IMAGE FUSION: AN INTRODUCTION TO MULTISPECTRAL SIGNAL PROCESSING

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ABSTRACT

A new generation of affordable infrared (IR) cameras provides both IR and visible images, which allows professors to introduce the concept of multispectral (and hyperspectral) signal processing in a particularly motivating way for students. We describe the use of a FLIR E60 camera in a graduate digital image processing course, in which IR and visible images were used as the basis for an open-ended final project in the course. We used both pre- and post-project questionnaires to confirm that the project was a positive experience for the students, and helped motivate them to master the course material.

***Index Terms*—** multispectral, hyperspectral, infrared, visible, fusion

1. INTRODUCTION

Researchers often need to acquire data using cameras or other imaging systems, and typically will need to manipulate and process this image data in various ways. For this reason, image processing (and to some degree, basic optical engineering) courses are often needed to fill the basic "signal processing toolkit" of many graduate students. As an added complication, images may not be simple visible images. IR images, using a pseudocolor mapping, are also becoming more prevalent for various research needs. Yet IR images, by themselves, are often difficult to interpret, as they may lack well-defined object edges or other visual cues that help a human observer interpret the image. For this reason, salient aspects of a visible image of the same scene may be selectively combined with the basic IR image to enhance the ability of humans to understand the image [1]. This technique of combining images from different parts of the spectrum is often called "image fusion." With this in mind, we added an open-ended final project in our graduate level image processing course that required the student to devise an acceptable method of image fusion. The course covered the topics in the first five chapters of the well-respected Gonzalez and Woods text [2].

It is generally accepted that interactive learning, exercises, and demonstrations are invaluable for helping students understand a given concept [3–9]. Even more effective than demonstrations are actual hands-on exercises and projects [10–16]. There are even specific books and websites that support hands-on projects [17, 18]. The image fusion project was devised as a hands-on project that would bring together nearly all of the concepts learned in the course. One point to note is that the final project deals primarily with grayscale images, since color models and color images are presented in Chapter 6 of the text (covered in our second image processing course).

Note that a less technical description of part of this work, focusing more on the student backgrounds and course content, was described in [19].

2. THE CAMERA

The camera used in this course was the FLIR model E60 [20]. See Fig. 1. The E60 provides two independent cameras: a primary IR camera, and a secondary visible wavelength camera. Each camera has its own optical path and image sensor, optimized for the appropriate wavelengths. Note in Fig. 1 that the image resolution for the two cameras is significantly different, since high resolution IR sensors are still relatively expensive. This difference, plus the difference in field-of-view (FOV) and the different optical axis for image formation between the two cameras, provide significant challenges to the students for the final project.

An exemplary image from an IR camera (a FLIR model C2) is shown in Fig. 2, with the MSX image fusion option enabled. The model C2 is more compact than the E60, but provides the same MSX image fusion option. The mapping for the pseudocolor assignment of color to temperature (in degrees Celsius) is shown in a vertical bar on the right edge of the image in Fig. 2. The temperature sensed at the center of the image is displayed at the upper left of the image. Image fusion extracts certain salient features, such as edge information, from the same-scene visible image, and "fuses" those features to provide an enhanced IR image. Without image fusion, an IR image will often lack sufficient visual cues for the observer to properly interpret the image.

3. THE PROJECT

For the final project in our digital image processing course, we challenged the students to come up with their own version of image fusion: use images from both an IR sensor and a visible-light sensor on the same unit to provide an enhanced IR image using certain features (that they choose) from the visible-light image. While the proprietary method used by FLIR is MSX, specific details of MSX were unavailable to the students. In order to make image fusion work for this scenario, one must take into account the differing resolutions, field of view (FOV), and other dissimilar aspects of the two types of image sensors. Creating a workable approach to image fusion is a difficult problem, and it draws upon all of the foundational image processing techniques the students have learned in the course. The students were told about this end-of-semester challenge project at the beginning of the semester, and its direct tie to current industrial practice both excited and motivated the students.

The scene shown in Fig. 3 was the basis for the sample images for this project. The IR image has lower resolution, more narrow FOV, and was obtained with different optics (having an optical axis that was offset from the optical axis of the visible-light camera). Since this first digital image processing course deals only with grayscale images, the images shown in Fig. 3 were converted to

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

Fig. 1: The FLIR model E60 IR camera. Left image courtesy of FLIR, Inc. [20] MSX is a proprietary image fusion technique.

