Purpose: Investigate methods of image fusion for infrared and visible images, drawing upon concepts covered over the entire semester.

Procedure: For *each* MATLAB m-file you write, be sure to comment the code sufficiently, and include initial comments as a crude help system (as described in the instructions for previous projects). Also in keeping with previous projects, no Image Processing Toolbox (or *any other* Toolbox) programs should be used for this project. If you're unsure, use the help files to see if the function you want to use is part of MATLAB or is listed as part of one of the Toolboxes. For displaying both spatial domain and frequency domain images, follow the guidelines given in previous projects. You should be quite familiar with them by now.

Background on the IR Camera: Infrared (IR) is the region of the electromagnetic spectrum has longer wavelengths than the visible light that humans can see. The *visible spectrum* spans wavelengths of approximately 400–700 nm [1, 2]. One representation of the electromagnetic spectrum is shown in Figure 1, where the IR wavelengths can be seen on the left of the visible spectrum. Humans can't see IR; any IR energy can only be directly sensed by humans as heat. Thus, an IR camera must assign a range of false colors that we are able see to represent the IR energy. This false color method is often called *pseudocolor* in the literature [3]. Capturing images in the IR wavelengths challenges camera designers. For example, normal glass appropriate for visible wavelengths tends to reflect rather than pass IR wavelengths, and normal camera imaging sensors (CMOS or CCD) have IR-blocking filters to prevent saturation [4, 5, 6]. This latter point is required because the silicon-based sensor arrays respond strongly to what are called the near-IR wavelengths, as can be seen in Figure 2. These and other challenges have been overcome by camera designers, and IR cameras are now available that combine reasonable price with acceptable image measurement quality.

