Image optimization on smartphone based HUD display

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Abstract

Smartphone based HUD display consists a smartphone for display input and a reflector. The input image has two reflections from both sides of the reflector. And these two images are overlaid with relative shift, so the output image is blurry. This paper introduces a new method to reduce blur on smartphone based HUD display. An optical model is set up and a linear model is built to analyze the system.

The method pre-compensates the overlay effect with linear least square solver. The output images w/ optimization look much less blurry than the one w/o optimization.

1. Introduction

HUD display was originally developed for military fighter aircraft. It is a transparent display that allows pilots to read important information without looking down on lower instruments. It was later introduced to commercial aircrafts and nowadays it's more and more popular on luxury vehicles. There are many companies that make low cost alternatives like a small display that projects images to the front shield window. But the image quality is so limited that there are two reflections overlaid together, which is very blurry (Figure 1). So, computational imaging method is being used to pre-compensate the input signals.

Figure 1 Example of blurry images

Ted X [1] developed a full windshield head up display based on emissive projection display technology. The windshield display can form high quality images with UV-Vis excitation. Diaz [2] introduced the HUD blur caused by double reflection from inner and outer surfaces of windshield. And he also briefly discussed a deblurring method that relatively tilted two surfaces can overlay the two virtual images together and reduce blur. Garmin [3] developed some aftermarket HUD unit that uses a reflector that attaches to the inner surface of windshield to avoid double reflection and blur.

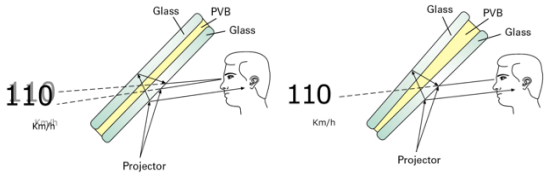

Figure 2 Deblur with relatively tilted surfaces [2]

1.1. Optical model

The double image effect is illustrated in Figure 3. The image displayed on smartphone is reflected at both surfaces of the windsheild glass. And what user sees is a combination of two virtual images with some verticle shift. The following schematic is a simplied model that neglects the depth difference of two virtual images because the depth difference is much smaller than the distance between user and virtual iamges. Also, the windsheild glass is modeled as a flat plate without any curvature.

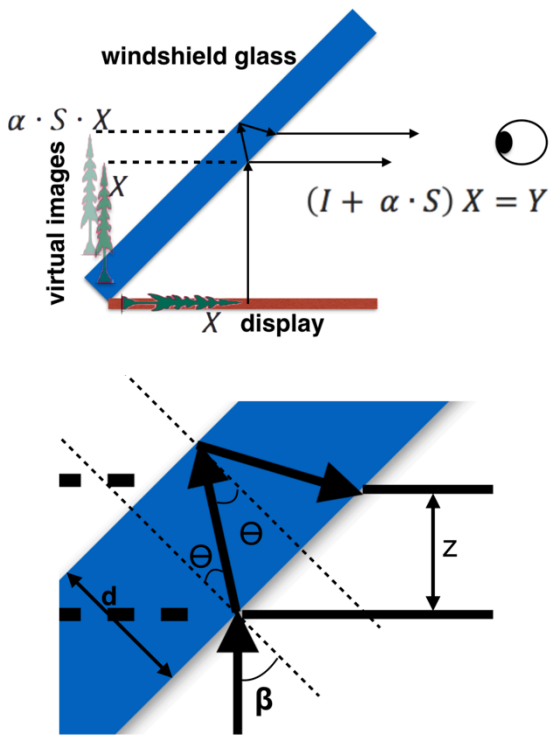

Figure 3 Optical model on double image (top: overview, bottom: zoom in view)

The variables in Figure 3 are as following.

X: Input image from cellphone display
I: Identity matrix
α: Luminance ratio between two virtual images
S: Shift matrix that shift images with z distance
Y: Output image that user receives
z: Relative shift between two virtual images
d: Thickness of windshield
θ: Exit angle
β: Angle between windshield and input display
n: Index of refraction for windshield glass

Based on this model, we can see a blurry image output example with a normal image input (2 mm thick glass), showed as Figure, 4.

