Technical Paper

Development of Missing tooth / Large rocks Detection System

Ryohei Emoto

Yuya Murakami

Shoji Sonoyama

In the operation sites of crushing and mining of Komatsu's customers, production activities are performed day and night. The production equipment used there are expected to provide high operating ratio. To enable our customers to use Komatsu machines with peace of mind, we have developed the missing tooth / large rocks detection system for a large wheel loader by utilizing AI. We introduce the outline and the function of this system which prevents breakage of the production equipment by the missing tooth and tire cut causing downtime of the loading machine.

Key Words: *Crushing, Mine, Wheel loader, Missing tooth, Large rocks detection, Image recognition, Deep learning*

1. Introduction

Most of Komatsu products are used as production equipment in operation sites of our customers. They are expected to offer high operating ratio and productivity for long hours every day to contribute to the customers. Considering such characteristics of the products, Komatsu develops technologies for monitoring the machine status to enable the customers to use the machines with peace of mind. It aims at not only machine maintenance but also improvement of productivity and safety in the customers' worksites.

This time, we have developed the missing tooth / large rocks detection system for a large wheel loader WA900-8R which automatically detects missing teeth of the bucket *1 and large rocks *2 around the machine (**Fig. 1**). Here we introduce the main features of the system.

*1: Missing of the teeth (claw) attached to the edge of the bucket for enhancing the digging performance by the breakage due to an impact during loading work.

*2: Rocks falling down after blasting or during loading in a mining site. Many of them have a sharp edge like a knife.

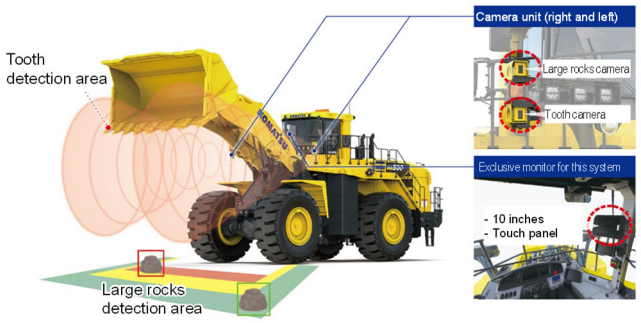


Fig. 1 Missing tooth / large rocks detection system

2. Target of development and methods of achievement

In crushing sites where large wheel loaders operate, missing tooth can cause failures of production equipment, such as damage of the crusher, while contact with a large rock can lead to tire breakage. Although a missing tooth is not a frequent occurrence, when it happens, it can cause a serious opportunity loss due to the production stop/decline, in addition to the repair cost of the production equipment. Tire breakage caused by a contact with a large rock can cause a high cost of the tire especially for large machine models, as well as a profit loss due to downtime during the repair. Furthermore, searching for the tooth that fell off in the operation site is very dangerous.

To address these issues, Komatsu has developed the missing tooth / large rocks detection system which

automatically detects missing teeth and dangerous large rocks by using AI. This system has been developed for the WA900-8R, a large wheel loader, which is mainly operated in the loading sites of blasted rocks.

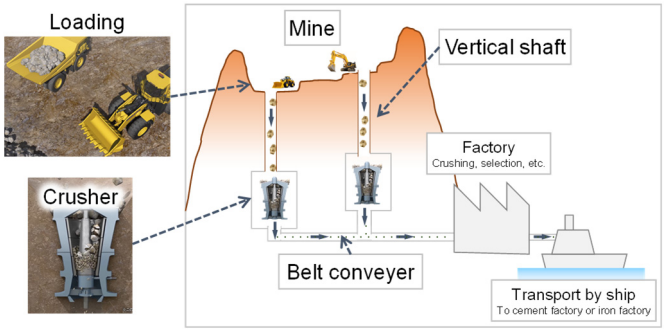


Fig. 2 Example of crushing site

Fig. 3 Missing tooth and contact with a large rock

3. Major features

3.1 Outline of functions

The missing tooth / large rocks detection system monitors the condition of the bucket teeth and the presence of large rocks with four cameras laid out around the right and left head lamps.