Fig. 2: An example IR image, with MSX image fusion. The image shows a kitchen backsplash on a wall with a poorly insulated fireplace behind it. The dark area in the upper left of the image indicates a colder region, due to insufficient or missing insulation.

grayscale (using a standard NTSC weighting scheme to convert RGB to luminance), as shown in Fig. 4. Note that the temperature annotations overlaid by the FLIR software on the IR image in Fig. 3 were turned off in Fig. 4. The IR image on the right in Fig. 4 is nearly featureless, and is therefore an excellent example of why image fusion can enhance many IR images.

The students, in teams of two, were instructed to create a solution for image fusion using the two images shown in Fig. 4. They were told that their solution should be generalized to work with any scene, and not just be a solution that works for this one given scene. Earlier in the semester, they were shown IR images with and without image fusion from the FLIR E60, and were given time to use the FLIR E60 during several class periods to familiarize themselves with details about the camera and the images it takes.

4. RESULTS

4.1. Image fusion

In general, the project results submitted by the 15 two-person student teams were very good. During the two weeks the students worked on the project, we readily answered any questions posed by the students, but great care was taken not to explicitly or implicitly imply any sort of preferred solution or method. The students were free to choose how to co-align (i.e., register) the two very different images, pick what features to extract from the visible image, and how to "add" some part of those features to the IR image. A common approach was to crop and shift the visible image, interpolate one or both images to a common resolution, detect edges in both images (typically using Canny or Sobel techniques), use the detected edges for alignment (i.e., image registration), extract edge information from the visible image, add a weighted version of the visible image edges to the IR image (often using techniques similar to adding visible watermarks in the spatial domain, such as $C = (1 - \alpha)A + \alpha B$ where A is the IR image and B is the edge detail), and then use some final image enhancement steps (such as Lapalacian sharpening or histogram equalization) on the now-fused IR image. A sample of student results are shown in Fig. 5.

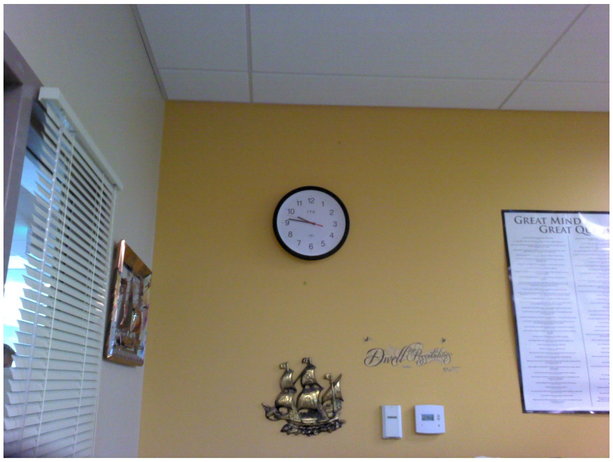
The top row of Fig. 5 shows typical results, which are reasonably good enhancements of the original IR image. The worst result of all the teams is shown on the bottom left of Fig. 5. This team failed to get the images to register or to even have the same FOV; you can see the IR version of the clock inside the superimposed visible image clock detail. In their defense, this team claimed to have "run out of time" before they could perfect their method. But all teams had the same amount of time. The best result of all the teams is shown on the bottom right of Fig. 5; this result is quite close to what the proprietary FLIR MSX method would have produced.

4.2. Assessment

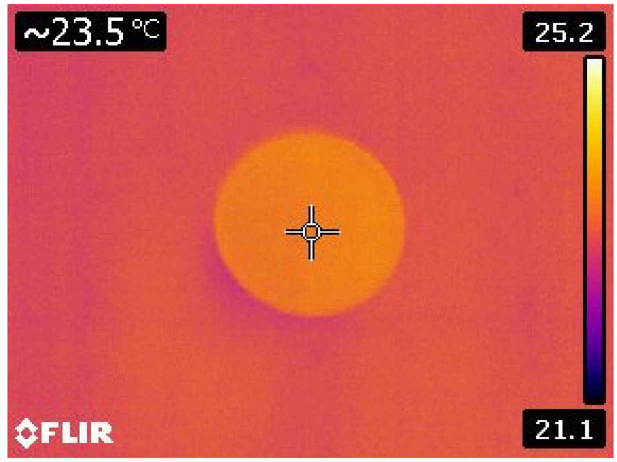
In order to assess the effectiveness of the project for both aiding in mastering the topics and motivating the students, two anonymous questionnaires were administered: one prior the beginning of the project, and one after completion of the project. Both questionnaires had a 100% response rate of $N = 30$; they used the 5-point Likert scale defined as: 1: Strongly disagree; 2: Disagree; 3: Neutral; 4: Agree; 5: Strongly agree.

