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ARFurniture: Augmented Reality Interior Decoration Style Colorization

Huilin Tong, Department of Electrical and Computer Engineering, Tufts University, Medford, MA, USA
Qianwen Wan, Department of Electrical and Computer Engineering, Tufts University, Medford, MA, USA
Aleksandra Kaszowska, Department of Psychology, Tufts University, Medford, MA, USA
Karen Panetta, Department of Electrical and Computer Engineering, Tufts University, Medford, MA, USA
Holly A Taylor, Department of Psychology, Tufts University, Medford, MA, USA
Sos Agaian, Computer Science, The City University of New York, New York City, NY, USA

Abstract

*Augmented Reality (AR) can seamlessly create an illusion of virtual elements blended into the real world scene, which is one of the most fascinating human-machine interaction technologies. AR has been utilized in a variety of real-life applications including immersive collaborative gaming, fashion appreciation, interior design, and assistive devices for individuals with vision impairments. This paper contributes a real-time AR application, **ARFurniture**, which will allow the users to envision furniture-of-interests in different colors and different styles, all from their smart devices. The core software architecture consists of deep-learning based semantic segmentation and fast-speed color transformation. Our software architecture allows the user prompt the system to colorize the style of the furniture-of-interest within the scene on their mobile devices, and has been successfully deployed on mobile devices. In addition, using eye gaze as a pointing indicator, a head-mounted user-centric augmented reality based indoor decoration style colorization concept is discussed. Related algorithms, system design, and simulation results for **ARFurniture** are presented. Furthermore, a no-reference image quality measure, Naturalness Image Quality Evaluator (NIQE), was utilized to evaluate the immersiveness and naturalness of **ARFuniture**. The results demonstrate that **ARFurniture** has game-changing value to enhance user experience in indoor decoration.*

1. Introduction

Augmented Reality (AR) technology aims to bring the virtual digital components into human perception of the real world through display modules and mobile capture devices [2]. The idea behind AR technology is simple and straightforward, however the development of both hardware sensors and software platforms only brought augmented reality into a truly immersive generation in the late 90s.

Since virtual elements and real world scenes harmoniously exist together, the virtual information can be displayed and used to provide assistance in real-life applications [3]. Numerous augmented reality applications exist; for example, AR navigation systems are used in GPS apps or digital compasses to provide services like mapping direction, locating nearby restaurants, and updating traffic information based on location [4]. Another good example is the AR technology for gaming using the camera on devices like smartphones, tablets, or portable gaming systems, which has led to industrial revolution of enhancing gaming experience [5]. For instance, Pokemon Go [6], considered as the most breakthrough AR gamming app based on Android and iOS, quickly captured players' attention starting in 2016. Moreover, AR can be used from a routine physical examination to a complex surgical procedure, AR can provide immense benefits and enhancements to patient and doctors. In addition, the development of advanced learning technologies using AR for army training is undergoing, which can bring combat/chaos capabilities into a synthetic environment in order to optimize team and individual performance [7]. Augmented reality technology are widely used for countless applications in fields such as health care, manufacturing, navigation, education and learning, gaming, sports, entertainment, usability research , and consumer electronics [8-10].

With the fast development of software solutions, arrival of a great diversity of hardware sensors has brought augmented reality into a relatively mature level [11]. For instance, rapid advances in smart phones introduce new ways to perceive and interact with things in the world around us in the any-time-any-where manner. Another paradigm is see-through devices, such as smart glasses, which allows the user to see the real environment with user-designed computer-generated overlaid virtual effect. Moreover, with emergence of eye tracking technology, augmented reality has a great potential to be upgraded into truly immersive systems. Considering eye gaze as a bridge between human, machine, and the real world, people will be able to interact with the real-world using their eye gaze instead of head movement, which is the current directional input for AR headsets.

Augmented reality technology carries great promise, especially for mundane applications – such as picking the perfect furniture to fit your living room. Imagine you are currently sitting on your sofa, looking around and wondering how to optimize the space in your apartment while keeping it beautiful at the same time. It is quite common that such questions arise when you are shopping in furniture store or when you feel the pangs of panic when you plan a housewarming party before you had a chance to decorate.

