Augmented Reality on FPGA

Realtime Object Recognition and Image Processing

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Introduction

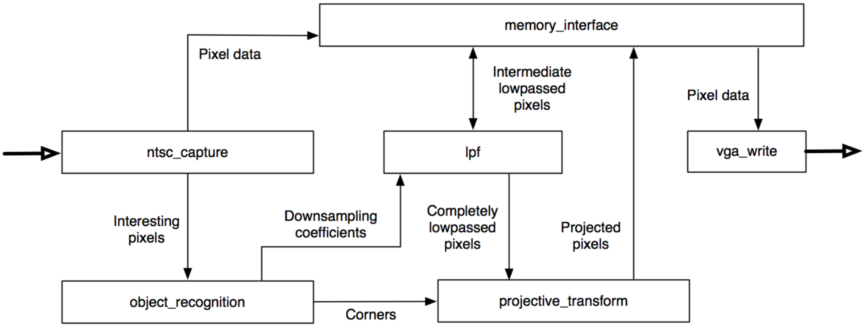
- Overlay a digital image on a physical object in realtime.
- In this case, we want to identify a picture frame in captured video, and output video with another image distorted to fit on top of the picture frame.

Example Image

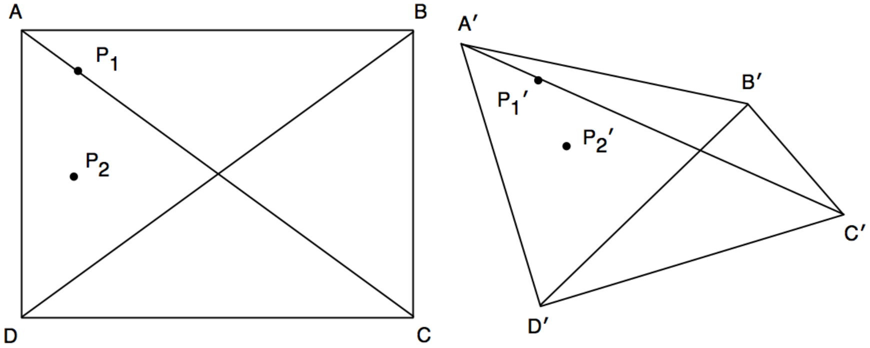
Example Image

Example Image

Top-Level Overview

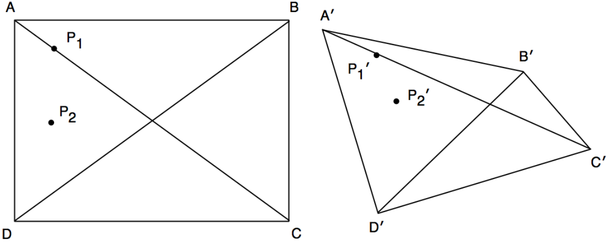


`projective_transform`: Purpose



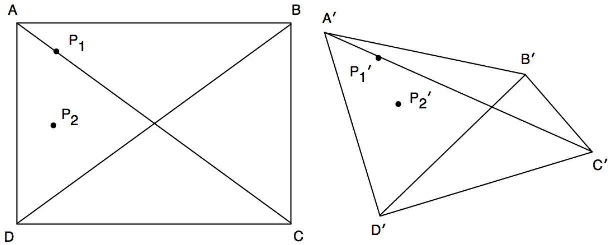
- Skew to any arbitrary convex quadrilateral

`projective_transform`: How the algorithm works



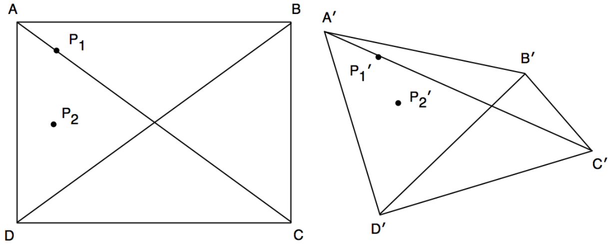
1. Calculate the distance of line $\overline{A\prime D\prime}$ and assign it to d_{ad}.
2. Do the same for $\overline{B\prime C\prime}$ and assign it to d_{bc}.
3. Create two "iterator points," point I_A and I_B initially located at $A\prime$ and $B\prime$.
4. Let $o_x = 0$ and $o_y = 0$
5. Calculate the distance between the iterator points, assign it to d_i.
6. Create a third iterator point, I_C at the location I_A.