The "before" questionnaire contained the following statements, and Fig. 6 shows the results.

1. I am already familiar with infrared cameras and images.
2. I already have a solid understanding of why image fusion is desirable for infrared images.
3. I already know how to implement image fusion for infrared images.
4. Being told we will be investigating the industrial challenge of image fusion for infrared images motivates me to better understand the topic of digital image processing.

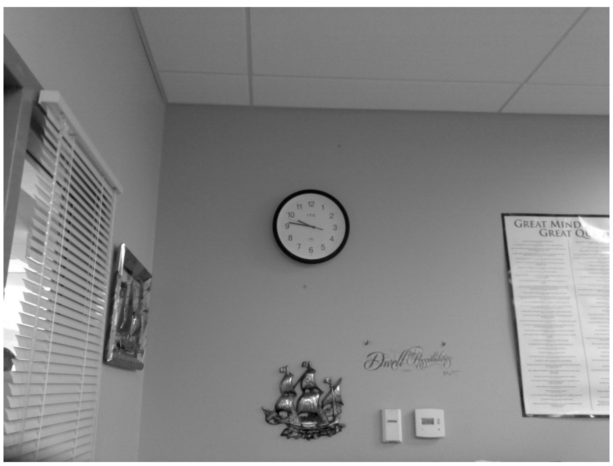


(a) Image from visible-light camera.

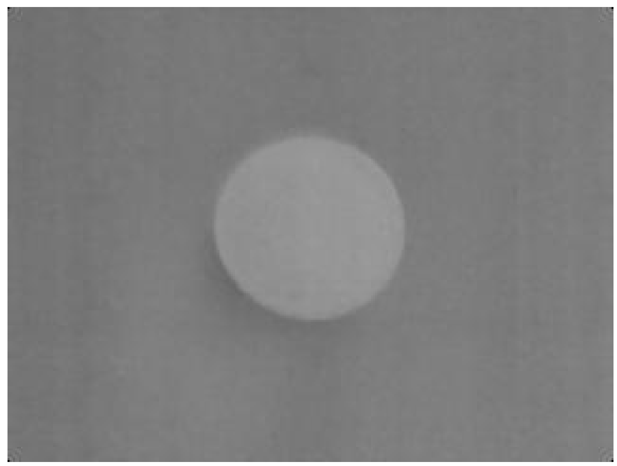


(b) Image from IR camera.

Fig. 3: Scene used to create sample images for the final project. Left: a 2048×1536 visible-wavelength image. Right: a 320×240 IR-wavelength image of the same scene.



(a) Image from visible-light camera.



(b) Image from IR camera, annoatations turned off.

Fig. 4: Grayscale versions of sample images for the final project.

5. Using current industrial challenges as the basis for a class project is a good idea.

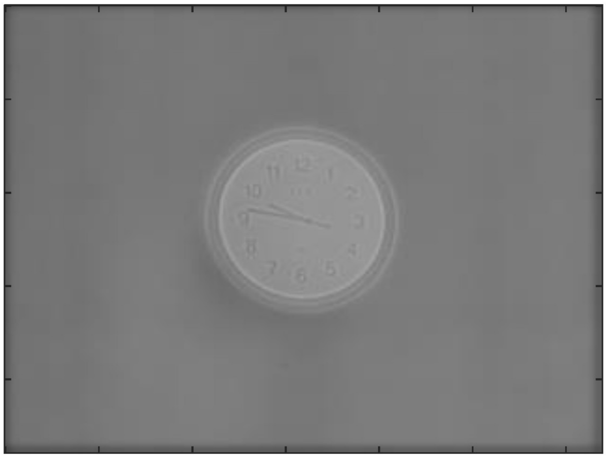
The "after" questionnaire contained the following statements, and Fig. 7 shows the results.

1. I am now familiar with infrared cameras and images.
2. I now have a solid understanding of why image fusion is desirable for infrared images.
3. I now know at least one way to implement image fusion for infrared images.
4. Investigating the industrial challenge of image fusion for infrared images helped me better understand the overall topic of digital image processing.
5. Using current industrial challenges as the basis for a class project is a good idea.