This paper contributes an augmented reality (AR) application to solve the real-life headache when people are having difficulties selecting their furniture style. Our proposed software architecture, ARFurniture, allows users to envision their furniture-of-interests in different colors, different styles, and in real-time, all from their smart devices. ARFuniture has been successfully deployed on iOS devices, which first recognizes and segments furniture-of-interests in users' field-of-vision (FoV) and overlays a user-designed virtual color on top of them. ARFuniture can be potentially adapted for user-centric AR headsets supplemented with eye tracking capabilities to enhance user experience in interior decoration and furniture shopping. By looking directly at the furniture-of-interest for a predefined amount of time, user can select the object to be recolored within the scene.

The rest of the paper is organized as follows. Background information about augmented reality, hardware and software development for AR technology, the history of AR technology breakthroughs and latest applications in the field are introduced in

Table 1.Comparison of AR an VR technology

Augmented Reality	Virtual Reality
System augments the real-world scene	Completely immersive environment
User maintains a sense of presence in real world	Sensors are under control of system
Needs a mechanism to combine virtual and real worlds	Need a mechanism to feed virtual world to user
Hard to register real and virtual	Hard to make VR world interesting

section 2. The proposed system software architecture, ARFuniture, are detailed described in Section 3. Section 3 also presents example results. Furthermore, a no-reference image quality measure, Naturalness Image Quality Evaluator (NIQE), was utilized to evaluate the immersiveness and naturalness of ARFuniture. Finally, Section 5 draws the conclusions and outlines future works.

2. Background Information and Related Work

In this section, we will present the basic terminology behind augmented reality, hardware and software development for AR technology, and a brief overview of AR technology application breakthroughs.

A. Terminology

For a long time, scientists have been debating to establish a hierarchy between virtual reality (VR) and augmented reality (AR). Figure 1 shows a general reality-virtuality continuum proposed in [1]. The most popular definition for augmented reality (AR) is stated by Azuma in [12-14] that "an AR system combines real and virtual objects in a real environment; registers (aligns) real and virtual objects with each other; and runs interactively, in three dimensions, and in real time".

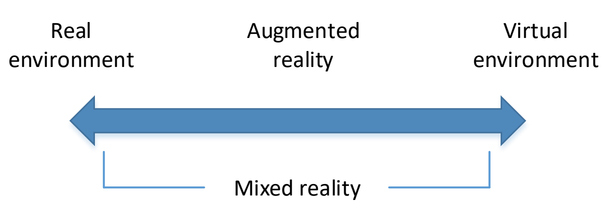


Figure 1. Reality-virtuality continuum proposed in [1].

B. Hardware and software development for AR technology

AR hardware can be categorized into see-through devices, hand-held, and monitor-based AR [15]. Modern eye tracking technology provides unobtrusive monitoring of pupil position [16, 17]. Head-mounted eye tracking technology is widely utilized in scientific research and relies on infrared cameras, which record and calculate the distance between the center of the pupil and position of artificially illuminated corneal reflections to effectively approximate gaze direction [18]. AR headsets with eye tracking add-ons open a new avenue for facilitating hands-free human-machine interactions. Figure 2 shows commonly used AR headset and an eye tracking add-on for AR headsets. By wearing the AR headsets with eye tracking capabilities, users will be able to engage with the real-world using their eye gaze direction as input.

Crucial software solutions for AR include user interface interaction, tracking and registration, such as visual UI, text display, gesture recognition, voice recognition environmental modeling, global positioning systems, and user's movement tracking.

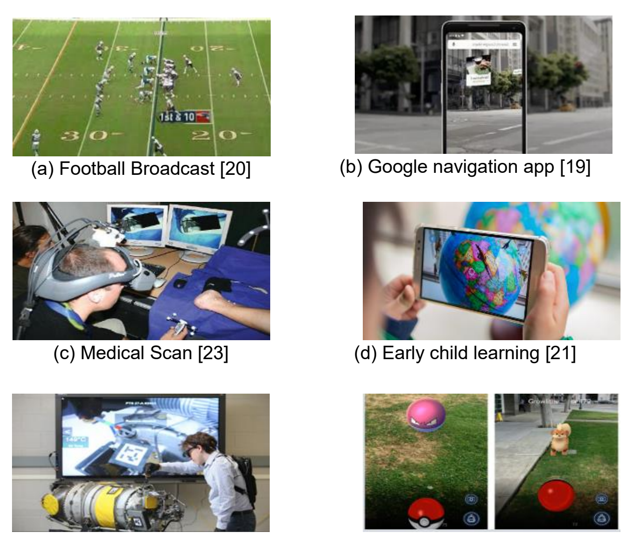
Figure 2. AR headset and an eye tracking add-on for AR headsets.

