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# Undercarriage Inspection of Railcars Using Duos Technologies VUE™ System

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## Summary

TTCI has evaluated the Vehicle Undercarriage Examiner (VUE™), a machine vision system from Duos Technologies, Inc. (Duos/Duostech) designed to inspect the undercarriage components of railcars. As a result of recent system improvements, the VUE™ has demonstrated strong progress in imaging capability along with an associated high reliability for identifying car types on a test train at the Facility for Accelerated Service Testing (FAST) at Transportation Technology Center (TTC) in Pueblo, Colorado.

The defect detection algorithms for this system are based on the foreign object detection (FOD) algorithms that Duostech has deployed for its security inspection systems. The FOD algorithm compares the most recent image of a railcar to a baseline or reference image. Differences between the images are scrutinized to identify defects. For the original FOD algorithm used in security inspection applications, differences on the order of 4 inches square are identifiable. For the VUE™, the size of the minimal detectable difference was reduced so that defects on the order of structural anomalies could be detected. With standard image reduction, this difference is about 1.6 inches square. With a proposed change in the processing, this difference can potentially be reduced to the order of 0.5 inch square. This should make it possible to detect defects such as large cracks or missing bolts. TTCI is still evaluating the detection statistics regarding probability of detection and the probability of false positives. It is estimated that the level of false positives may be high. Environmental factors such as weather, dirt, and sunlight can cause variations in the images. Duostech is working on methods to distinguish these variations from defects.

This study is being performed under the sponsorship of the Association of American Railroads (AAR) Strategic Research Initiatives (SRI) Program.



**INTRODUCTION**

As part of the AAR’s SRI Program, TTCI has been testing machine vision inspection systems for evaluating components of moving railcars. Thus far, systems designed to inspect safety appliances, truck components, and undercarriage components have been evaluated at FAST, which provides an ideal location for vendors to test and develop their detection systems without interrupting operations. In 2013, Duos Technologies, Inc. (Duostech) installed its Vehicle Undercarriage Examiner (VUE™) technology at FAST. The VUE™ hardware is similar to security inspection systems that Duostech has deployed at international border crossings and in Mexico. TTCI has evaluated the latest revisions of VUE™ and found that it has demonstrated a strong imaging capability and an associated high reliability of identifying car types on the test train at FAST.

**VUE™ HARDWARE**

The system consists of several components. Figure 1 shows the primary camera and lighting module. This module mounts on top of a tie on a tangent strip of track.



**Figure 1. The VUE™ Camera/Lighting Module, and Precision Linear Speed Sensor**

The three cameras within this module are high speed, high resolution, line scan cameras. They capture images along an elongated (300x2048 pixels) band that spans the width of the carbody. The optical opening is narrow, opening just wide enough to allow light to enter from directly overhead. This reduces infiltration of ambient light.

High intensity LED lighting is mounted within this module directly adjacent to the camera opening. These lights illuminate the narrow strip of the undercarriage on which the cameras are focused. There is no hinged cover on the camera module. The lens is kept clean by an air knife — a component of the system that blows high velocity air over the lens opening when the train is passing. A wayside blower shown in Figure 2 powers the air knife and circulates cool air over the camera and lighting module.



**Figure 2. Blower Motor for Air Knife and Cool Air Circulation**

The line scan images are stitched together into a continuous image. In order to do this accurately, train speed must be known very precisely. Duostech has created a high-precision Linear Speed Sensor (LSS) for this purpose. Figures 1 and 3 show the high-precision speed sensor. The LSS is concurrent with the camera and lighting module. It attaches to the web of the gage face using strong rare earth magnets. The sensor has a series of closely spaced wheel flange sensors that measure the arrival of each wheel multiple times as it passes the camera module. This speed is then converted to a nominal frequency that controls the line speed of the cameras.

The system requires additional wayside components for identifying individual railcars. Figure 3 shows these wayside components. Automatic Equipment Identification (AEI) readers are an integral part of the VUE™. They are co-located with “car cutting” lasers and situational cameras. The situational cameras provide a visual recording of each car passing the system. The laser sensors are used to identify the ends of each car. The AEI and car end information is used to parse the continuous image at the exact location of each car.

