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Development of Automated Inspection of Structural Components Algorithm

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Summary

Railroads are increasingly turning to technology to aid in the inspection of rolling stock. As part of the Association of American Railroads' Strategic Research Initiatives Program, the Transportation Technology Center, Inc. is overseeing the development of the Automated Inspection of Structural Components (AISC) system by Beena Vision Systems Inc.

This is a machine vision based system designed to inspect the railcar's undercarriage. Proof-of-concept testing of the system and hardware development was completed in 2011. Preliminary results show good detection reliability and repeatability for most of the basic components listed. Additional development and testing is continuing to complete the list.

Software development to create algorithms to fully automate the system is now under way. To aid in this effort, a risk assessment model was completed using Federal Railroad Administration accident statistics.¹ This model was then used to create and prioritize the following list of components that have the potential to be inspected by the AISC system:

1. Coupler retaining pin/cross key, draft gear/mechanism
2. Brake rigging, brake components, hand brake linkage or connection, brake pipe
3. Truck bolster, truck side frame
4. Center sill, side sill, draft sill, body bolster, other body defects
5. Bottom outlet doors, bottom outlet door attachment

The first step in algorithm development was to conduct tests on images generated by the system to determine the feasibility of detecting the listed components.

Once component detection has been satisfactorily completed, work will begin on component evaluation. The algorithm will need to distinguish between good components and defective components. This will require manual analysis of the images to positively identify various failure modes for each component. The algorithm will then be revised to recognize these conditions as defective and alarm as necessary.



INTRODUCTION

Machine vision technology has been used in manufacturing for some time. The technology lends itself to performing routine inspections where repetition and inspector fatigue are issues or where environmental conditions hinder or preclude manual inspection. In recent years, railway applications like wheel profile and brake shoe measurement systems have been developed and deployed with some degree of success.

Because of their location and orientation, inspection of undercarriage components is difficult to perform during routine manual train yard inspections. Undetected defects can result in catastrophic failure of undercarriage components. Machine vision has the potential to improve the undercarriage inspection process by providing detailed assessment of undercarriage components.

BACKGROUND

Under direction of the Association of American Railroads’ Strategic Research Initiatives (SRI) Program, the Transportation Technology Center, Inc. (TTCI) has been involved in the research and development of a machine vision based inspection system to evaluate the condition of railcar undercarriages. An initial proof-of-concept demonstration was completed by the University of Illinois at Urbana-Champaign in 2007. Hardware development of the Automated Inspection of Structural Components (AISC) system was started at the Transportation Technology Center (TTC), Pueblo, Colorado, in conjunction with Beena Vision Systems Inc. and, after extensive prototype testing, was completed in 2011. The final arrangement uses a total of nine line-scan cameras positioned below the rail. Each camera gives a slightly different perspective of the railcar undercarriage.

Figure 1 shows a graphical representation of the AISC camera placement. Figure 2 shows the AISC installation at Gallup, New Mexico. Algorithm development to fully automate the system is currently under way.

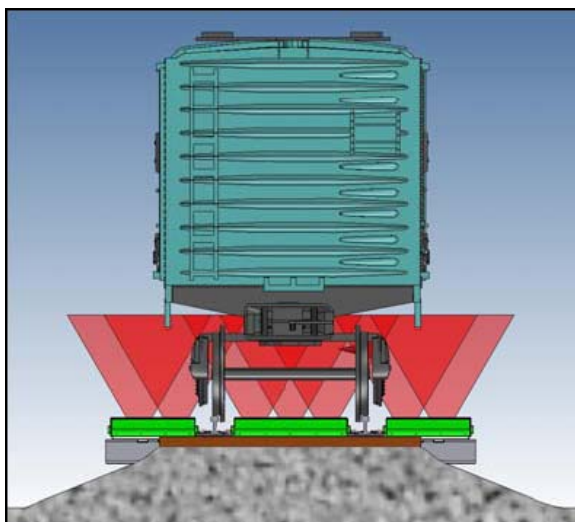


Figure 1. AISC Camera Schematic



Figure 2. AISC located at Gallup, NM

To facilitate algorithm development, a risk assessment was completed to evaluate the risk associated with each type of component failure/problem that is applicable to inspection by the AISC system. This risk model was used to prioritize algorithm development for the AISC system. Once the risk assessment was completed and components were prioritized, algorithms were tested for their ability to detect the targeted components.

