Presentation

MOSAIC Project #2 : Infrared Camera

I- Introduction

- Presentation of the subject
- Why the subject is interesting
- Co-design/Management/ strategy

II- Optical design

- Specifications of the optical system
- Methods
- Some results

III- Matlab

- Application of the article
- Methods : phase mask and filter
- Results

IV- Future

- Planning
- Tolerancement
- Solidworks
- Conclusion

I- Introduction

Presentation of the subject : presentation of the camera and its application for autonomous vehicles.

- An IR camera place in the front of a car to detect people in a wide range
- Use of numerical treatment, optical design and phase mask to optimize sharpness and depth of field

What do we do ?

We want to increase the depth of field of an IR camera with a phase mask which will average the PSF on a larger distance than the hyperfocal so the sharpness is globally better on a greater distance but not as good as the best sharpness possible on one field

And to create a numerical treatment alongside the phase mask to obtain the best sharpness on the greatest distance

Interesting : Interesting for us and for society :

- for us because it allows us to develop our skills on Zemax and Matlab
- For society because a broader field would allow the car to locate people more easily

Management / co-design :

- Co-design : phase mask and filter
- 2 different groups (Zemax and Matlab → why these softwares ?)
- Strategy

Describe the components

Scene : POV of a car, everyday situation with people in front and far of the car (we want to detect everybody)

Phase mask : parallel blade engraved to add a specific phase to the wave front

Usefulness ?

Infrared imaging plays a crucial role in safety applications, such as advanced driver-assistance systems (ADAS), where it is essential to detect objects at various distances. The ability to detect and recognize objects in both near and far ranges using a single optical setup can significantly enhance vehicle safety by ensuring reliable identification in diverse conditions.

By increasing the depth of field through a phase mask, the camera will capture sharper images across different distances, crucial for object detection in dynamic environments like urban streets

II Optical Design

Specification : IR camera : sensor : 1024x768 pixel size : 12µm,

f' = 14 mm

Bande spectrale : LWIR (8 µm - 12 µm)

Détecteur non refroidi

Ouverture la plus grande possible (f number < 2)

Diffraction limited system. We want to create the optical system that samples well the PSF so we need to respect : 1/(lambda*N) > 1/(2*pixel)

Methods : Start with one lens with one wavelength that we optimize for an infinity -> focal plane conjugation on the axis (minimize the spherical aberration). Then we added field so problem of coma, astigmatism and field curvature. So we added one more lens. Then : increase a little bit the field then optimize the MTF, then increase a little bit the aperture (decrease N) and optimize the MTF, etc…

Results :

Image field near the maximum Y = 6 mm + aperture : N = 1.8 + show graph (cross section + MTF)

III Matlab

Model settlement :

Scene model :

The photo of a crowded street, where people are in different planes of view (for now the photo is not in infrared). The IR camera is intended to be installed on a vehicle to detect and identify objects of varying temperatures, such as pedestrians, cyclists, and distant buildings. These objects present different thermal signatures, which the system aims to accurately distinguish and process, ensuring safe and reliable detection in various everyday driving scenarios.

Noise model :

Additive White Gaussian Noise to mimic the effect of many random processes that occur.

REFERENCE: EE 392B: SNR and Dynamic Range Stanford University

Under well-lit conditions (e.g., in sunlight), SNR can reach **40 dB - 60 dB**, corresponding to high-quality images. In low-light conditions, SNR significantly decreases, possibly down to **10 dB - 30 dB**, especially when dark current noise and readout noise dominate.

AWGN is often used as a general model because many independent noise sources (like the ones listed above) contribute to the total noise, and according to the Central Limit Theorem, the sum of many independent random processes tends to follow a Gaussian distribution. Furthermore, "white" refers to the fact that the noise is equally distributed across all frequencies, meaning it has no frequency preference or bias. In practice, AWGN provides a useful approximation to the overall noise characteristics in many imaging systems, especially when multiple noise sources are present.