Additional wayside components include a train presence detector to alert the system when the train approaches, and a control box for the precision speed sensor control module. At FAST, these components are mounted on a large wooden pole, as shown in Figure 4.

The VUE™ system also requires a wayside bungalow or equipment shed to house the control/storage computers and the communications networking equipment. The computer rack is about 6 feet tall and would fit into most common, weather tight, climate controlled wayside spaces.

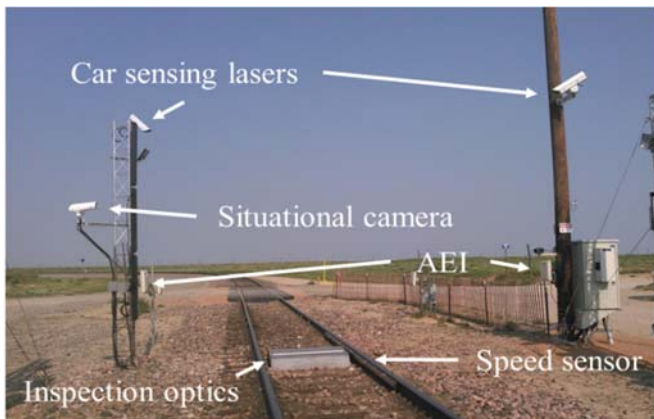


Figure 3. VUE™ System and Wayside Equipment



Figure 4. VUE™ Wayside Control Box

**VUE CAPABILITY**

The current version of the VUE™ system was installed by Duostech in December 2015. Imaging performance of this system is superior to the level of hardware that was originally installed in 2013. In the early version, light infiltration and other sources of image noise caused the component identification algorithms to perform poorly.

Figure 5 shows an example of the previous image quality versus the present. The car and component identification algorithms have now progressed to a prime accuracy of over 99 percent.

The system operates by comparing the most recent car image to a reference image of the same car. Defects are detected by identifying the differences between the two images. To accomplish this, a number of processing steps must be followed. First, the VUE™ identifies the car type by its visible features, and then Duostech applies a correlating railcar template. This template is specific to each car type and is used by the processing algorithm to mask regions of interest that it will be inspected for image variations. For the current testing at TTC, the component masks are programmed to inspect the structural underbody components; e.g., center sill and cross bearers. (The system cannot inspect components that are not directly visible on a line of sight from below such as body bolsters, which are obscured by the truck bolster.) Comparisons are made between the current image and the reference image within the masked area. The reference is stored the first time a given car passes the system.

Difference detection requires analysis over a two-dimensional area of the image. Duostech has been working to determine the smallest area difference that can be reliably detected. As an example, TTCI created an artificial crack on the center sill just aft of the second axle. This crack was actually a bead of silicon caulk about 6 inches long and a 0.25-inch wide. Figure 7 shows the reference image and the analyzed current image with the artificial crack circled in red.

After the component mask is applied, the absolute difference between the images is created. This raw difference is shown in the left hand image in Figure 8. The simulated crack is clearly visible, but there are also other features (noise) visible in this raw difference image.

Additional filtering and thresholding are required to eliminate this noise. For features the size of this crack, the defect is lost after thresholding.

