was inspired by the Vectrex game console, but allows to set a starting point directly.

Design

The interface is essentially an settable integrator for X and Y deflection voltages. The output of the board provides ±2.5V on its (analog) output.

Normal use is as follows:

- Transmit x and y coordinates of the starting point via SPI to the A/D converter
- Strobe the doMOVE signal to set initial values of the integrators
- Transmit x and y values for the speed via SPI
- Strobe the doDRAW signal to draw the vector with the actually set speed

The x and y coordinates are 12 bit values producing an output range of ±2.5V. Thus:

- 2047 is 0V
- 0000 is -2.5V
- 4096 is +2.5V
- 1024 is -1.25V
- 3072 is +1.25V.

The duration of the doMOVE signal must be at least 30µs long to have the initial value settled, due to the output resitance of the op amp of about 100Ω to load the 10nF integration capacitor.

It must be inactive again before the draw signal is used.

While the doDRAW (and the doMOVE) signal is inactive, the integrators are halted, i.e. do not change their current value for seconds. Once the doDRAW signal is active, the current x and y values give the (relative) speed at which the coordinates are changed. These are also 12-Bit values with the same encoding as above, i.e. 2047 is zero, which means no change. The values of 0 and 4095 mean full speed in decreasing and increasing the coordinate voltages.

As the time constant of the integrators is 20kΩ*10nF=200µs, a 400µs strobe with maximum speed input (0 or 4097) would be requied to move from one border to the other one. Shorter vectors could be drawn either by decreasing the speed voltage or strobe time. As the controlling computer may not be able to produce short pulses with e.g. 1µs resolution or accuracy, the MOVE pulse is automatically truncated (internally) to 50µs. Thus, the maximum possible move is a difference of 0.25 in either direction which is 12.5% of the screen width. To draw a line from one border to the other, eight or more moves must be used. It is assumend that normally the controlling computer will generate a 60µs pulse and set the speed to control the length of the vector according to a 50µs move. Note that WWI could only draw vectors of half the length.

Although the interface would allow to chain moves without repositioning the starting point, the time to set the starting point should be invested.

An intensification signal for the electron beam (z-axis) is automatically generated while the integration runs, i.e. during the doDRAW signal, thus truncated to 50µs.

Single point display

In order to show a single point, the starting point is moved to and a vector of zero speed drawn.

Calculating the speed amount

For each dimension, the speed is calculated by the difference of the end and start coordinate.

Using fixed point numbers for coordinates, the middle of the screen is at (0.0, 0.0) and (-1.0, -1.0) is the lower left corner.

Thus, a maximum speed of -1.0 or +1.0 moves the point by 0.25.

In WWI, the vector length is given in upto 31 steps of 2^8 units. To move the point one unit, thus the speed must be 4^{-6} per unit. As the resolution is 11 bit (without sign), the vector length in the range of 0..31 is multiplied by 64 (and added to 2048 finally).

Vector intensities

To draw vectors of uniform intensity, the effective speed in the direction of the movement must be the same for all vectors. Then, the length of the vector is determined by the duration of movement.

This may be one reason that the vectors in WWI are limited in length, so that long vectors — if ever required — are shown as a chain of short ones of uniform intensity.

Drawing circles

Circles should be drawn as short vectors. A number of 60 vectors for a full screen circle is in general visibly satisfying. Multiplying the radius (in the range of 0.0 to 1.0) with 60.0 and truncating the result as integer number of points will speed up small circles. A minimum of 6 points is recommended.

Character display

Character display is currently done in software by drawing those vectors that are intensified; thus it takes upto 0.7ms per character, as a single line uses 30µs + 60µs = 90µs.

Lightgun

The lightgun uses a 3-pin connector with ground, +5V and a single input.

The sensor OPL801-OC can be connected without electronics; the input has a pull-up of 4.7kΩ to 5V.

As the controlling computer might not be quick enough to catch a short pulse, it sets a flipflop which is reset with each new position move.

In order to avoid false triggers if the lightgun is pointed outside the screen, only the starting edge is used to set the flip-flop. Continuous light still generates one signal when beginning, but it is unlikely that the right time window will accidentially be used.

More CRTs

To support two (or more) CRTs and lightguns, the deflection circuits remain the same, as the X and Y signals are common to all.

Two additional GPIO outputs enable the corresponding Z-Signals. The polarity is selected for each on board.

One additional input is required for the second light pen.

Mechanical and electrical hints

The interface is a small board with the following connectors:

Output is a 8-pin connector for the X-, Y- and Z-signals plus a ground pin for each for easier cable connection. The signals are ±2.5V to ground.

Input is wired to 26-pin Raspberry double row pinning for simple connection to the latter; to use an Arduino, a shield providing this connector is recommended.

The SPI interface must use the levels defined by VADC, which is normally either 3.3V or 5.0V. The D/A-converter works from 2.7 to 5.5V, as it has an internal referece of 2.048V. So it may be used with Raspberry Pi boards at 3.3V and also with older design that use 5V logical levels.

The +5V input is used as supply for the internal logic and as reference for the conversion to ±2.5V; the necessary negative supply is generated on board.

The two logic inputs may be any logic; <2V for inactive and >3V for active.

The GPIO Pins used are (besides SPI):

- 17: Move to vector start position
- 22: Draw vector for 50µs
- 23: Enable Z-strobe 1
- 24: Lightgun 1 input
- 25: Lightgun 2 input
- 18: Enable Z strobe 2
- 27: Keyswitch on board

Various

Z-inputs

For some Oszilloscopes with Z-input (e.g. HM 512-2), the signal is assumed to be short negative pulses darkening a (small part) of the signal shown as a time or event marker. As the coupling is via capacitor to the high voltage, a clamp diode is required to determine the default without pulses. This diode is often such that negative pulses reduce the intensity, so that normally the beam is visible. To support positive pulses to show the beam, the diode must be reversed. If a switch is used, check for sufficient voltage withstanding, or use an appropriate relay.

Split power

The current design uses a D/A converter (MCP4821) that runs equally well from 3.3V and 5.0V supplies, including logic, if 1.024±1.024V are selected.

All logic in- and outputs use MOS-FETs (2N7000) that allow both voltage levels.

The analog section uses the output voltage range of the D/A converter, i.e. 0V to 2.048V, with 1.024V as analog reference zero. An output stage converts this to ±2.5V; the required negative supply is provided on board.