Image Restoration: Wiener Filter

To reconstruct the image and reduce noise, we consider using the Wiener filter, a well-known method in image restoration. The Wiener filter is designed to minimize the mean square error (MSE) between the restored image and the original, uncorrupted image. It operates based on both the degradation function (such as blurring) and the statistical properties of the noise and the original image.

Properties of the Wiener Filter:

1. Noise Reduction:

The Wiener filter is particularly effective in reducing noise, especially additive white Gaussian noise (AWGN). It accounts for the noise characteristics in the image, offering a more adaptive approach than simple deconvolution methods.

2. Balancing Restoration and Noise Suppression:

One of the key features of the Wiener filter is that it finds an optimal balance between inverting the degradation (such as blur) and suppressing the noise. This helps avoid amplifying the noise during the deblurring process.

3. Adaptivity:

The Wiener filter is adaptive, meaning it adjusts based on the local signal-to-noise ratio. This ensures better restoration in areas with high signal quality while applying more aggressive noise reduction where the signal is weak.

Best Filtre to Reconstruct the Graph: Average Wiener Filter

Considering the PSF diffusion in a defocused situation, for an optical imaging system, its imaging function can be expressed by the following formula:

$$I(r) = h_{\psi}(r) * O(r) + n(r),$$

,

where *h* is the system's point spread function (PSF), which in the case of defocusing, is given by

$$h_{\psi}(r) = |F\{P(r)\exp[i(\varphi(r) + \psi r^2)]\}|^2,$$

where psi represents the difference of phase for different conjugate and phi the phase mask where we will introduce afterwards

$$\psi = \frac{\pi R^2}{\lambda}\left(\frac{1}{f} - \frac{1}{d_o} - \frac{1}{d_i}\right);$$

If we want to minimize the psi for different conditions, we could define average MSE as:

$$\mathrm{MSE}_{\psi} = \int \left|\tilde{d}(\nu)\tilde{h}_{\psi}^{c}(\nu) - 1\right|^2 S_{OO}(\nu)d\nu + \int |\tilde{d}(\nu)|^2 S_{nn}(\nu)d\nu$$

$$\mathrm{MSE}_{mean} = \frac{1}{n_{\mathrm{MSE}}}\sum_{i=1}^{n_{\mathrm{MSE}}} \mathrm{MSE}_{\psi_i}$$

$$\mathrm{MSE}_{\psi} = \langle|\hat{O}(r) - O(r)|^2\rangle.$$

The deconvolution filter that minimizes is calculated by taking the derivative of average MSE with respect to d(v). The solution of this calculus is

$$\tilde{d}(\nu) = \frac{\frac{1}{n_d}\sum_{i=1}^{n_d} \tilde{h}_{\psi_i}^{c^*}(\nu)}{\frac{1}{n_d}\sum_{i=1}^{n_d} |\tilde{h}_{\psi_i}^{c}(\nu)|^2 + S_{nn}(\nu)/S_{OO}(\nu)}.$$

In our codes, we define a Average Wiener Filtre according to this formula and simulate the images of different imaging distance

4. Phase mask

why use phase mask:

We use phase masks for wavefront coding to extend the depth of field (DOF). We already got theMSEaverage, which is minimized at different distances, now we use phase mask to minimize it.

how to choose:

- **we use MTFmodulation transfer function to evaluate the quality of our image，which is the vertical coordinate. the horizontal coordinate is frequency.**

We compared the phase masks in several articles, and we need to find one that:

1.The MTF smoothly decreases as the frequency increases in the frequency domain, with low noise;

2.The MTF decreases slowly with increasing frequency, ensuring that the system's transfer capability, resolution, and image quality remain good at higher frequencies;

3.The MTF for images at different distances should ideally be stable and consistent；

4.The computation time is acceptable, meaning the number of parameters is relatively small.

After comparing rational, cubic, exponential, and logarithmic models, we chose the exponential model, which has only two parameters and can meet our requirements well.

how to optimize:

$$\phi_{\mathrm{EPM}}(x) = \beta x \exp(\gamma x^2),$$

we use MSE as the **evaluation criteria** for optimizing the phase mask parameters. The smaller the Mean Squared Error (MSE) value, the smaller the difference between the recovered image and the original photo .

