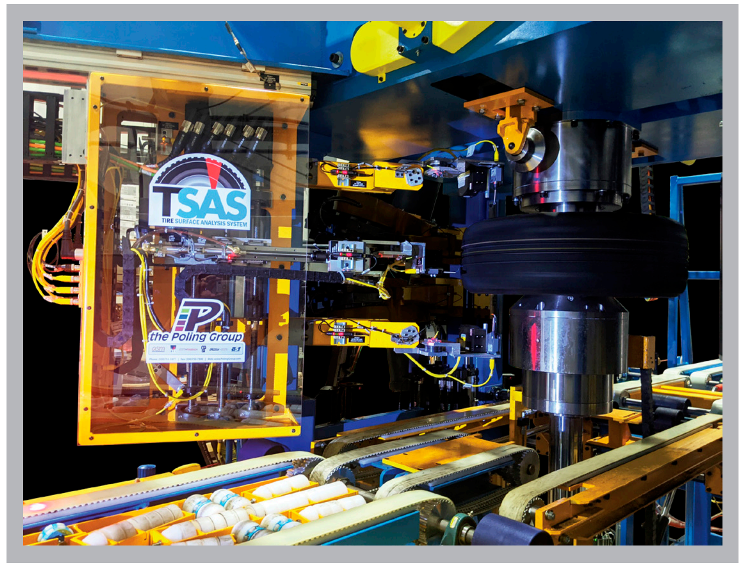
Deep Learning for Visual Inspection and Classification of Tire Defects

Deep learning is an artificial intelligence method by which a computer model can parse inputs and produce outputs in a way that is inspired by how neural networks in the human brain work. With the advent of self-driving vehicles, facial recognition, and surveillance cameras able to automatically detect suspicious behavior, computer vision is a quickly developing field within deep learning. Visual identification tasks that were once the sole domains of human inspectors are increasingly achievable by intelligent computer vision systems. Tire manufacturers have an opportunity to use this technology on top of their existing equipment investment to provide even better quality control.

Tire Geometry Testing

Towards the beginning of this century, many tire manufacturers began investing in tire geometry systems using laser profile sensors, sometimes referred to as "sheet-of-light" sensors. These sensors scan each sidewall and the tread of an inflated and rotating tire to create a 3D image.

The specialized tire geometry software examines each image to detect, measure, and grade any geometry defects along with radial and lateral runouts. These images contain most of the exterior of the inflated tire, so why not use them as a second chance to check for visual defects?



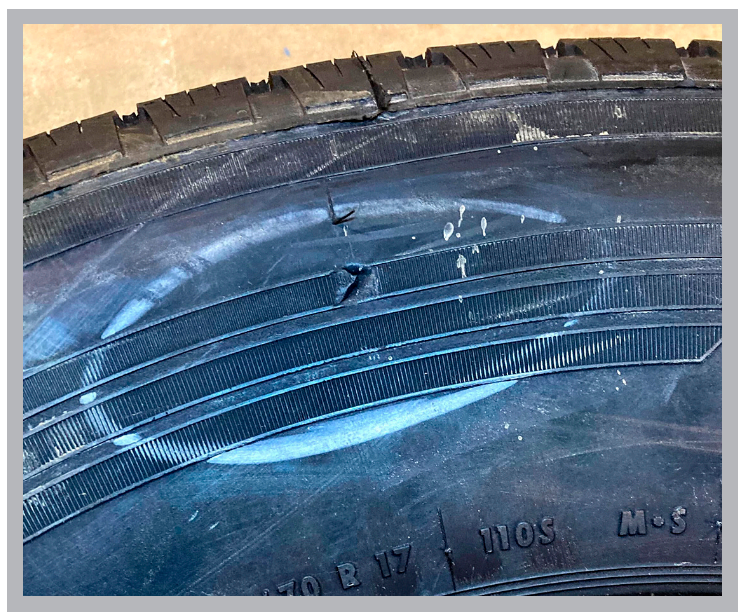
The Poling Group's TSAS - Tire Surface Analysis System

Missed Opportunities

In a typical tire factory, cured tires are fully inspected, inside and outside, prior to final finish testing by a specialized workforce of tire inspectors. Downstream from this inspection, tires may be rejected or flagged for further inspection by any final finish test machine. Otherwise they are sent to the warehouse and eventually sold to the customer without additional inspection.

Therefore, it's possible that tires with curing defects, missed by the tire inspectors, or tires that suffer visual damage by their handling after cured tire inspection, still end up in the warehouse. These tires eventually get installed on vehicles, where the customer can notice the visual defects, reflecting poorly on the factory's quality control.

