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A Machine Vision System for Monitoring Railcar Health: Preliminary Results

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Summary

Wayside inspection systems are under development to examine mechanical components using machine vision techniques and to assess the health of certain aspects of a railcar. The machine vision system will use advanced cameras stationed trackside that image railcar components as trains pass by. Inspection algorithms will be used to analyze these images to detect worn or defective components.

One machine vision system researched by the University of Illinois Urbana-Champaign (UIUC), under sponsorship of the AAR's Technology Scanning Strategic Research Initiative, has demonstrated that machine vision can be used for inspection of railcars. The UIUC prototype system inspect wheel, truck, and brake system components by automated, machine vision-based systems. Machine vision-based wheel and brake shoe inspection systems are already or will soon become commercially available. Inspection of other truck components will soon follow. This further work by UIUC will focus on other aspects of car inspection, particularly in the area of safety appliances.

Federal Railroad Administration (FRA) data indicates that failure of mechanical components is the primary cause of over one-third of mainline railroad derailments. For many of these components, the principal means of monitoring their structural integrity is by visual inspection. Mechanical inspectors must walk each train and carefully examine each component to determine if repairs are needed. Under these conditions the potential exists for certain defects to be missed.

Another difficulty is that the present system has no "memory" of previous inspections. Coupled with FRA inspection regulations, this means that the same components are being inspected repeatedly at relatively short intervals, even if they were judged more than satisfactory in their previous inspection. Components have service lives far in excess of the typical inspection interval (maximum ca. 1,000 miles or less). Consequently, much of an inspector's time is expended examining items that do not need inspection. Automating as many of the tasks as possible will enhance both efficiency and safety.

The inspection system approach was developed based on a review of background information including inspection procedures, existing automated systems, inspection priorities of railroads, and repair shop on-site visits.

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INTRODUCTION

Machine vision systems are being developed for wayside inspection of moving railroad cars to assess the condition of their components. The system described here uses a camera to image each railcar truck as trains pass by. Machine vision algorithms will analyze these images for detecting worn or defective components using guidelines set by the Association of American Railroads (AAR).

The current means of monitoring railcar component condition is by frequent manual inspection. The system being developed can improve both the efficiency and effectiveness of the mechanical inspections and provide tracking of the railcar component's health over time. Furthermore, the system could automatically alert appropriate personnel about critical component problems prior to failure.

APPLICATION OF MACHINE VISION FOR INSPECTION

A study was conducted to better understand the railcar inspection procedures carried out by railroad personnel. Sources of information used were manuals, videos, site visits, and component failure histories. The suitability of different machine vision techniques to different inspection tasks was also evaluated.

Background information covering the breadth of the required component inspections performed on typical freight cars was acquired from the *Field Manual of the AAR Interchange Rules*, the Railway Educational Bureau's inspection guide, and an inbound car inspection video from Training Technologies, Inc., among other sources.^(1, 2, 3) Field research was conducted at the CN Rail yard in Champaign, Illinois, and the Norfolk Southern (NS) repair shop in Decatur, Illinois, to obtain a firsthand understanding of how inspections are performed and the underlying visual methods used by manual inspectors to detect component wear and abnormalities. A database of hundreds of images has been assembled and categorized. In addition, a survey of existing work on other automatic inspection systems currently under development was conducted to avoid duplication of other efforts.⁽⁴⁾

High priority inspection tasks were identified through discussions with railroad personnel and other performance data and a prioritized list of these was developed based on discussions with railroad mechanical and TTCI personnel. Wheelsets, brake components, bearings, and several other truck components were emphasized. In addition, factors affecting the ratings included safety issues and analysis of train derailment cause statistics.⁽⁵⁾

Requirements of machine vision techniques and image acquisition methods were used to determine which inspection tasks would have a high likelihood of success using a machine vision approach. Some of the criteria used included the visibility of the component to be inspected, the particular inspection requirements, the identification of a reasonable computer vision solution or approach, and the expected level of the overall task difficulty.

INSPECTION SYSTEM UNDER DEVELOPMENT

The future wayside inspection system must be able to image parts of a moving train, identify critical elements in the train, analyze key portions of the images for worn or defective components, and withstand the railroad environment. There are three principal elements of the machine vision system design: the imaging system plan, the machine vision algorithms under development, and the future wayside system.

The imaging approach has been developed to maximize the number of components inspected while using a minimum number of cameras in easily mounted locations. This has been achieved by identifying a group of components, from the high priority inspection list, which can be imaged from the side rather than underneath or above, thereby alleviating many camera-mounting difficulties. This single camera view of the truck is taken parallel to the truck from approximately axle height. Half of the truck is imaged at a time, covering the outer leading wheel to the middle of the spring set. (This image is referred to as the "half-truck view.") A companion image is taken of the trailing wheel and is reversed before processing so all images have the same basic structure. Figure 1 is an example of the half-truck view. The main components that can be seen in this view are the wheel, side frame, brake shoes, bearing adapters, end caps, friction wedges, and the spring nest.