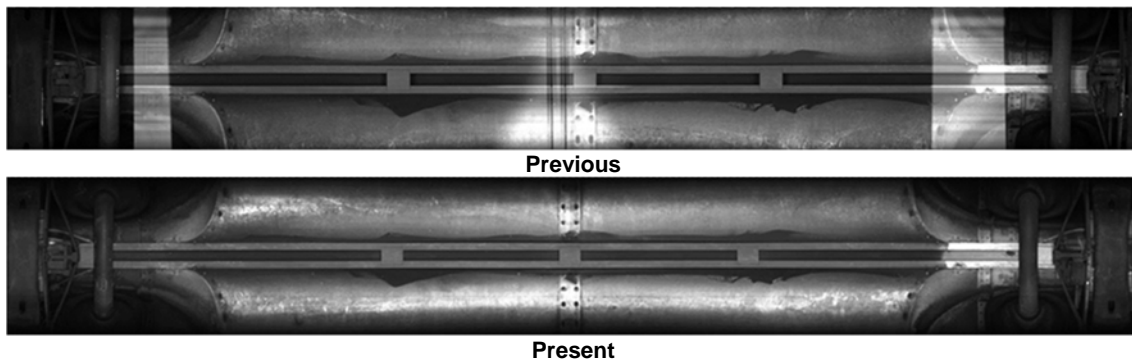
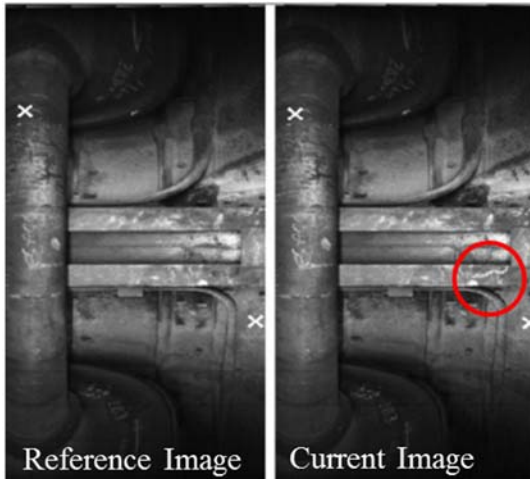


Figure 5. Example of VUE Image Quality Improvement with Latest Inspection Optics



**Figure 7. Reference Image versus Current Image for a Simulated Crack Defect**



**Figure 8. Raw Difference versus Filtered Threshold Image Difference**

Duostech performed a sensitivity analysis using a virtual target array. With this process, an actual image was modified with targets of varying size. The modified image was processed through the FOD algorithm. Duostech determined that with the level of processing used in the previous example, the minimum detectable defect size was about 1.6-inch by 1.6-inch. Therefore, a defect such as the crack, which cannot completely cover the 1.6-inch by 1.6-inch area, is always susceptible to removal by the threshold filtering.

Duostech then determined that by changing its image processing pipeline, it could reduce the minimum detectable defect size even further. Using a sensitivity analysis once again, Duostech processed the data without the image reduction step, which is usually performed at the very beginning to reduce processor burden. By analyzing

the entire image, Duos determined it is possible to detect image differences as small as 0.5-inch by 0.5-inch. This is on the order of bolt heads and rivets. As such, it should be able to detect missing bolts and large structural cracks that have opened to more than 0.5 inch.

### SYSTEM PERFORMANCE

The Duostech VUE™ system has been imaging the FAST train nightly with good reliability. Images generated during the dark hours are consistent and clear. Occasional image noise is introduced during those hours when the sun is near the horizon, or at high noon. Because Duostech is continually updating the detection algorithms, TTCI has not yet scheduled a test train with known defects to pass the system. There are no performance summary statistics available as of this writing, although false positive detection is expected to be high. Duostech is working to reduce the false positive tendency. Environmental factors such as dirt and rain can cause image differences that must be distinguished from actual defects. The operating environment at FAST provides an ideal opportunity to test the false alarm capability. Repeated passes of the same train produce statistical results that can be analyzed for trends. Unexpected variations can be traced back to the actual conditions at the time of occurrence. This should facilitate elimination of environmental factors.

### IMPLEMENTATION

To date, two North American railroads have contracted Duostech to install the VUE™ undercarriage examiner; one eastern and one western line, respectively. These installations also include additional camera equipment for monitoring other components of the train.

### FUTURE WORK

TTCI has requested that Duostech increase the number of components inspected. Initially, the system was configured to inspect the structural body components including center sill, draft sill, and body cross bearers on the FAST gondolas. The system also produced high definition images of the draft sill and couplers. Exploratory work was performed in 2015 to investigate the feasibility of monitoring draft gear components.<sup>1</sup>

This work was inconclusive, but was performed before the most recent hardware upgrades were installed. Duostech is working on preliminary methods to monitor draft gear and coupler performance.

### REFERENCES

1. Witte, Matthew, R. Chaparro, Jr., and A. Meddah. "Facilitating Machine Vision of Draft Gears." *Technology Digest* TD-16-049. TTCI/AAR, Pueblo, CO. November 2016.

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