C. Applications overview

The very first AR technology systems were designed for the military, industrial and medical applications, then AR systems for commercial use and entertainment followed. Table 2 below shows the areas that benefit from augmented reality. Figure 3 presents example applications.

Table 2. Fields of applications benefit from AR

Fields of applications	Related work
Navigation	Mobil app [4] [19]
Entertainment	Gaming[6] Football Broadcast[20]
Education	Training/Learning[21]
Military	Design/assembly/maintenance[22] Combat and simulation [7]
Medical	Medical Scan and surgery[23]



(a) Football Broadcast [20]
(b) Google navigation app [19]
(c) Medical Scan [23]
(d) Early child learning [21]
(e)Jets assembly [22]
(f) Gaming [6]

Figure 3. Fields of applications Examples.

3. The proposed system: ARFurniture

In this section we will demonstrate the proposed ARFurniture. The complete system architecture for ARFurniture is presented in

Figure 4. A wearable device is carried by users, which has a front scene camera to capture the front scene view in a real-time manner. The core algorithm of ARFurniture first takes the live video and converts it into individual frames. A deep-learning based semantic segmentation is operated on each individual frame. Then a fast-speed colorization algorithm is implemented on the pixels on furniture-of-interests. Finally, the output images will be displayed to the user.

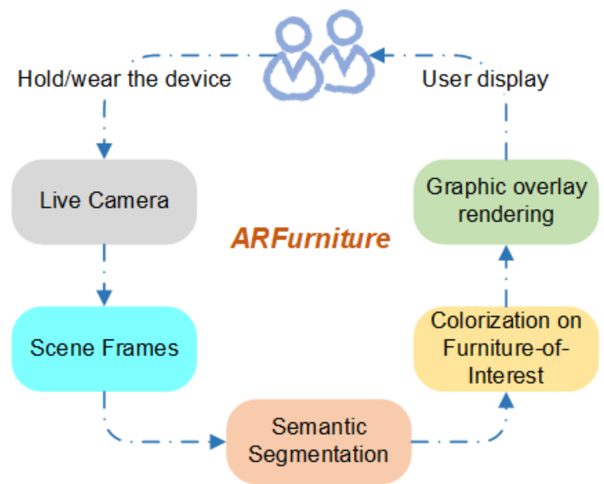


Figure 4. The complete system architecture for ARFurniture.

ARFurniture has been successfully deployed on smart phone devices (iOS).The development environment, detailed algorithms, configurations, challenges and accordingly solutions about ARFurniture for iOS are presented in section A. In addition, potential deployment of ARFurniture on augmented reality headsets is discussed in B. It is an eye-gaze directed, head-mounted, user-centric augmented reality interior decoration style colorization application.

Image Semantic Segmentation with Deep Learning: Image semantic segmentation algorithm aims to segment the target image into different classes and label each pixel with its corresponding class. Semantic segmentation only distinguishes different classes but not different objects which belong to the same category. A number of approaches have been used to improve semantic segmentation. DeepLab3 [24-28] has been released by Google which is one of the state-of-art image semantic segmentation models. Standard DeepLab3 is a deep convolutional neural network (DCNN) implemented in TensorFlow. DeepLab3 is trained in image classification, which is re-purposed to the task of semantic segmentation. Then a bi-linear interpolation is applied to up-sample by a factor of 8 the score map to reach the original image resolution, yielding the input to a fully-connected Conditional Random Field that refines the segmentation results.

Image Colorization: Colorization has become one important member in the computer vision community. Previous colorization algorithms can be described as two categories: 1) Transfer color according to the user selected reference images [29, 30]. 2) Other algorithms describe how to recover color automatically from grayscale without user interaction by using convolutional neural networks (CNNs) [31, 32].

Theoretic, all colorization algorithms can be applied in our proposed ARFurniture, for instance deep-learning style colorization. In this work, as colorization step, we utilized a fast-speed, low cost yet efficient colorization model as illustration. Furniture-of-interest is segmented from the front scene video frame, the pixels of segmented region is first transferred into to grayscale intensity image and then recolored back into RGB color model.

A. iOS platform

Mobile devices capture the current scene first as the system input. Apple AVFundation framework [34] is used to subtract each frame considering DeepLab is an image-based semantic segmentation algorithm. We transferred the Deeplab MobileNetv2 [35], which is a fast network structure designed for mobile devices, to coreML model. Training code and export model code were sourced from DeepLab Github [36]. Training set ware Pascal VOC data sets [37]. Segmentation process outputs the binary mask of furniture objects, then adjusting RGB weight for the image to change the color. Figure 5 below is the flow chart of iOS development of ARFurniture.