1.2. Improve blur by reducing glass thickness

To improve the image quality, we can make the glass thinner to make the image shift z smaller.

Normal human eye's visual acuity is around 1 arc min [4]. So, to make the shift nonvisible at all, the maximum glass thickness can be calculated as following. (Assume distance between user and virtual image is 500 mm)

$$\begin{cases} z \leq 2\times 500\times \tan(1\ arc\ min/2) \\ z = \sqrt{2} d \tan\theta \\ 1\times \sin\beta = n \cdot \sin\theta \end{cases}$$

So, the maximum thickness of glass is:

$$d \leq 0.1924\ mm$$

1.3. Improve blur by pre-compensating input

Obviously the maximum thickness is not practical due to physical strength limit of glass. So, to avoid blurry image, we need to pre-compensate the shift from the input side.

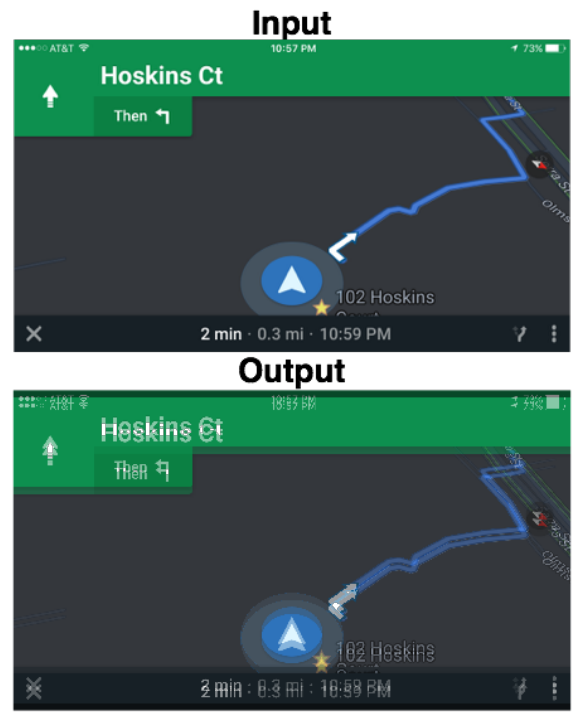

Figure 4 Blurry image with normal image input

If we want user to see a clear image, we should pre-compensate the input. And this problem becomes an optimization problem. The object is Y and we need to find X accordingly.

By setting Y as the target image we want to display, our goal becomes:

$$\min_x \frac{1}{2} \|(I + \alpha \cdot S)\, X - Y\|_2^2$$

with following constraints:

$$
\begin{cases}
1\times \sin\beta = n\cdot\sin\theta \\
z = \sqrt{2}d\tan\theta \\
m = \dfrac{z}{pixel\ size} \\
S = \begin{bmatrix} 1 & 1 & \cdots & 0 & 0 \\ 0 & 1 & & 0 & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & 0 & \cdots & 1 & 1 \\ 0 & 0 & & 0 & 1 \end{bmatrix}^m \\
X \geq 0
\end{cases}
$$

z is the shift distance between two virtual images and m is number of pixels within that distance. The shift matrix is to calculate the secondary virtual image based on primary virtual image. By multiplying shift matrix with an image, it will get a image with shift specified as m (pixels).

Please note that the constraint of $X \geq 0$ is very important since all physical devices cannot display negative luminances. And without that restriction, you can easily get perfect optimization results (the output will look exactly like what you want to display) but it's not practical and reasonable.

The optimization calculation was done with linear least square solver with bounds or linear constraints in MATLAB.

Figure 5 showed the input image and output image after optimization. The pre-compensated input image looks wavy because it was calculated to compensate shifted images. It's very clear that the output image has less blurr than the one w/o optimization. We can still see some ringing at strong edges but overall the image looks much more readable and cleaner.

Figure 6 and Figure 7 are more examples of the optimization results on different apps.

The results showed that most areas are nice and clean without any defects. But the area with large luminance contract has some ringing defect in the optimizaed output results. This can be improved by adding more weights on the strong edges or by reducing local contrast peaks.