It is known that not all curing defects are found, with some factories reporting that 1% of tires have defects and 10% of those defects are missed by tire inspectors. Due to those missed defects, some factories report that they re-inspect approximately 5% of their tires.



Damage from material handling

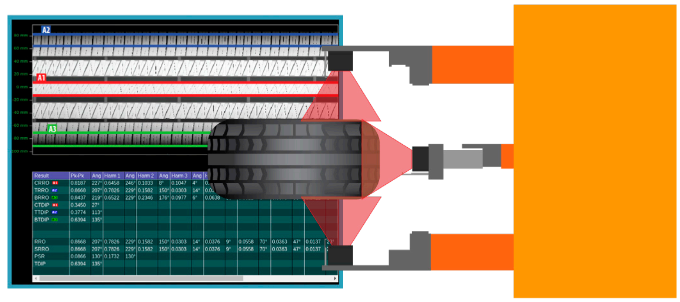
Visual Inspection from Tire Geometry Images

For a small investment, a factory can add a software-based Visual Inspection System from the CTI Division of the Poling Group that can help find these defects by examining their already-collected tire geometry images. This allows a factory to gain even more value from its prior large investment in geometry systems.

Tire geometry systems are typically integrated into tire uniformity machines, dynamic balancers, and even their own dedicated inspection machines. On the majority of these machines, the tire is inflated and rotating at a constant 60 rpm, and typically three laser profile sensors—covering the top sidewall, bottom sidewall, and tread—collect measurement data for one revolution. The geometry system provides its specialized measurements of bulge, depression, lateral runout, radial runout, wobble, etc., to the machine's control system, which uses them to determine a tire's final grade.

These geometry systems use laser profile sensors, providing 3D high-resolution images containing at least 1000 profiles per revolution, a field of view of at least 75mm of tire surface, and a Z-axis (or height) measurement resolution less than 10 micrometers. Sensors are available with different standoffs, measurement ranges, and fields of view to meet the wide range of machines and tires for geometry testing.

Our Visual Inspection System can work with 3D images from any laser profile sensor. It does not require the latest sensors.

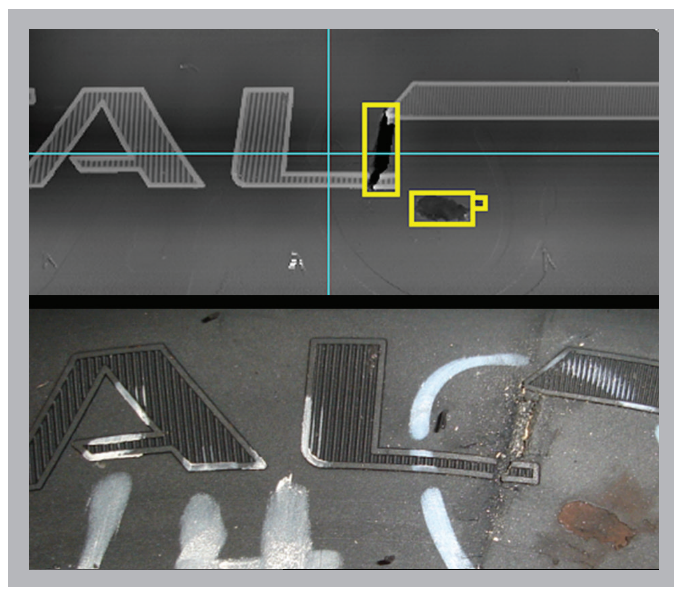


Laser Profile Sensors scan each sidewall and the tread of an inflated and rotating tire, creating a 3D image.

Getting More from Your Stored Images

The only visual defects detected by geometry systems are bulges and depressions in the sidewalls and bumps and dents in the tread. These defects are normally caused by tire construction issues, but other visual defects appearing in the geometry images go undetected.

These could be caused by contaminated tire molds (as shown to the right) or rubber not flowing correctly in the tire mold. Or they could be caused from damage due to tire handling equipment or even damage from improper processing by machines upstream to the geometry systems, such as flash or pin-vent trimming stations, white sidewall grinders (or buffers), and tire uniformity machines with grinding, causing grind appearance issues.