Few challenges are: 1) the segmentation process should be in real-time; 2) colorization process need to show the result without losing any details; 3) for iOS development, all the models should be trained to fit in CoreML format; 4) user interface on mobile device.

(1) Development environment

ARKit was selected as our AR software development kit (SDK) [38]. Apple announced ARKit during the Worldwide Developers Conference (WWDC) on June 5, 2017, which allows to create AR project on iOS devices easily. The newly released version ARKit 2 enables multiple users to use their iOS devices for a simultaneously AR experiences. ARKit 2 extends image detection to support full 2D image tracking, so movable objects can be part of

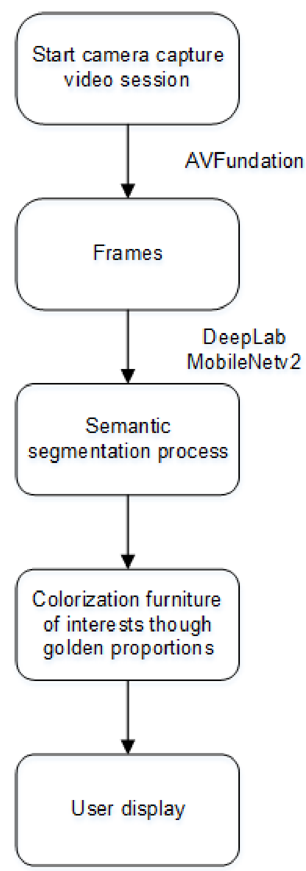


Figure 5. The complete flowchart for iOS realization.

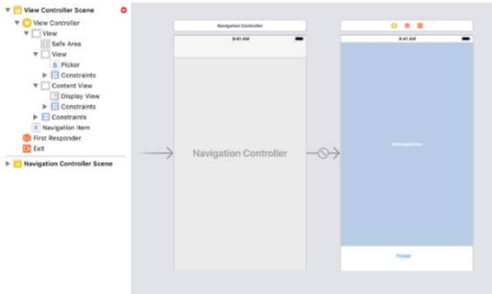


Figure 6. User interface design layout of iOS App

Figure 7. Transferred CoreML DeepLab model

AR experiences. ARKit 2 also adds the ability to detect 3D objects. The newly added features enable us to detect furniture in real-time video rather than 2D image.The reasons behind selecting ARKit 2 is that it is a free, open source, fast-speed, user-friendly platform.

(2) Real-time iOS ARFurniture processing

Apple AVFundation provides a video and audio processing framework. AVCaptureSession controls input and output of mobile camera device. Once the output function is defined, we can call this function every time a new frame is available. Detail implementation of the semantic segmentation algorithm is then defined in the output function.

Table 3. comparison between different AR SDK [39]

	Vuforia	Wikitude	ARKit
License	Free/Commercial	Commercial	Free
Support platform	Android, iOS, UWP	Android, iOS	iOS
Smart glasses	support	support	support
Unity	support	support	support

(3) iOS ARFurniture image semantic segmentation

As we need to build our application on mobile devices, one prerequisite is low computational load. Google newly released version of MobileNetv2 can achieve efficient performance to get real-time results on live video.

In order to utilize DeepLab model in iOS development, we need to convert it into CoreML model by using TFCoreML. The input of CoreML model is an image with 513x513 pixel size. Therefore, when dealing with input images, resize work must be done before using the model for segmentation. Those detected as background is set as 0 and those objects are all set to 1. Output segmentation result is a binary mask.

(4) Colorization

S. Agaian proposed a fast-speed and robust image colorization in [24], which utilizes the golden ratio proportion (1.6180). The presented recolor model was proved to recolor the image in an art-feel style. Figure 9 presents the example results for recoloring furniture-of-interest. The image recolor parameters from (a) to (f) in both examples are: (a) $(\psi, 1, \sqrt{\psi})$; (b) $(\psi, \sqrt{\psi}, 1)$; (c) $(1, \psi, \sqrt{\psi})$; (d) $(\sqrt{\psi}, \psi, 1)$; (e) $(1, \sqrt{\psi}, \psi)$; (f) $(\sqrt{\psi}, 1, \psi)$. Details about how to configure the parameters can be found in [24].