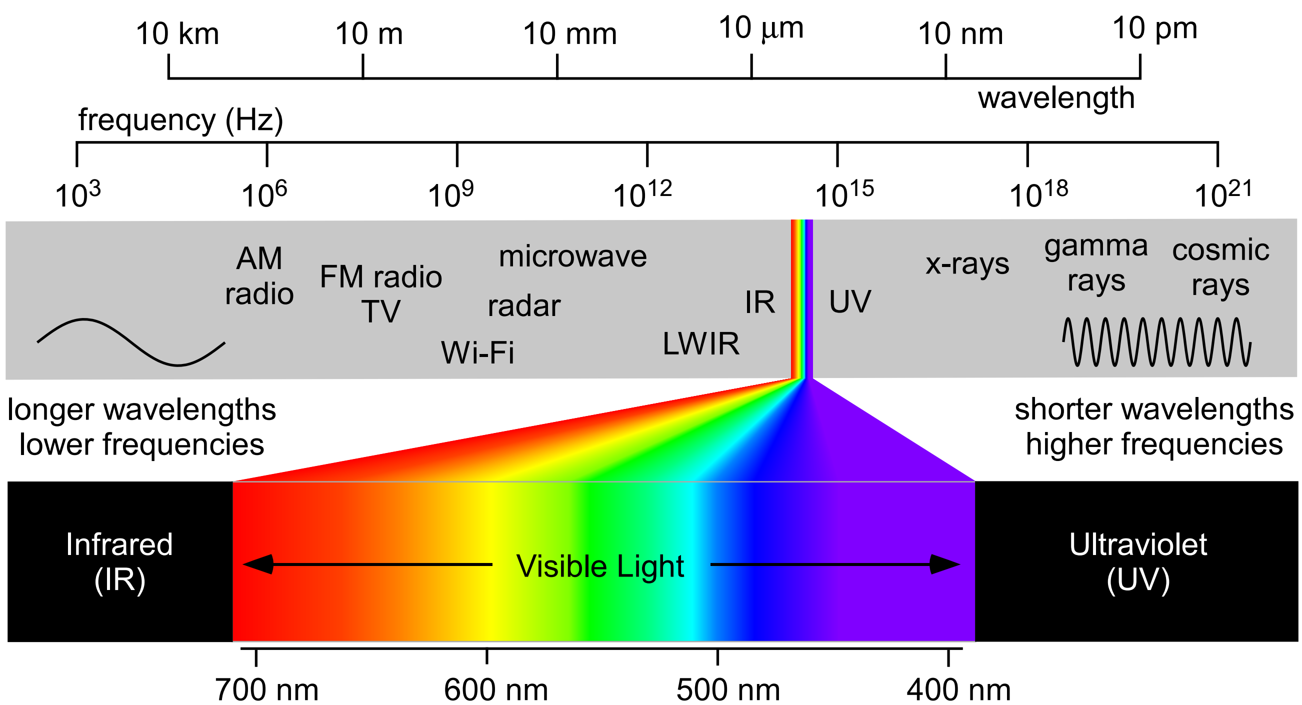

Figure 1: Regions of the electromagnetic spectrum pertinent to this discussion.

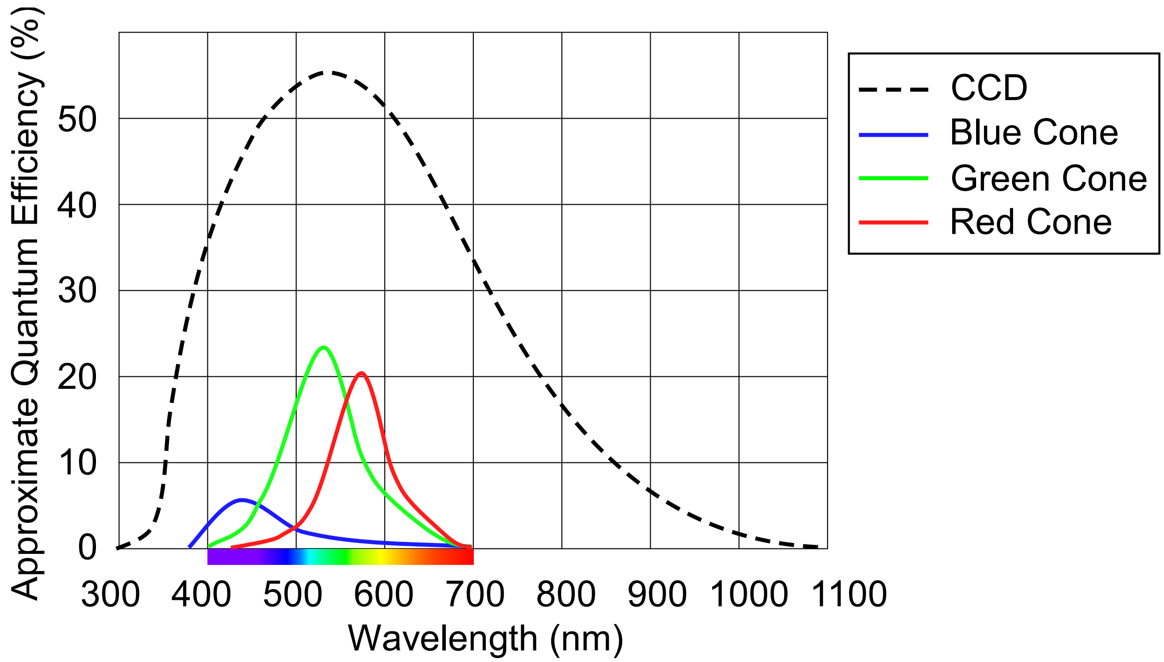

Figure 2: Comparison of a typical silicon-based image sensor to human photoreceptors.

The particular camera used for this project was the model E60 by FLIR [7]. See Figure 3. The E60, like many IR cameras, actually provides two independent cameras: a primary IR camera, and a secondary visible wavelength camera. Each camera has its own optics and image sensor, optimized for the appropriate wavelengths. Note in Figure 3 that the image resolution for the two cameras is quite different, since high resolution IR sensors would be very expensive. This difference, plus the different field-of-view (FOV) and the different optical axis for image formation between the two cameras, provide significant challenges for the final project in the EE 5620 image processing course.

A typical image from an infrared camera (a FLIR model C2) is shown in Figure 4, with the MSX image fusion option enabled. The model C2 is more compact than the E60, but also provides the MSX image fusion option. Note the key for the pseudocolor assignment of color to temperature (in degrees Celsius) is shown in a vertical bar on the right edge of the image. The temperature of the center of the image is displayed at the upper left of the image. Image fusion takes some salient features, such as edge information, from the associated visible image, and combines those features to provide an enhanced IR image [8]. Without image fusion, many IR images lack sufficient visual cues for the observer to know just what the image is showing.