`projective_transform`: How the algorithm works



7. Assign the pixel value of I_C to pixel (o_x, o_y) in the original image.
8. Move I_C along line $\overline{I_A I_B}$ by an amount $= \frac{d_i}{width_{original}}$.
9. Increment o_x.
10. Repeat steps 7–9 until $I_C = I_B$.

`projective_transform`: How the algorithm works



11 Move I_A along line $\overline{A\prime D\prime}$ by an amount $= \frac{d_{ad}}{height_{original}}$.

12 Move I_B along line $\overline{B\prime C\prime}$ by an amount $= \frac{d_{bc}}{height_{original}}$.

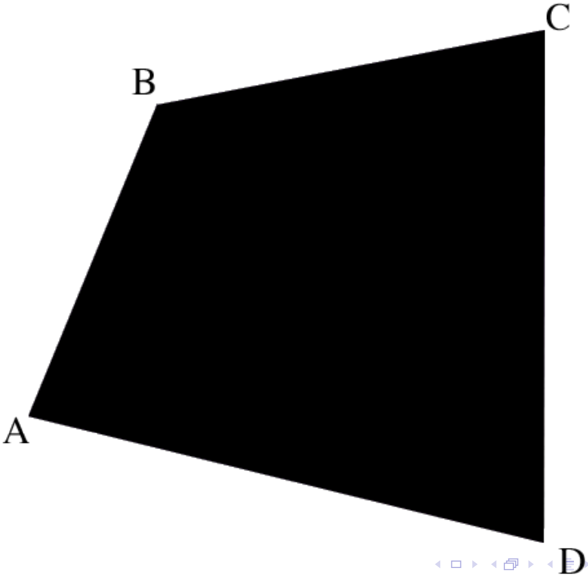
13 Increment o_y.

14 Repeat steps 5–13 until $I_A = D\prime$ and $I_B = C\prime$.

`projective_transform`: Example

Figure: The original image

`projective_transform`: Example



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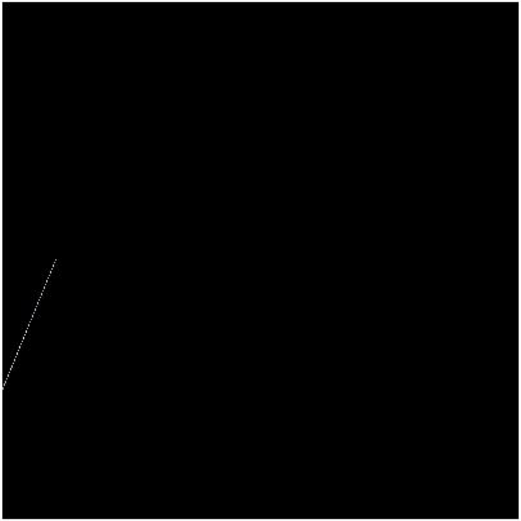

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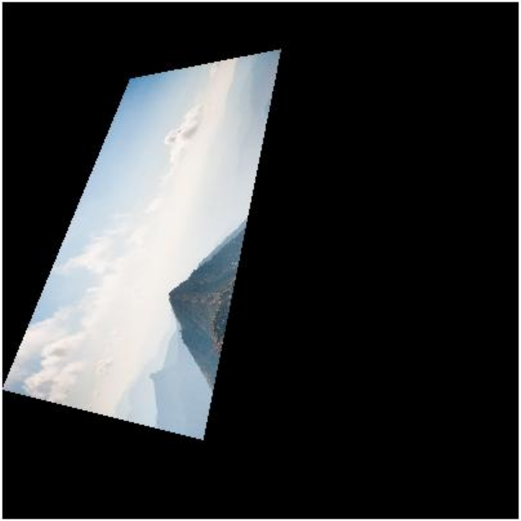
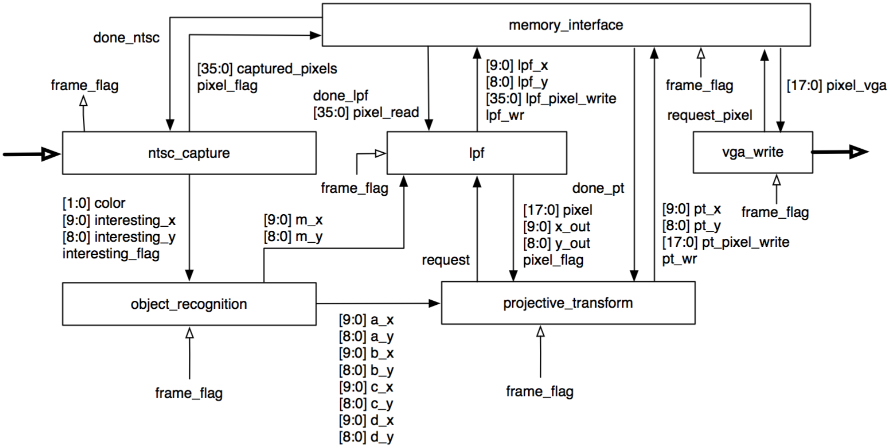


