A Multiple Color-Filter Aperture-Based Depth Estimation and Its Application

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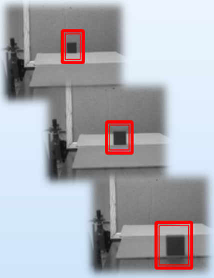
  - Distance estimation at interest objects

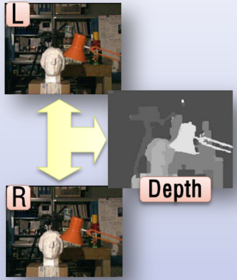
Why use MCA?

Depth from Defocus



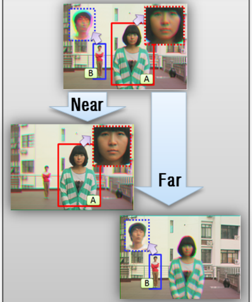
- It has ambiguity problem between defocus and any other blurs like motion

Stereo camera



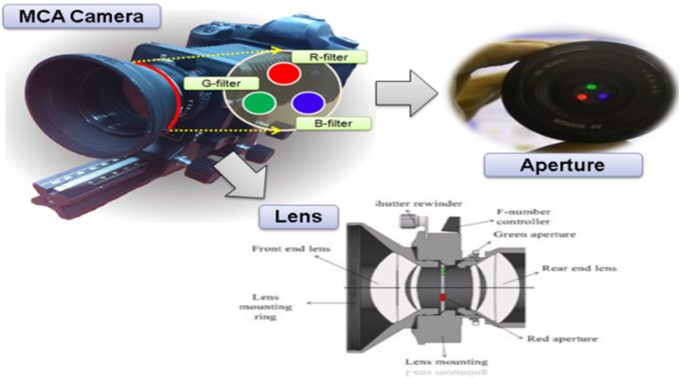
- Pair of images in the same scene should be acquired by two cameras

Multiple Color-filter Aperture



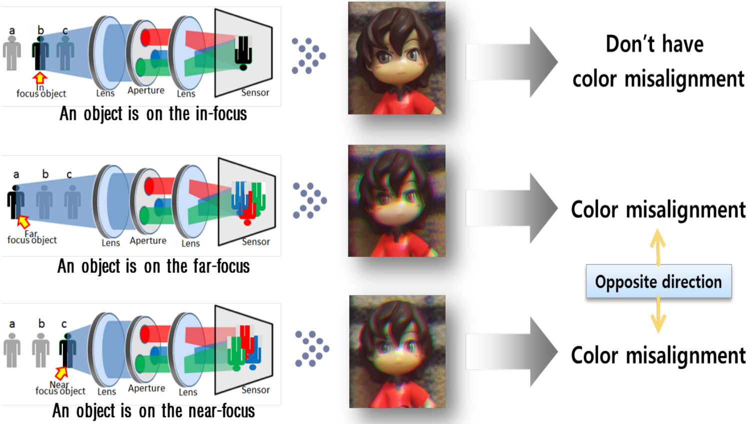
- It can be configured using any general lens

What is MCA camera?



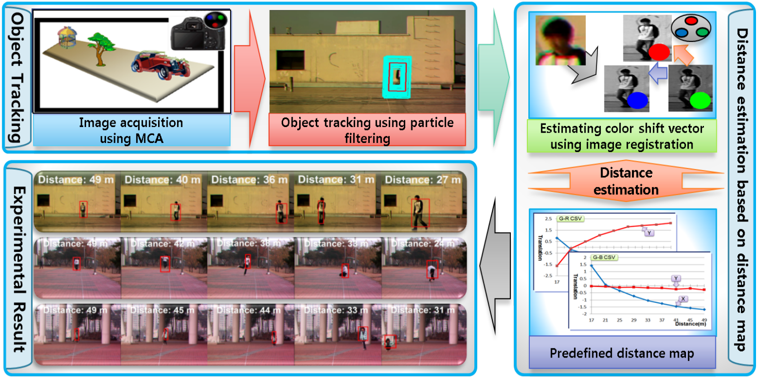
- Use three apertures with red, green, and blue
- Insert into lens at aperture