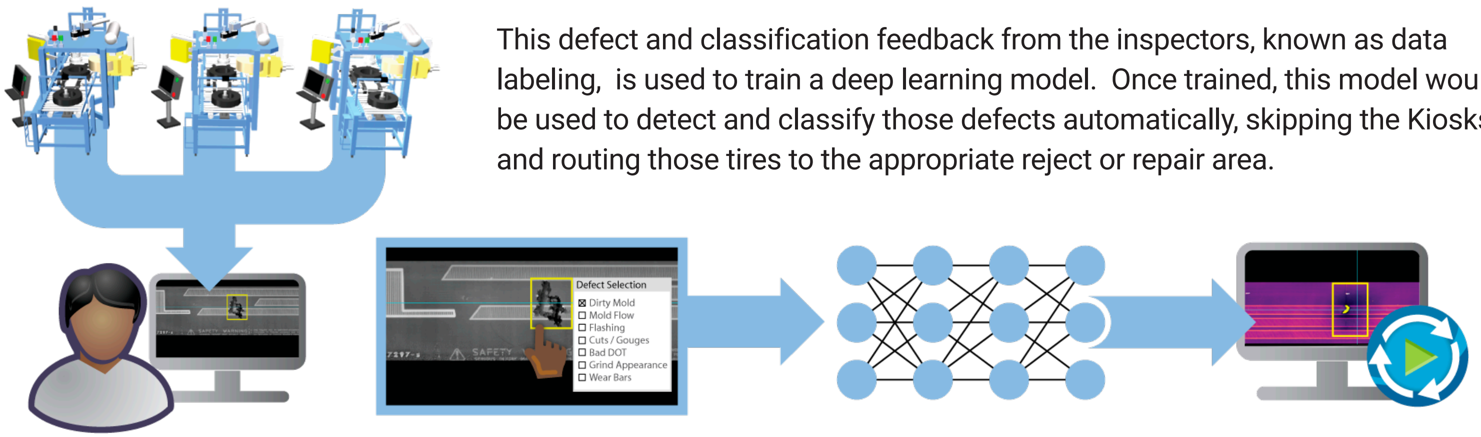


Scanned 3D image and actual photograph of tire defect detected by our Visual Inspection System

This is where our Visual Inspection System can add value. It processes the 3D high-resolution geometry images in a completely different manner, focusing on sharpening and flattening the image to provide the clearest picture. It detects and classifies any visual defects found in the geometry images.

misidentified. The inspector can also manually identify any new defects and classify them in the same manner.

This defect and classification feedback from the inspectors, known as data labeling, is used to train a deep learning model. Once trained, this model would be used to detect and classify those defects automatically, skipping the Kiosks, and routing those tires to the appropriate reject or repair area.

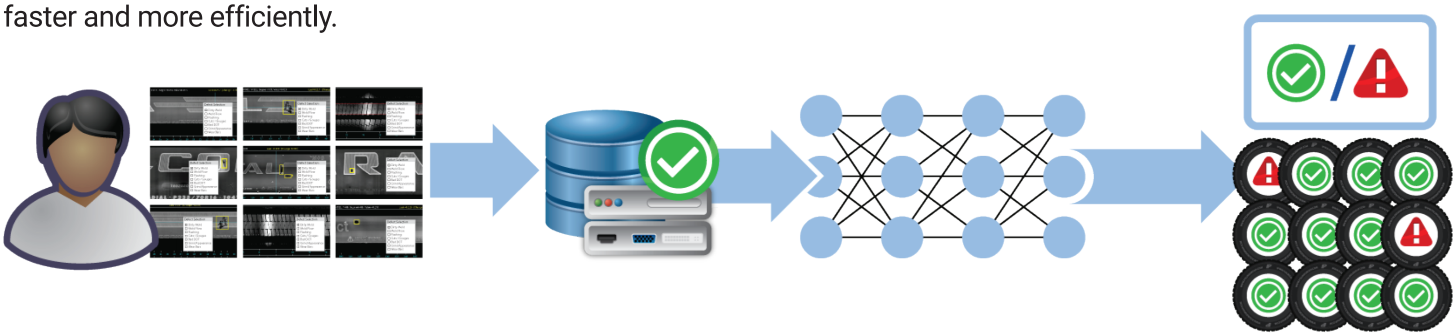


Labeled Data as part of an existing Inspection Process

One of the biggest limitations industries face when looking to implement deep learning is the unavailability of labeled data to train these models. Data labelling is a human task and can take armies of labelers. If labeled data is not being produced as part of a normal production process, it can be very expensive to generate.

That is why tire manufacturers have a unique opportunity to bring this transformative technology within reach by simply making the commitment to label data as part of an existing inspection process.

Multiple tire factories within the same organization can share their labeled data, training the deep learning models faster and more efficiently.