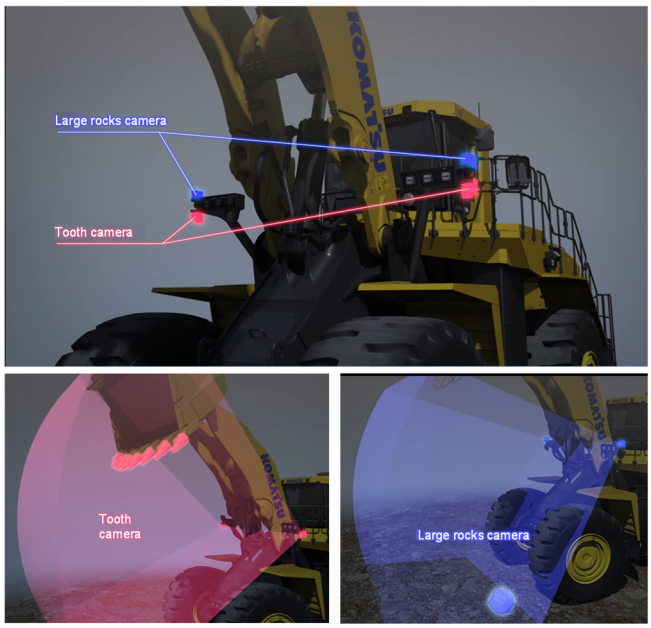


Fig. 4 Four camera units

The detected condition of the missing tooth and approaching large rocks is notified to the operator in real time through the 10-inch touch-panel monitor in the cab and warning sound to urge to check the tooth or avoid the large rocks. The tone and volume of the warning sound and the warning range can be changed on the monitor.

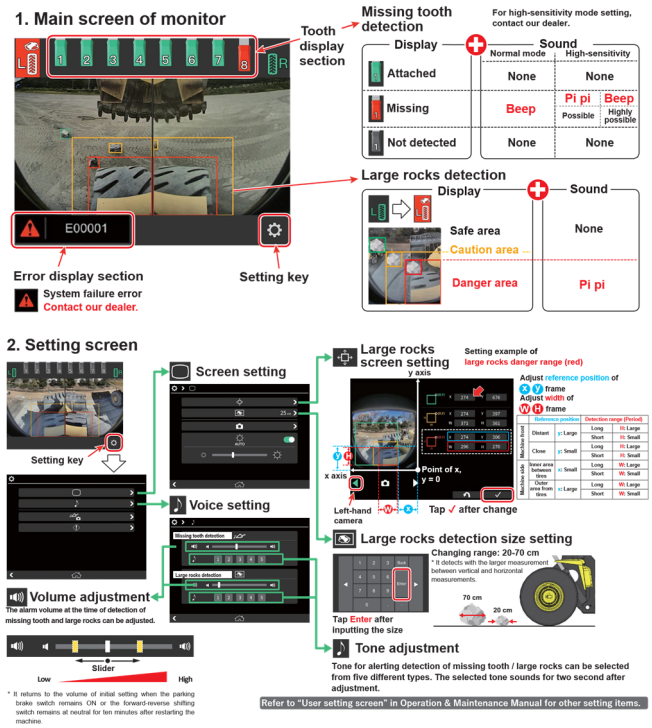


Fig. 5 Detected condition and setting items

To improve the productivity and the safety for all customers who purchased the WA900-8R, this system can be retrofitted to the WA900-8R machine already in use. Besides, the system does not require calibration of the positions and angles of the body, the bucket, the teeth and the cameras to minimize the downtime due to the operation stop of the production machine for the system installation.

The large rocks cameras display the information of the condition around the tires which is not visible from the operator's seat on the monitor, allowing the operator to check danger around the tires, which contributes to the safe operation. In addition, by adding the KomVision (an optional feature for the WA900-8R), the operator can check the inner area between the tires by the KomVision and the front and outer areas by the large rocks cameras, which enhances the preventive performance for large rocks.

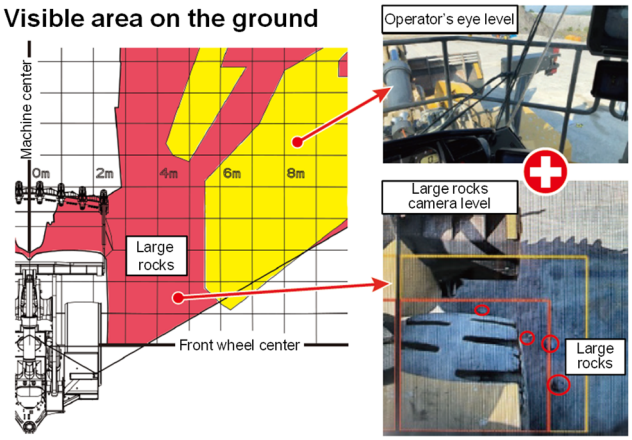


Fig. 6 Operator's eye level and view of large rocks camera

3.2 Mechanism of detection

Both of the detection functions for missing tooth and large rocks consist of AI and rule-based judgment.

AI has high detection performance but has some uncertainty to make wrong detection depending on the condition. The detection performance of our system has been improved by combining AI with rule-based judgment. The AI proposes the candidates of missing teeth, and then the rule-based algorithm determines whether they are missing or not.