The property of the MCA camera at different distance



Simultaneous object tracking and distance estimation

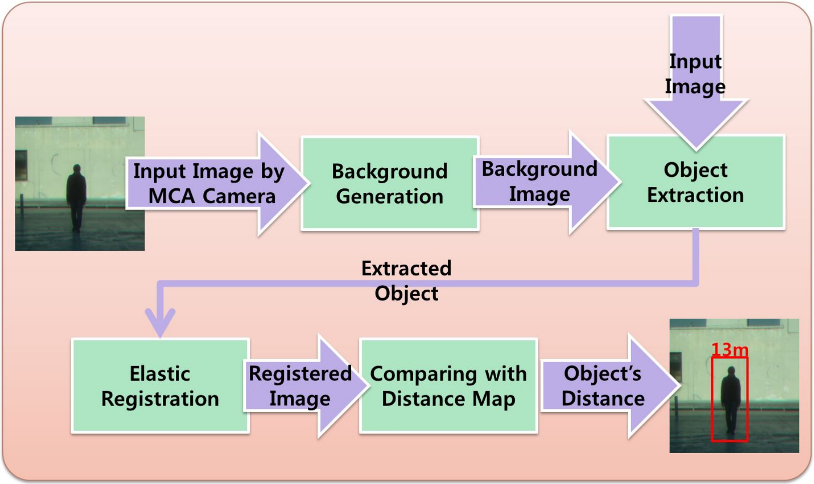
Framework of proposed algorithm



- S. Lee and J. Paik, "Simultaneous object tracking and depth estimation using color shifting property of a multiple color-filter aperture camera," IEEE Proc. Int. Conf. Acoustics, Speech and Signal Processing, May 2011.

MCA Cameras for Surveillance System

The overall algorithm



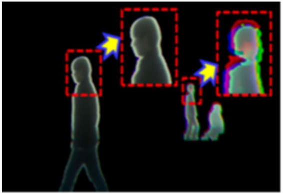
- The step of background generation
  - Estimate optical flow between each images
  - Background is updated at motionless pixels slowly.
  - Object is detected using color-based background subtraction as follow

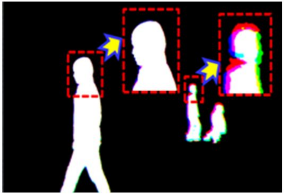
$$f_O{}^c(x,y) = \begin{cases} 1, |f_B{}^c(x,y) - f^c(x,y)| & > \theta_B \\ 0, \textit{otherwise} \end{cases} \text{, for } c \in \{R, G, B\}. \quad (1)$$

The result of object detection


(a) input image

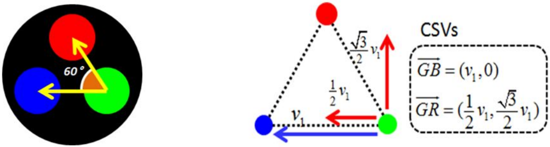

(b) background image


(c) Detected object regions


(d) the masked foreground
of the input image

Depth estimation of an extracted object

- Simplified Elastic registration
  - Estimate the depth of an extracted object.