`projective_transform`: Example

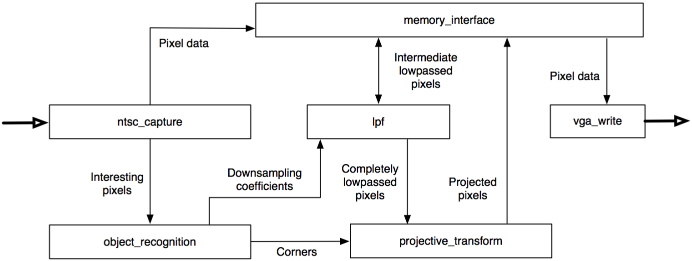
projective_transform: FPGA implementation

- Straightfoward implementation of the above algorithm
- Uses coregen Divider modules for the divisions
- Requires only 2*640*480 + 4*480 multiplications per clock cycle
- Uses an iterative algorithm for finding distances (pipelined at the end of each line of the image)
- Processes pixels “on-the-fly” from LPF
- Negligible memory requirements (a handful of registers)

projective_transform: How it Interfaces



object_recognition



- Mark corners of frame with four differently colored dots.
- Recognition begins in the `ntsc_capture` module, which detects these colors as it is capturing data and sends the pixel info to the `object_recognition` module.

`object_recognition`

- Take linear weighted center of mass for each image
- Sums the (x,y) coordinates for each color as it receives them. (8 running sums, 2 for each color)
- When the frame is done, divide each sum by the number of summed items
- The resulting 4 (x,y) pairs are the corners of the frame
- By looking for pixels in `ntsc_capture` we significantly reduce the amount of time spent in `object_recognition`

LPF: its purpose

- projective_transform → aliasing

graphic showing normal signal

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graphic aliases

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- `projective_transform` → aliasing
- Aliasing reduces the quality of an image

zoom in on aliased pixels

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- Aliasing reduces the quality of an image
- Lowpass filtering prevents aliasing

picture depicting lowpass filter in 2D

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picture of original picture

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picture of other image

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picture of original phase with other's magnitude

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frequency response of Parks-McClellan filter

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- FIR PM filter reduces mem. acceses to 1.5/pixel

LPF: the algorithm

1. Given an arbitrary image & skewing coefficients M_x & M_y.

graphic showing the interface between object_recognition and LPF
image
magnitude fourier plot of image

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magnitude plot of image
magnitude plot of filter with cutoff pi/2

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magnitude plot of filter with cutoff pi/2
magnitude fourier plot of filtered

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4. Fetch a filter with cutoff $\frac{\pi}{M_x}$.

magnitude plot of filtered image

magnitude plot of filter with curoff pi/4

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4. Fetch a filter with cutoff $\frac{\pi}{M_x}$.
5. Filter each row and output to `projective_transform`.

magnitude plot of filtered image
mangitude plot of filter with cutoff pi/5
magnitude plot of output

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2. Fetch a filter with cutoff $\frac{\pi}{M_y}$.
3. Filter each column and store in memory.
4. Fetch a filter with cutoff $\frac{\pi}{M_x}$.
5. Filter each row and output to `projective_transform`.
6. Repeat this process every refresh cycle.

magnitude plot of original
magnitude plot of filter
magnitude plot of output

memory_interface

- 1 image is a lot of data:
  $640 \cdot 480 \cdot 24$ bits ≈ 0.88MiB

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- Let's store store 18 bits per pixel or 2 per address

memory_interface: operation

1

system io: `ntsc_capture`

system io: vga_write

timeline