3.2.1 Principle of missing tooth detection

This function is designed to detect and notify the operator of missing tooth issues. In this section, we describe the outline of the algorithm of the missing tooth detection. The overview is shown in **Fig. 7**.

First, the system detects the candidate positions of all of the teeth roots and the teeth edges from the image taken by the cameras. For the detection, we adopt a Convolutional Neural Network (CNN) because of its well-balanced performance and computational costs, thereby achieving both speed and accuracy. The detected candidates of the teeth roots and the teeth edges are paired based on the distance on the image. The tooth root and tooth edge successfully paired are treated as one tooth.

And then, the judgment of the missing tooth is made by detected tooth length on the image. Normally, when a tooth falls off, the tooth adapter is exposed and the length becomes short compared to the tooth that is not missing. Using this criterion, the tooth that is significantly shorter than the other teeth in the same image is judged as a missing tooth candidate.

Finally, the system judges final state by considering the temporal changes of the tooth state. In the operation sites, the tooth state may be wrongly judged instantaneously with the environment factors such as backlight and dust. Therefore, the final judgment is determined based on the time-series changes of the tooth and the sensitivity that the operator set. When there is one or more teeth judged as missing, the system displays the missing icon(s) on the monitor and beeps an alert to the operator.

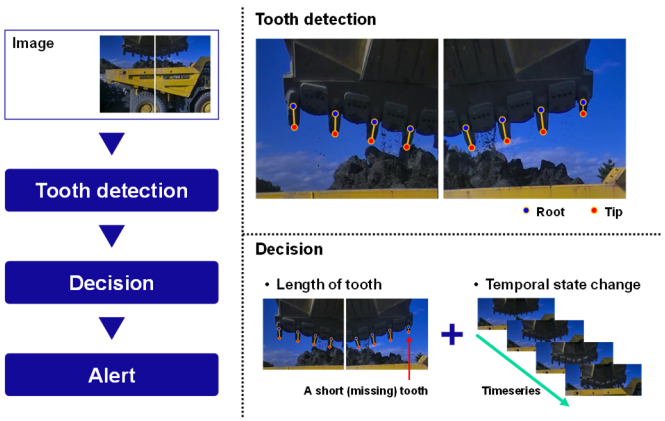


Fig. 7 Overview of missing tooth detection algorithm

3.2.2 Principle of large rocks detection

This function is designed to detect and notify the operator of large rocks. In this section, we describe the outline of the algorithm of the large rocks detection. The overview is shown in **Fig. 8**.

First, the system detects the candidates of large rocks from the image taken by the cameras. It adopts CNN architecture and archives high-speed detection. At this stage, the candidates include objects that not to be notified such as small gravel and distance rocks. In the next step, the system identifies large rocks which need to be notified.

The system filters the candidates based on three rules: (1) Size, (2) Position and (3) Gear state. The details of the filtering are as follows.

(1) Size filtering

The large rocks detection should detect and notify only rocks large enough to cut tires. Therefore, the size filtering is effective. Only rocks larger than the size specified by the setting will be notified.

(2) Position filtering

Large rocks near the front wheels have a higher risk to get run over. Therefore, the area of the large rocks detection is defined so that only large rocks in that area will be notified.

(3) Gear state filtering

The highest risk of running over a large rock is in the series of operations of shoveling the material. During this operation, the operator concentrates on the bucket and may not be careful enough about the front wheels. Therefore, notification will be given only when the gear is set to the forward traveling position.

When the candidates pass these three filtering rules, the system judges it as an issue and notifies the operator by displaying the icon(s).

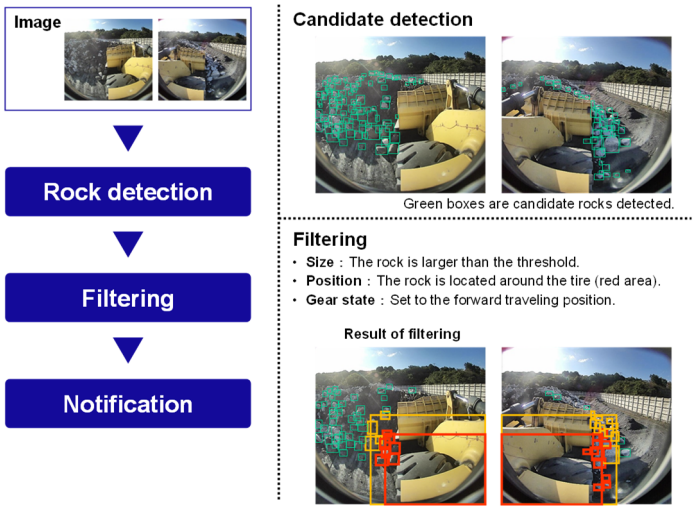


Fig. 8 Overview of large rocks detection algorithm

3.2.3 Dataset

In deep learning, the more data we have, the better the accuracy we can achieve. In particular, supervised learning that utilizes annotated data is the most effective method. However, it is also known that using data of similar features or data with inconsistent annotation leads to low accuracy.