Data files for this Project. You will use monochrome image data files created specifically for this project. Load the "mat" file `proj_IR.mat` from the "Images" section of the course website. This file contains two MATLAB arrays:

- The array `IR` is a 240×320 spatial domain image taken with the IR camera and optics of a FLIR E60.
- The array `visible` is a 1536×2048 spatial domain image taken with the visible camera and optics of a FLIR E60.

	FLIR E60
IR camera resolution	320 × 240
IR FOV	25°
IR spectral range	7.5 – 13 μm
IR temperature range	–20° to 650° C
Visible camera resolution	2048 × 1536
Focus	Manual
Image Fusion	Yes, MSX

Figure 3: The model E60 IR camera from FLIR. Left image courtesy of FLIR, Inc.[7] Note: MSX is an image fusion technique proprietary to FLIR.

Figure 4: A typical IR image taken with a FLIR C2, with the MSX image fusion option enabled. The image shows a kitchen backsplash on a wall with a poorly insulated fireplace behind it. The dark area in the upper left indicates a colder region, due to insufficient or missing insulation.

Note that it is common for camera and monitor manufacturers to specify image or display resolution as "columns × rows," whereas image processing literature more often specifies image or display resolution as "rows × columns."

➪ In this project, you will be drawing upon the knowledge you have gained about image processing in this course to solve the problem of image fusion. Basically, you will have a relatively high resolution visible sensor image and a lower resolution IR sensor image, acquired from two slightly different optical axes. The objective is to extract certain features (such as edge information, for example) from the visible image, and merge them on to the IR image. This project will have three main parts:

1. experiment with various ideas and approaches for image fusion,
2. choose your preferred method, and
3. demonstrate the application of your chosen method on the images you are provided.

Questions/Discussion: The write-up for this project is intended to be **minimal**. No background section is needed, except as you may see fit to explain your chosen approach. The write-up will mainly provide a brief description of the methods investigated, identification of the method you chose to implement, and images of your results. An appendix with your code listings will be included. Fair warning: excerpts of your write-up and your images may appear in a future conference paper for the American Society of Engineering Education.

Turn in: For this Project, turn in (as one or more e-mail attachments sent to me as part of a single e-mail message):

➪ An electronic project report (as a PDF file regardless of the program used to create the report). Name your PDF file "`Last1_Last2_proj05.pdf`" please, where "Last1" is the last name of team member 1, and "Last2" is the last name of team member 2. Be sure to follow the format given on the course web site (see the `Admin` section of the course web site).

➪ Any MATLAB m-files you created for this project. There is no need to send me any data or image files that you generated. I'll run your m-files and generate your images myself. If for some reason I need additional files from a particular student, I'll request them separately.

This is a fairly open-ended project, and doesn't require much of a write-up, but don't let that make you underestimate this. Plan to put a reasonable amount of time into this project, and get an early start.

References

[1] R. Sekuler and R. Blake, *Perception.* New York: McGraw-Hill, 3rd ed., 1994.

[2] J. D. Bronzino, *The Biomedical Engineering Handbook.* Boca Raton, FL (USA): CRC Press, 1995.

[3] R. C. Gonzalez and R. E. Woods, *Digital Image Processing.* Hoboken, NJ (USA): Pearson, 4th ed., 2018.

[4] A. Daniels, *Field Guide to Infrared Systems, Detectors, and FPAs.* Bellingham WA (USA): SPIE Press, 2nd ed., 2010.

[5] M. Bass, ed., *Handbook of Optics*, vol. I. New York: McGraw-Hill, 2nd ed., 1995.

[6] G. C. Holst and T. S. Lomheim, *CMOS/CCD Sensors and Camera Systems*. Bellingham, WA (USA): SPIE Press, 2nd ed., 2011.

[7] "FLIR website, Exx-series IR cameras." `http://flir.com/instruments/exx-series/`.

[8] "Infrared resolution and contrast enhancement with fusion," 2013. U.S. patent 8,520,970 and 8,565,547.

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