Currently designs for a portable trackside unit are underway to capture images from actual moving trains at local yards. This prototype will be able to acquire images under different circumstances such as location, lighting, or weather. The images from this unit will be used to further test the machine vision algorithms under these environmental conditions. These design efforts are in different stages of development. The following section gives highlights of the progress in these areas.

The preliminary development of the machine vision algorithms has concentrated on the identification of the wheel, the brake shoe area, the bearing end cap bolts, and the spring nest.

The components are located by searching at the pixel level using geometric shape constraints and heuristic knowledge of the structure of the four-wheel truck. The wheel is located first, then the bolts, brake and spring areas. Once these part locations have been identified, inspections can be performed using the specific criteria for that particular component. For example, once the bearing end cap and bolts are identified, the presence of all of the required bolts can be verified. As for the brake shoes, once they are identified, measurements on the amount of wear can be made. Similarly, missing or fully compressed springs can also be determined.

PRELIMINARY RESULTS

Several components of interest have been successfully located using custom machine vision algorithms operating on images of actual railcars. The inspection criteria of these components have been outlined and are being incorporated into the existing algorithms for component verification. As an example, a method for fault identification for a missing component has been developed.

Several algorithms have been developed that can identify the location of particular parts of a railcar truck. Figure 1 shows that the wheel of the truck has been identified and highlighted in the image. The algorithm has also identified the location of the brake shoe, which has been highlighted as well. This is the first step in the determination of the state of the brake (whether the brake is applied or not) and in the identification of the brake shoe itself. This will then allow the determination of the shoe thickness by calibrated measurement techniques. This thickness measure will be automatically compared to the minimum requirements for brake shoe thickness specified by the AAR (e.g., 1/2 inch for cast iron and 3/8 inch for composite shoes).



Figure 1. Brake Location Identified

Figure 2 depicts the identification of the location of the spring set and the springs highlighted by the algorithm. From these measurements, the algorithm will be able to determine if the springs are fully compressed. It should also be possible to determine if one of the front springs in the set is missing.



Figure 2. Spring Set Location Identified

Figure 3 shows that the bearing end cap bolts have been identified and highlighted by the algorithm. The algorithm is robust enough so that the bolts can be identified despite the many types of bearing end cap styles. This algorithm can then determine if the required number of bolts is present. It was tested on an image with a missing bolt provided by the NS car repair shop (Figure 4). Note that the image is not taken from exactly the same perspective as our other images, but the algorithm was still able to successfully detect the missing bolt.

Currently, UIUC is developing an expanded database of images taken from the half-truck view that contain worn or missing components for further testing of the algorithms.



Figure 3. Bearing End Cap Bolts Identified



Figure 4. Missing Bolt Detection

FUTURE DEVELOPMENT

The next steps for this project involve algorithm development, use of new prototype cameras, and design of the prototype trackside unit.

Machine vision-based inspection of railcars is being implemented with the development of wheel and brake inspection systems. The work done by UIUC helped show that such systems are technically and economically feasible. Commercial development of products directed at these components has begun and some are being tested at TTCI. Further AAR-sponsored research by UIUC will be directed at other aspects of car inspection that have potential for this sort of automation.

Future plans include experimentation with newly developed camera prototypes. These could be used to provide properties such as panoramic views, images with even illumination, and images with sharp focus. These prototypes can provide a panoramic view with both wheels of a single truck in one image or even a single image of a section of an entire train. One prototype system could provide these panoramic images with all objects in focus regardless of their distances from the camera. A portable trackside camera unit will also be designed to capture images of moving trains. This will be the initial method for field testing the algorithms. Incorporation of computing and external communication will also be developed in future units.

CONCLUSION

Inspection of railcar components is an important element of maintaining railcar health and improving railway safety. However, the large number of components on a single railcar, combined with the large population of railcars (over 1.5 million) in service makes this a daunting task. The approach of using machine vision to aid in the detection of these worn or defective components shows promise. Preliminary results have demonstrated the feasibility of capturing images, analyzing them and successfully recognizing safety-critical railcar components. Many inspection tasks have been identified that can potentially be performed by a trackside unit with a camera imaging system and the appropriate machine vision algorithms. These inspection results could be transferred to railroad information technology systems and automatically record and update data for each railcar, thus enabling possible trends to be detected and allowing for better programming and scheduling of maintenance. This type of system would be capable of detecting problems on moving trains prior to component failure.

References

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