Thus, dataset building with “a wide variety of data” and “high-quality annotation” is the essence of the deep learning technology. In this section, we describe our work for the dataset building.

(1) Data collection

In the initial stage, we created a logger which can be mounted on the vehicle to record the images and the vehicle operation data at the same time for collecting data samples to be used for learning and evaluation. The scenes for learning and evaluation were automatically selected by using the machine operation information from the data recorded by the logger, which improved the efficiency in the development. The data collection was conducted not only in our testing site but also with the cooperation of our customers, which realized a wide variety of data of a cumulative total of hundreds of hours.

(2) Annotation

The annotation is added by human hand. It can have variation due to the gap between senses of the workers. Even when one worker works on, annotation can vary depending on his/her work timing. For this development, we created the annotation manual including boundary samples to achieve high-quality annotation.

3.3 Hardware

For the AI processing, we adopted the on-vehicle controller with the built-in AI processor for edge devices. This realized both high environment resistance (temperature, vibration, power supply noise, etc.) required of construction machinery and high-speed, high-accuracy image recognition.

We adopted a visible-light camera for the sensor, which enabled a low cost compared to LiDAR or an infrared camera.

The system can be concluded with this on-board hardware, so that the operation is possible in crushing sites in mountain areas with insufficient mobile network.

3.4 Precautions for use

As the missing tooth / large rocks detection system detects missing of the teeth and approaching large rocks through the images by the cameras, its detection performance may degrade due to weather, environmental conditions, or dirt on the camera covers. Therefore, we need to ask customers to use the machine with full understanding of the characteristics of the system having the possibility of wrong detection with an attached tooth or rocks other than large rocks. To enhance customers' understanding, we provide a safety brochure and a quick reference guide available in the cab, that explain the proper use of the system. The operation and maintenance manual is printed in full color and includes visual illustrations, such as screen displays, to help customers easily understand the system.

Fig. 9 Quick reference (top) and safety brochure (bottom)

4. Future outlook

Komatsu produced this kind of system for the first time and now sell this system to our existing customers only. But we would like to spread its use through the sales in the market and the development to the models other than the WA900-8R in the days ahead.

Also, the AI system developed this time is not limited in the detection of the missing tooth and large rocks and can be applied to recognition of various objects such as a human, a dump car, and an obstacle on camera. In the future, we would like to promote remote handling, automation, and digitalization of Komatsu machines by the application of the recognition technology like this to realize safe, productive, smart and clean worksite of the future with our customers.

5. Conclusion

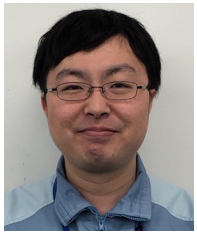
This paper introduced the missing tooth / large rocks detection system for the WA900-8R. We expect that this system will be installed in the WA900-8R machines operated all over the world to contribute to the improvement of productivity and safety for our customers. We remain committed to leveraging its technologies to find solutions for our customers and will continue to provide valuable proposals to meet their needs.

Acknowledgments

We received great cooperation from the major Japanese crushing users, Todaka Mining Co., Ltd. and Oita Taiheiyo Mining Corporation for the development of this system.
Both companies provided invaluable support, including data acquisition during the system planning stage, proof of concept for the trial system, and continuous feedback and advice as experienced users. Their insights have greatly influenced the design and usability of this system and user interface (UI), which are now appreciated by our customers worldwide.
We would like to take this opportunity to thank them.

Introduction of the authors

Ryohei Emoto
Joined Komatsu Ltd. in 2011.
Digital Innovation Development Center, Development Division



Yuya Murakami
Joined Komatsu Ltd. in 2017.
Vehicle Development Center 1, Development Division

Shoji Sonoyama
Joined Komatsu Ltd. in 2016.
Automation Development Center, Development Division

[A comment from the authors]

The system of detection for missing tooth and large rocks is the first attempt for Komatsu and the AI on board is also advanced one for us. During development, we encountered various challenges but successfully completed the system. As designers, we are pleased that Komatsu's technological innovations have aligned with our customers' needs, enabling us to introduce the system without issues. While receiving high reputation of the system as the solution in the worksites, we also receive many requests for the improvement of the system from the customers who introduced it. Moving forward, we remain committed to refining the system and enhancing customer satisfaction.