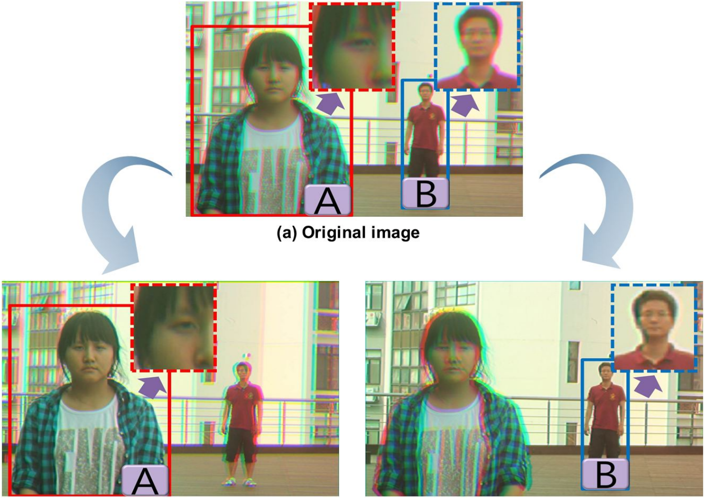
(a) Geometric configuration of the MCA

(b) Color shifting property based on the green channel

  - Simplify elastic registration using the property of the MCA.

  - Further simplify using the position property of the MCA.

Registration results of the two different depth objects



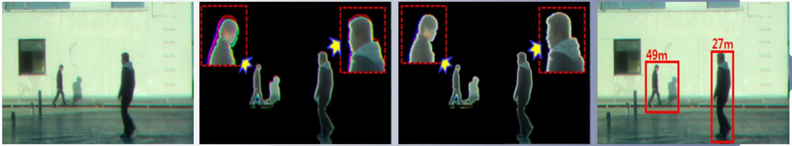
(a) Original image

(b) Registered result of the object A

(c) Registered result of the object B

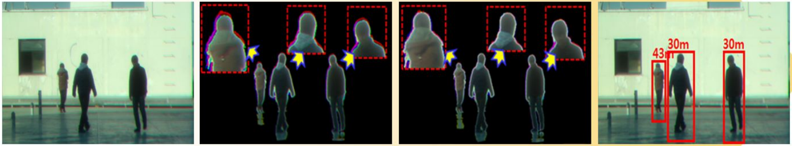
Results of depth estimation each objects

- **Result 1**



(a) (b) (c) (d)

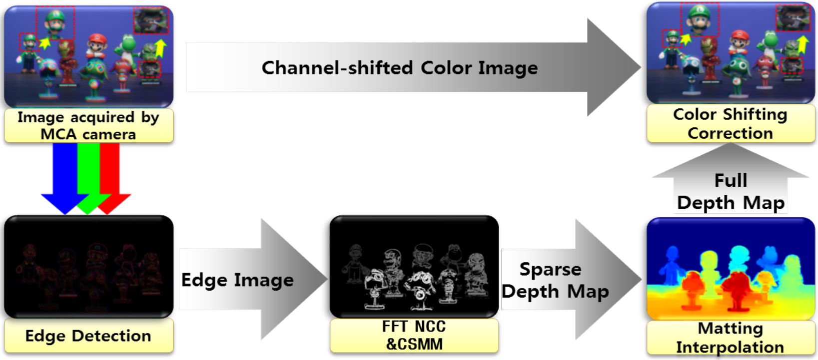
- **Result 2**



(a) (b) (c) (d)

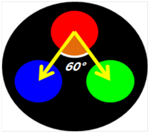
Full Depth Map Estimation

The proposed framework

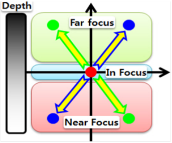


- At the edge, we estimate CSVs Using normalized cross correlation combined with color shifting mask map
- A full depth map is generated by depth interpolation from sparsely estimated CSVs at an edge location

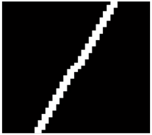
Color shifting mask map (CSMM)



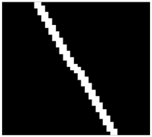
Geometric configuration
of MCA



Color shifting property
based on red channel



Color shifting mask map
(R−G channels)



Color shifting mask map
(R−B channels)

- Apply a priori constraint on the feasible pattern of CSVs
- This pattern enforces the color shifting property of the MCA in the form of the mask