METHODOLOGY

Development of the risk model used Federal Railroad Administration (FRA) accident statistics to determine the total number of undercarriage component related accidents and the associated costs.¹ Table 1 lists the accident cause codes identified as potentially caused by undercarriage component defects/failures that may be visible using the AISC system. Only the primary accident “cause of” was used in this analysis. Defects were then prioritized based upon the average cost per incident.

Once component prioritization was completed, images generated by the AISC systems located on track at TTC’s Facility for Accelerated Service Testing (FAST) and on the BNSF railway at Gallup were used to test the detection capabilities of the algorithm. Most of the mechanical parts on the undercarriage of a railcar are geometrically well defined. With the images provided by the AISC system, there is a potential to use this geometric information to detect the relevant mechanical parts for image analysis. The algorithm looks for edges and the geometry of the various parts for detection. As an example, wheel axles are always present in a pair. The shape and the distance between the two axles are very consistent. Therefore, the axles, once detected, offer a very reliable reference with which the other objects-of-interest; e.g., truck bolsters and brake-beams, can be located.

Table 1. Cause Codes used in Risk Analysis

Cause Code	Undercarriage Component
E02C	Brake pipe
E04C	Brake components
E07C	Rigging down or dragging
E0HC	Hand brake linkage/connection
E20C	Body bolster
E21C	Center sill broken or bent
E22C	Draft sill broken or bent
E27C	Side sill broken
E29C	Other body defects
E33C	Coupler retaining pin/cross key
E34C	Draft gear/mechanism
E44C	Truck bolster
E45C	Side frame
E85C	Bottom outlet door
E86C	Bottom outlet door attachment

RESULTS

Accident Frequency of Occurrence

Data from FRA accident statistics was used to generate a comprehensive list of accidents for approximately the past 5 years.¹ Figure 3 is a plot of the average number of accidents per year between 2006 and November of 2010 in rank order.

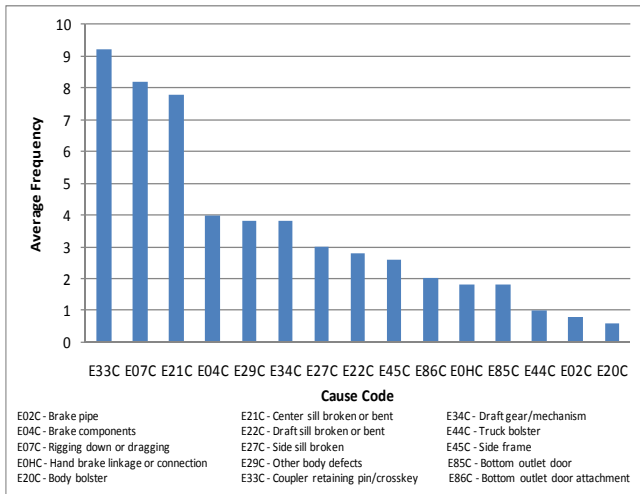


Figure 3. Average FRA Accidents per Year between 2006 and 2010

Accident Cost

The FRA accident data was queried for cost for those cause codes identified.¹ Each accident listed in the FRA accident data gives an accident damage cost. The total accident cost per year for each accident cause code and the average count per year were used to calculate an average cost per accident.

Figure 4 displays the average cost per accident since 2006 in rank order.

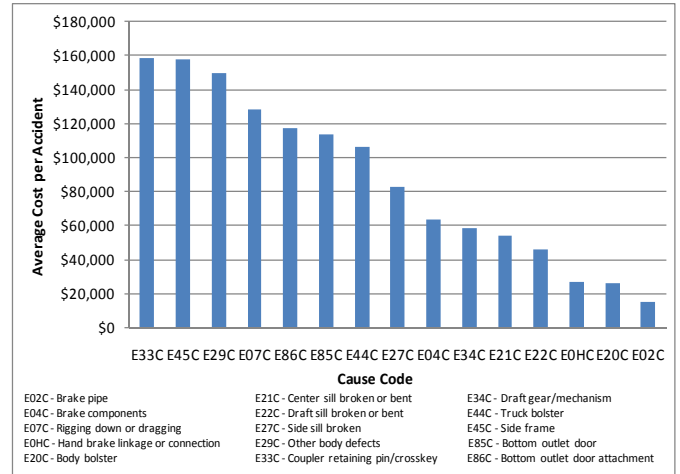


Figure 4. Average Cost per Accident

Risk Assessment Model

A risk assessment model was completed using the combination of data shown in Figures 3 and 4. Data from each of the figures was given a rank based on the number of accidents per year for each cause code and the average cost per accident. Next, the product of the two ranks was calculated to determine a score or severity index. This orders the cause codes by risk. The lower the score, the more risk.