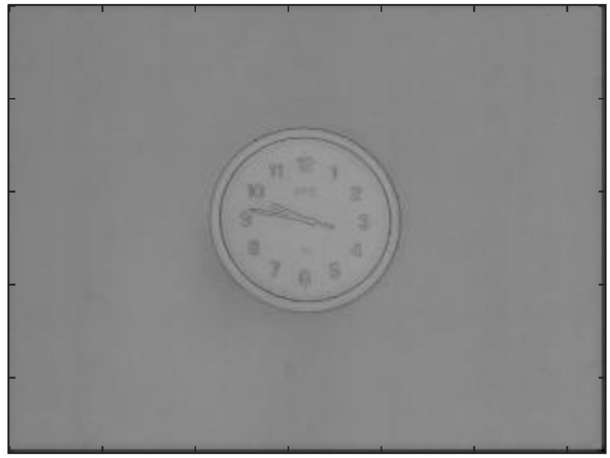
For the questionnaires, questions 1, 2, and 3 assessed (via a before-after gain) how students learned new concepts as a result of the project, and questions 4 and 5 assessed the level of motivation due to the project. Questions 1, 2, and 3 showed significant gain from before the project to after it. Questions 4 and 5 were very high both before and after the project. Both of these results are what we had hoped to see.

5. CONCLUSIONS

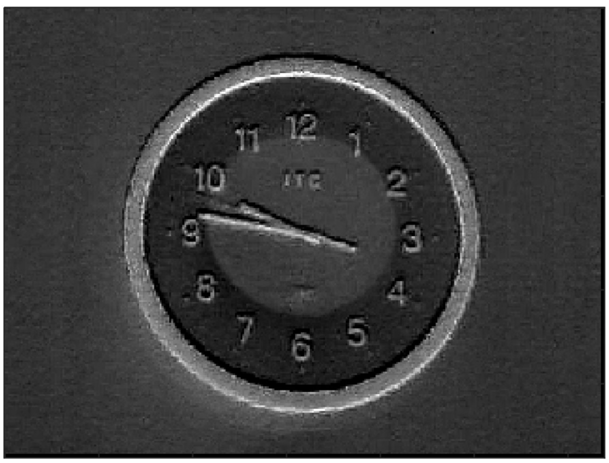
Modern IR cameras can be used in the classroom to introduce the concept of multispectral signal processing and to provide additional motivation for students to learn various concepts. We found that incorporating an open-ended final project, using IR and visible images to solve the challenge of image fusion, provided enhanced learning and significant motivation for the students. This was confirmed by the assessment data provided by questionnaires.



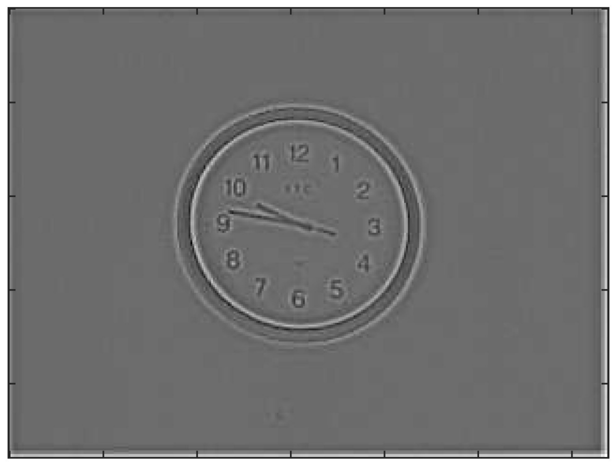
(a) A typical result.



(b) Another typical result.



(c) The worst result.



(d) The best result.

Fig. 5: Samples of student results for the final project. These are four representative results from a total of 15 teams that completed the project.

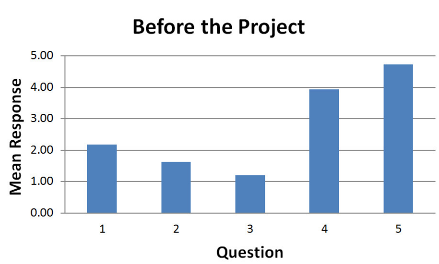


Fig. 6: The results of the “before the project” questionnaire.

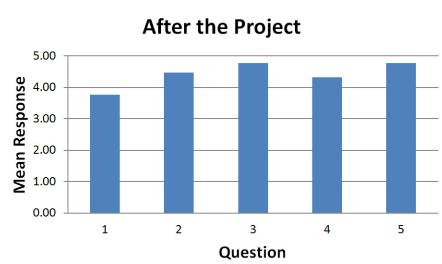


Fig. 7: The results of the “after the project” questionnaire.

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