Therefore, we use a `minsearch` function, treating the two parameters as variables, and establish an anonymous function to find the optimal parameters that minimize the MSE.

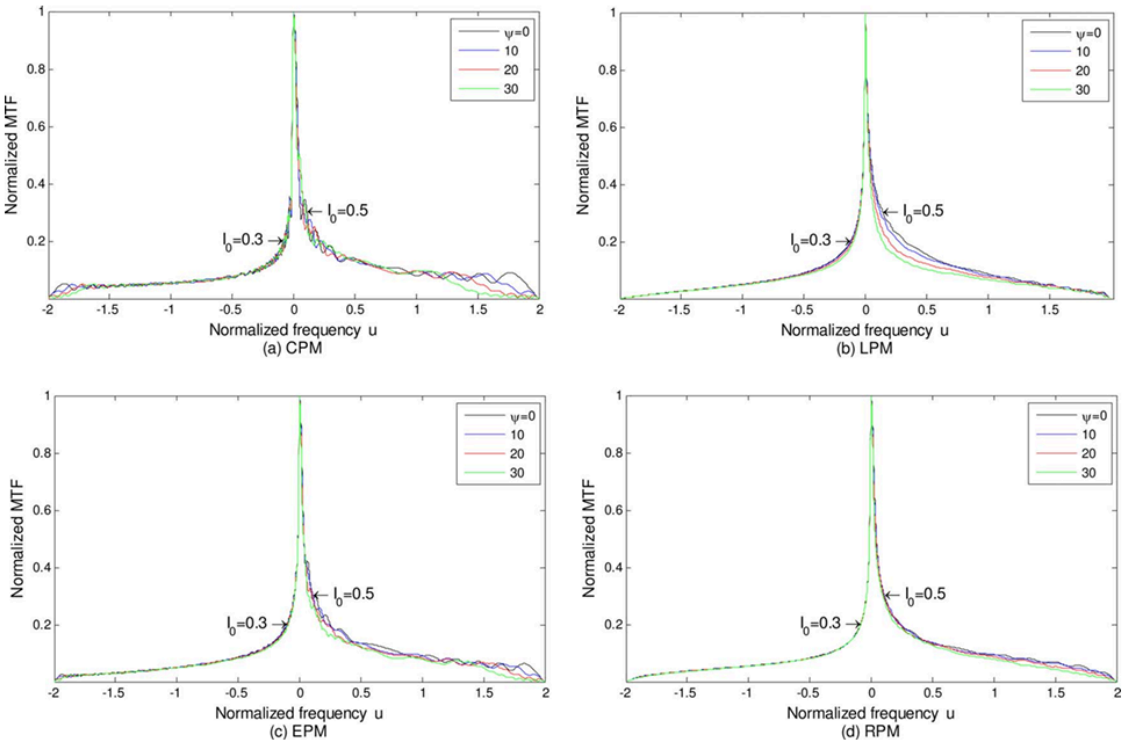

Fig. 2. (Color online) Normalized MTF curves with various defocus parameters.

After that, we got γ **and** β **that minimize MSE.**

And to visualize We fix gamma and vary beta .It's clear that MSE is minimized when beta equals the value we got. the result is rather good.

IV Plan for the future

Matlab

-> Deconvolution, filter

Deconvolute the image (object, PSF and noise) using a filter to get the most neat result for a greater DOV.

-> Wiener filter

The filter used is the average Wiener filter for different object distances. The Wiener filter is the one that minimizes the minimum mean square error.

-> Noise

-> Defocus psi

Depends on the radius of the aperture, the focal length (14mm), the object distance and the image sensor plane distance (14mm).

-> Phase mask

->Compare different phase masks at different distances in frequence space

Zemax :

-> Optimization

-> Airy spot >= 2*pixel

-> Field 29,5mm (cf reference sensor dimensions)

-> N<2 and minimize it

-> Tolerancement

-> Optomecanique

-> Ameliorate what we already have