Sparse depth map estimation

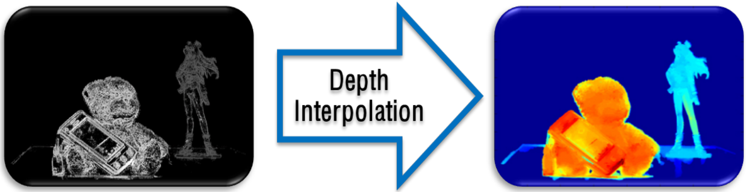
- CSV is estimated by maximizing NCC subject to CSMM constraint as follows

$$CSV(x, y) = \arg\max_{u,v}\ C_N(u, v), \text{subjectto } CSMM(u, v) = 1 \tag{2}$$

- The depth of a point at (x,y) is determined as

$$D(x, y) \ = \ -sign(v) \times \sqrt{u^2 + v^2} \tag{3}$$

Generation of the full depth map



Sparse depth map

Full depth map

- The depth interpolation is performed by minimizing the following energy function

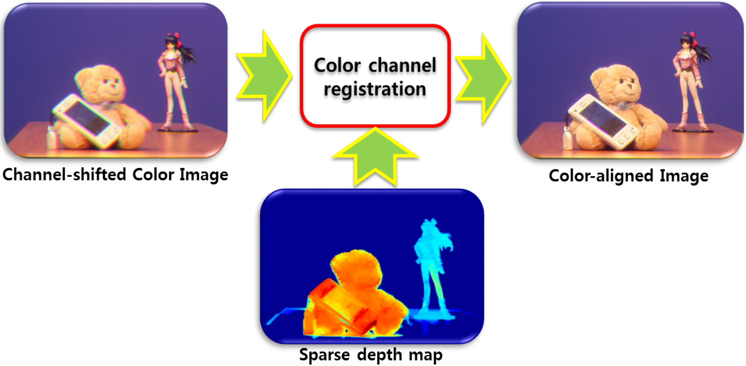
$$E(d) = d^T L d + \lambda (d - \hat{d})^T A (d - \hat{d}) \tag{4}$$

- The closed form solution for minimizing (3) is given as

$$d = (L + \lambda A)^{-1} \lambda A \hat{d} \tag{5}$$

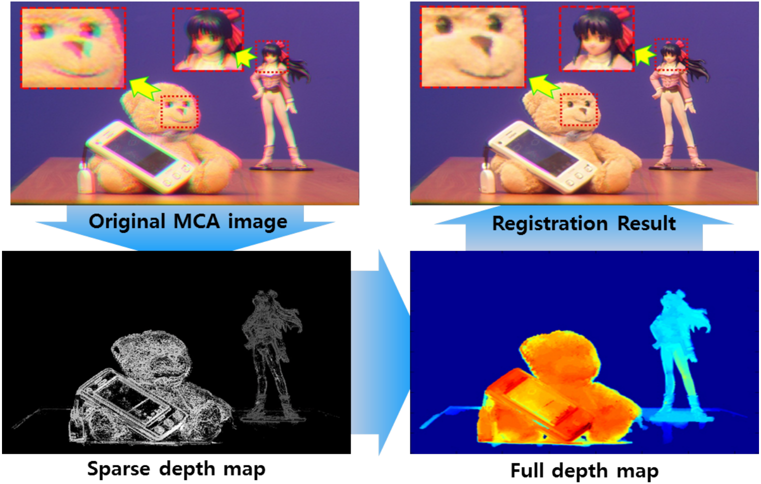
1. A. Levin, D. Lischinski, Y. Weiss, "A closed-form solution to natural image matting", IEEE Trans. Pattern Analysis and Machine Intelligence, vol. 30, no. 2, pp. 228-242, Feb 2008.
2. S. Zhuo and T. Sim, "Recovering depth from a single defocused image," International Journal of Pattern Recognition, submitted, 2011.