(5) Evaluation

A no-reference image quality measure, Naturalness Image Quality Evaluator (NIQE), was utilized to evaluate the immersiveness and naturalness of ARFuniture. Table 4 below presents the immersiveness and naturalness our new proposed ARFuniture results on iOS development environment. The resulting score has proved that our proposed system can provide an immersive augmented reality experience.

Table 4. NIQE immersiveness and naturalness score of ARFuniture results on iOS development environment

chair	niqe score	sofa	niqe score
original	3.6316	original	2.4575
(a)	4.3303	(a)	3.5205
(b)	3.9338	(b)	3.4975
(c)	4.1193	(c)	3.5062
(d)	3.6236	(d)	3.536
(e)	3.8534	(e)	3.5344
(f)	3.7562	(f)	3.5501

(6) Enhancement

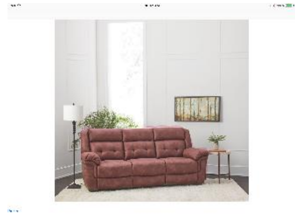
DeepLab shows poor result when dealing with complex environment with sunshine and shadow or furniture with similar colors. To achieve better and more detailed segmentation result, active contour can be utilized. Active contour uses image edge information [40], can simply be added to improve the segmentation process. Figure 8 shows the refined edge after using active contour.

However, this method is based pixels, which will take a long time to process data in each frame and hard to implement to fit into the real-time requirement.

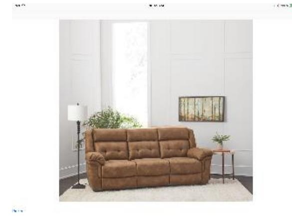
Original frame   Refined Segmentation   Recoloring

Figure 8. Refined semantic segmentation example results.

This is a brown color sofa in a living room. User can hold their phone and run the proposed ARFurniture app real-time changing the color of the sofa. Images on the right are the example recolored sofa screenshot captured from an iPad device. Ψ the golden ratio proportion (1.6180) parameter demonstrated in [24].



(a)



(b)

(c)

(d)

(e)

(f)

This is a white chair in a classroom of Tufts University. User can hold their phone and run the proposed ARFurniture app real-time changing the color of the chair. Images on the right are the example recolored chair screenshot captured from an iPad device. Ψ the golden ratio proportion (1.6180) parameter demonstrated in [24]

(a)

(b)

(c)

(d)

(e)

(f)

Figure 9. Example results.

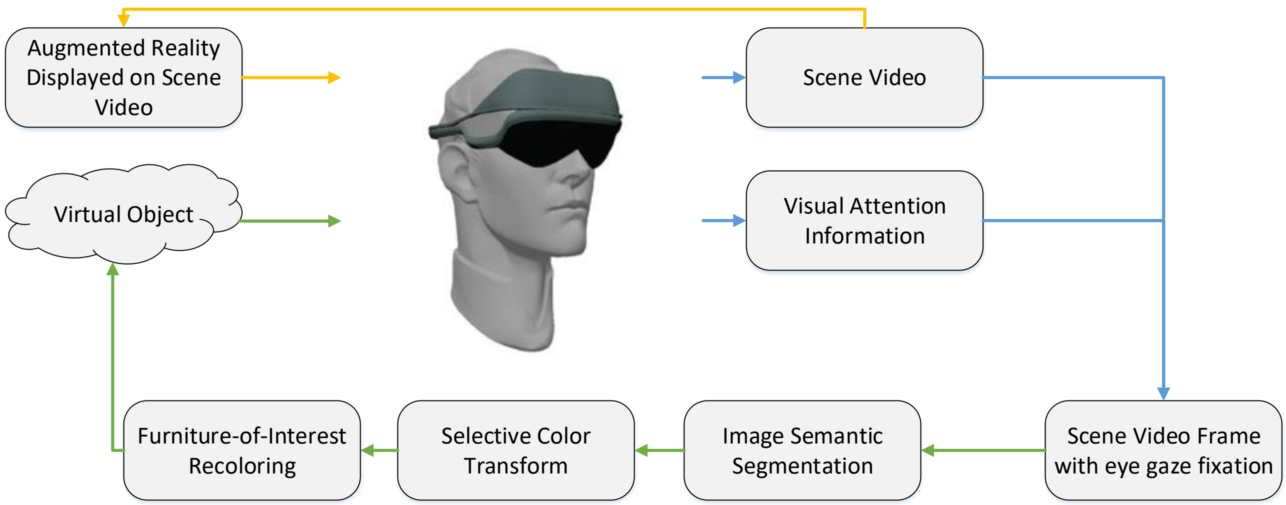


Figure 10. The complete flowchart of ARFurniture on augmented reality headsets.