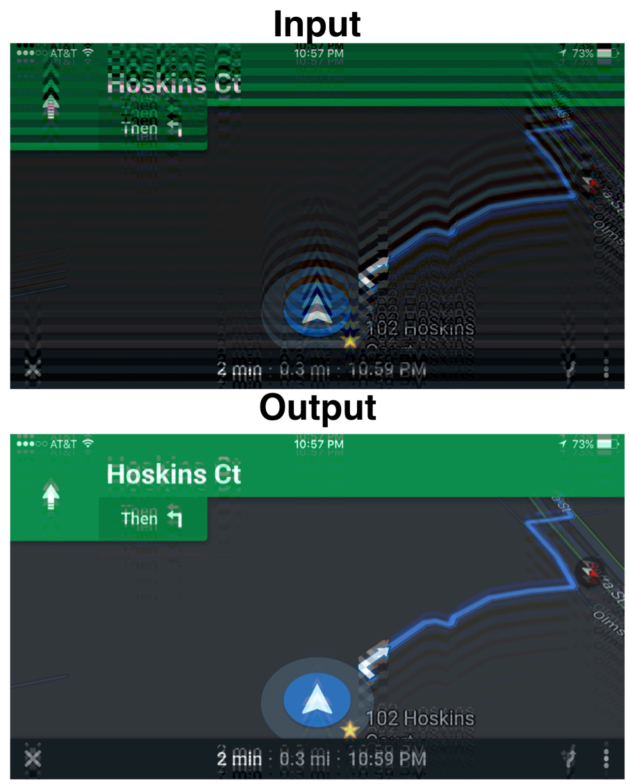

Figure 5 Input and output image after optimization

Figure 6 Optimization results on another navigation app

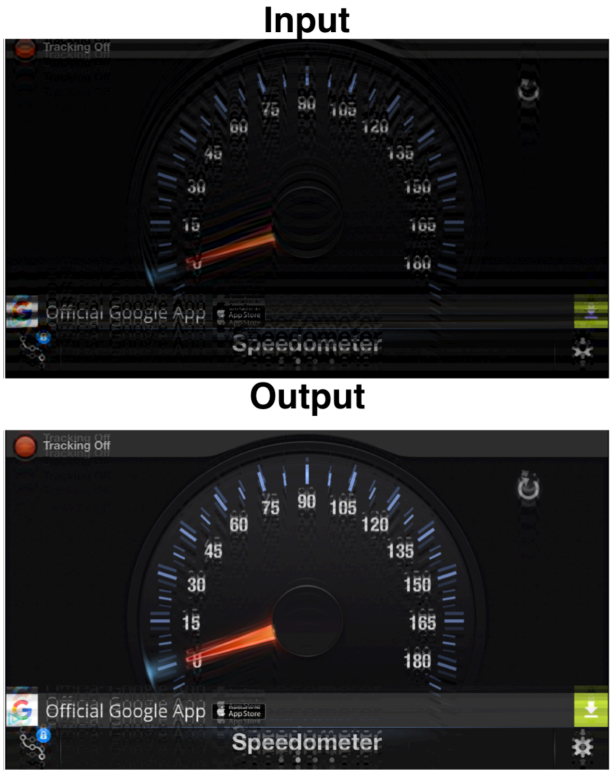

Figure 7 Optimization results on dash info app

2. Future work

To validate the simulation results with experiments, the glass reflection performance needs to be carefully characterized to find the value α.

The optimization results can be improved by adding more weights on the strong edges so that the ringing around edges can be minimized.

Also, the algorithm can be further improved to make it more compatible with smartphone calculation capability. Current calculation developed for this paper is based on MATLAB in desktop platform. In the future, it will need optimization for smartphone calculation capability so that all contents can be displayed on windshield fluently without processing on server side.

References

[1] Sun, Ted X. "47.4: A Novel Full Windshield Heads-Up Display Technology." SID Symposium Digest of Technical Papers. Vol. 46. No. 1. 2015.

[2] Díaz, L. "Optical aberrations in Head-Up Displays." Universidad Pontificia Comillas Madrid (2005).

[3] https://buy.garmin.com/en-US/US/on-the-road/discontinued/hud-head-up-display-/prod134348.html

[4] Jacobson, Homer. "The informational capacity of the human eye." Science 113.2933 (1951): 292-293.