Color channel registration

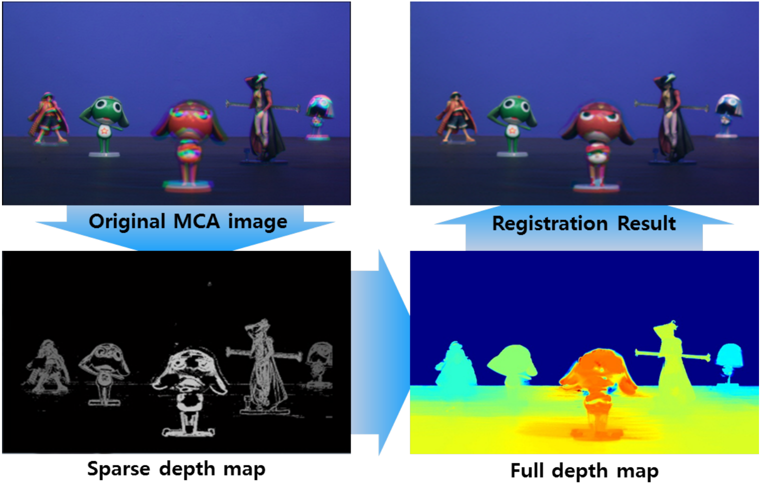


- Calculate the full CSVs from the full depth map
- Green and blue channels are shifted by inverted CSVs
- Bicubic interpolation is implemented at the holes

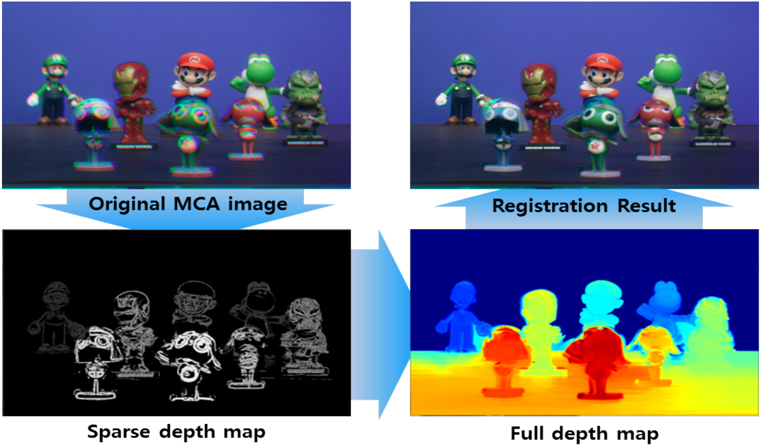
Experimental result 1



Experimental result 2



Experimental result 3

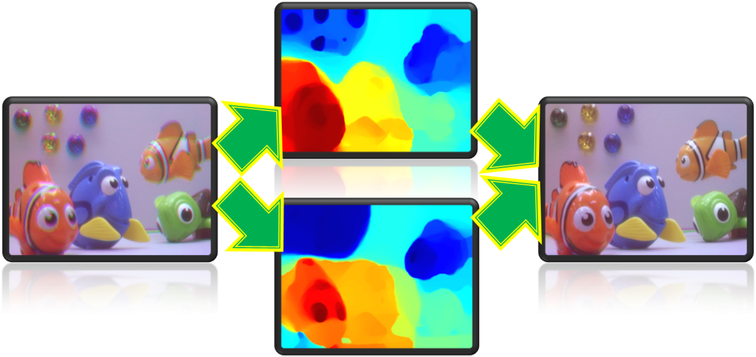


- Color channel registration fails in some occluded regions
- Depth discontinuity is not considered in the color channel matching step

Conclusion

- Provide depth information in the single-camera framework.
- Proposed a single camera-based full depth map estimation.
- Can not only estimate the full depth map but also correct color misalignment to make photo-realistic color images.
- More accurate depth estimation will be provided by considering the complex background and the occlusion between objects in the future research.

Future research



- Optical flow-based CSV estimation method will be presented for more accurate depth estimation.

Thank You for Attention

Questions and Answers