B. ARFurniture on AR headsets with eye tracking

The complete system flow diagram of the ARFuniture software architecture is presented in Figure 10.

For investigating the application for indoor decoration, ARFuniture is developed to enhance user experience to the different furniture colors.

This application is consisted of a head-mounted AR headset containing basic eye gaze monitor, scene capture device, as well as audio-visual information such as augmented objects and sound module, superimposed on the real object.

Users are able to go on an augmented reality journey as they interact with real furniture in indoor room setting. Different styles and colors of furniture are digitally overlaid onto users' direct field of vision when viewing an indoor room setting. The users can see the augmented reality scene directing the headset (i.e., their gaze) and use a certain period of fixation duration on a specific area to trigger the style colorization function. Hence they can select the best style for their room. In addition, a voice module can be used to introduce more information of the specific furniture they are interested in. Overall, ARFuniture is a novel software architecture to improve indoor decoration shopping user experience.

4. Conclusion and Future Work

This paper contributes a real-time AR application, ARFurniture, which will allow the users to envision furniture-of-interests in different colors and different styles, all from their smart devices. Our software architecture successfully allows the user prompt the system to colorize the style of the furniture-of-interest within the scene on their mobile devices. In addition, using eye gaze as a pointing indicator, a head-mounted user-centric augmented reality based indoor decoration style colorization concept is discussed. Related algorithms, system design, and simulation results for ARFurniture are presented. Furthermore, a no-reference image quality measure, Naturalness Image Quality Evaluator (NIQE), was utilized to evaluate the immersiveness and naturalness of ARFuniture. The results demonstrate that ARFurniture has game-changing value to enhance user experience in indoor decoration.

Future works include 1) improving current image coloration method using deep learning recolor models and 2) deployment ARFuniture on AR headset hardware; 3) release our current ARFuniture in Apple store.

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Author Biography

Huilin Tong received her B.S. in Measurement and Control Technology and Instrumentation from North China Electric Power University (Beijing, China). She is currently pursuing her M.S. in electrical and computer engineering at Tufts University. Her current research interests include image and video processing, and machine-learning applications.

Qianwen Wan received her B.S. in information engineering from Wuhan University of Technology (Wuhan, China), B.S. in law from Wuhan University (Wuhan, China), and M.S. in electrical and computer engineering from Tufts University (Medford, MA, USA). She is currently pursuing her Ph.D. in electrical and computer engineering at Tufts University. Her current research interests include designing automated tools for cognitive science, analyzing mobile eye tracking data, facial recognition, image and video processing, and machine-learning applications.

Aleksandra Kaszowska received her B.A. from Clark University (Worcester, MA) and M.S. from Tufts University (Medford, MA) in Psychology. She is currently working towards her Ph.D. in Experimental Psychology and Cognitive Science at Tufts University. Her research interests focus on utilizing eye tracking and think aloud protocols for investigating cognitive processes underlying decision making, problem solving, and strategy selection in a variety of contexts.

Karen Panetta received the B.S. degree in computer engineering from Boston University, Boston, MA, and the M.S. and Ph.D. degrees in electrical engineering from Northeastern University, Boston. Dr Panetta is currently a Dean of Graduate Engineering Education and a Professor in the Department of Electrical and Computer Engineering and Adjunct Professor of Computer Science at Tufts University, Medford, MA, and Director of the Dr Panetta's Vision and Sensing System Laboratory.

Holly A. Taylor received her B.A. in Mathematics from Dartmouth College (Hanover, NH) and her Ph.D. in Cognitive Psychology from Stanford University (Stanford, CA). She is currently a full professor of Psychology, and adjunct professor of Mechanical Engineering, and co-director of the Center for Applied Brain and Cognitive Science at Tufts University.

Sos Agaian is currently a Distinguished Professor at The City University of New York/CSI. His research interests include computational vision and machine learning, large scale data analytic analytics, multi-modal data fusion, signal/image processing modeling, multimodal biometric and digital forensics, 3D imaging sensors, information processing and security, and biomedical and health informatics. He is a Fellow of the SPIE, a Fellow of IEEE, Fellow of the IS&T, and a Fellow of the AAAS.