Table 2 shows the breakdown of cause code and risk. Results from the model indicate that broken coupler retaining pin/cross key failures result in the most severe accidents. This is followed by brake rigging caused accidents. These 15 cause codes can be grouped according to similarity into the five classifications shown below Table 2.

Table 2. Risk Ranking

Cause Code	Avg. Freq.	Avg. Freq Rank	Avg. Cost	Avg. Cost Rank	Score	Rank
E33C	9.2	1	\$158,674	1	1	1
E07C	8.2	2	\$128,279	4	8	2
E29C	3.8	5	\$150,049	3	15	3
E45C	2.6	9	\$157,710	2	18	4
E21C	7.8	3	\$53,745	11	33	5
E04C	4	4	\$63,554	9	36	6
E86C	2	10	\$117,156	5	50	7
E27C	3	7	\$82,446	8	56	8
E34C	3.8	6	\$58,335	10	60	9
E85C	1.8	12	\$113,600	6	72	10
E44C	1	13	\$106,405	7	91	11
E22C	2.8	8	\$45,877	12	96	12
E0HC	1.8	11	\$26,946	13	143	13
E02C	0.6	15	\$25,739	14	210	14
E20C	0.8	14	\$14,971	15	210	15

1. Coupler retaining pin/cross key, draft gear/mechanism (E33C, E34C)
2. Brake rigging, brake components, hand brake linkage or connection, brake pipe (E07C, E04C, E20C, E0HC)
3. Truck bolster, truck side frame (E44C, E45C)
4. Center sill, side sill, draft sill, body bolster, other body defects (E21C, E27C, E22C, E02C, E29C)
5. Bottom outlet doors, bottom outlet door attachment (E85C, E86C)

These classifications are listed in order based on the highest risk model rank in each classification. This list was used to prioritize AISC system algorithm development.

Algorithm Testing and Development

Tests were conducted to determine if detection and segmentation of some of the basic prioritized components could be performed in a relatively reliable manner. Using images generated by the AISC systems located at FAST and Gallup, an initial investigation of the system’s capabilities to reliably and repeatedly detect components of interest was performed. Axles, truck bolsters, and brake beams were identified repeatedly by the algorithm. This same process is currently being tested to locate coupler pin retaining straps, body bolsters, brake pipe components, and brake rigging components.

Figure 5 shows an AISC generated image of a railcar undercarriage. The image is enhanced by the algorithm using a well-established technique called histogram equalization.



Figure 5. Enhanced AISC0-Generated Image

Figures 6 and 7 show the initial steps for algorithm detection of the axles, truck bolster and brake beams. These parts are well defined by edges and geometric features that can be exploited for successful detections.

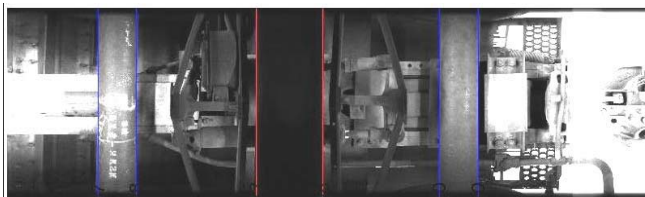


Figure 6. Edge Detection of Axles and Truck Bolster



Figure 7. Classification of the Bolster and Brake Beams

CONCLUSION

Test results indicate a possibility of automating the AISC inspection system to detect the components identified by the risk assessment model. However, due to the complexity and variety of railcar undercarriage configurations, it is necessary to continue validating the detection algorithms on additional images generated by the AISC systems. Further development will also be necessary to complete the detection of all of the components identified by the risk assessment study. This work is ongoing.

FUTURE WORK

Once component detection has been accomplished, work will begin on component evaluation. The algorithm will need to distinguish between a good component and a defective component. This will initially require manual analysis of the images to positively identify various failure modes for the each component. The algorithm will then be revised to recognize these conditions as defective and alarm as necessary. This work will continue under the SRI program at the direction of TTCI personnel in conjunction with Beena Visions Systems Inc.

REFERENCES

1. Federal Railroad Administration. <http://safetydata.fra.dot.gov/OfficeofSafety>