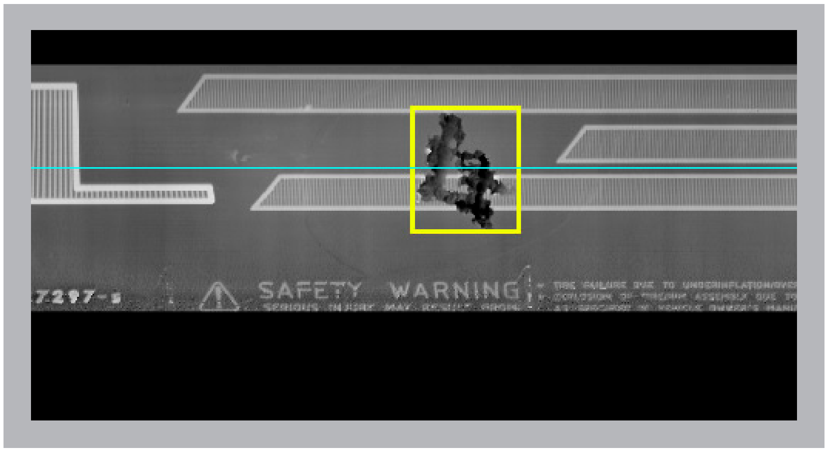


Anomaly Detection and Object Detection

Two common deep learning applications for image processing are Anomaly Detection and Object Detection. Our Visual Inspection System takes advantage of both of them.

Anomaly Detection is when a computer model analyzes a whole image and then identifies any anomalies that deviate significantly from the norm. Anomalies are deviations that occur very rarely in the images and whose features differ significantly from most of the images. Each tire from a common curing mold would use its own Anomaly Detection model. These models can be trained very quickly with just a few good tires. They can identify any anomalies within the geometry images as potential defects and highlight them at the Kiosks for confirmation and classification, providing feedback (i.e. labeled data) for training the comprehensive Object Detection deep learning model.

An Object Detection model for identifying and classifying defects is trained from the feedback provided at the Kiosks. This model is used for all tires, since it is trained to find specific defects and how they are classified on every tire. Object Detection computer models separate the image into multiple parts. The parts are then analyzed, allowing for automatic detection, location, and classification of objects within an image. The Object Detection model is continually re-trained from the feedback at the Kiosks. This makes it more accurate and keeps it updated with any new defects encountered in the future.

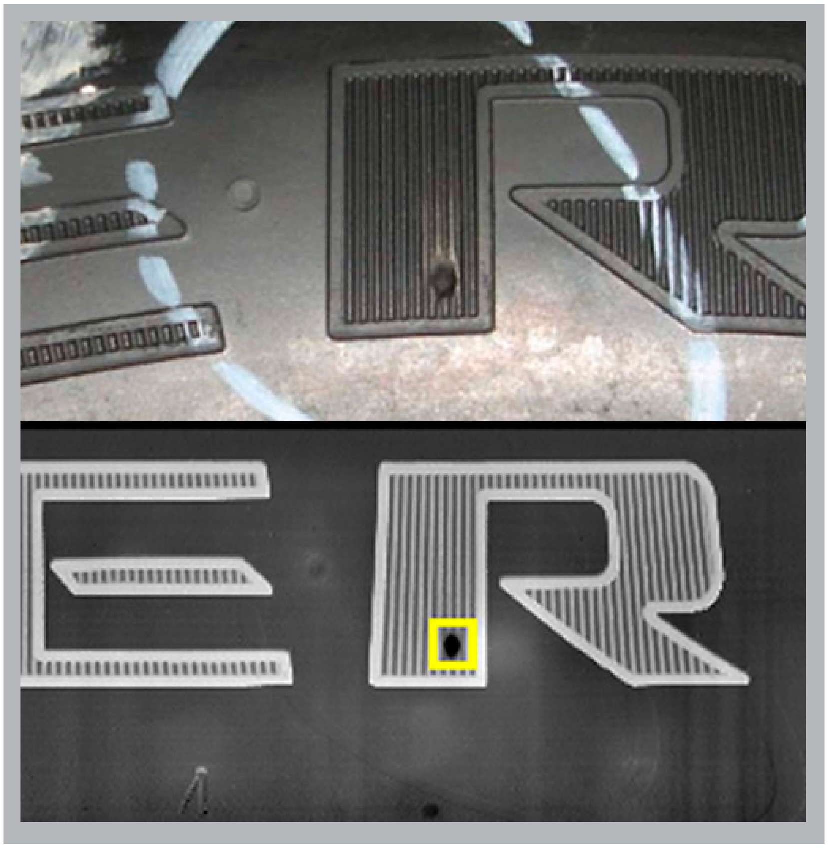


Anomaly Detection : defect from curing mold contamination

Our Visual Inspection System also supports other Object Detection models that can be trained to find different objects like the DOT, the treadwear indicator bars, or other specific objects as desired by our customers.

Rules-Based Image Classification

In parallel with the deep learning models, our Visual Inspection System uses rules-based image classification algorithms that are specific to finding defects that meet its pre-programmed criteria. Any defects beyond a pre-defined surface area or volume threshold are identified in the geometry images and sent to the Kiosk for confirmation and classification, providing feedback for training the deep learning models.

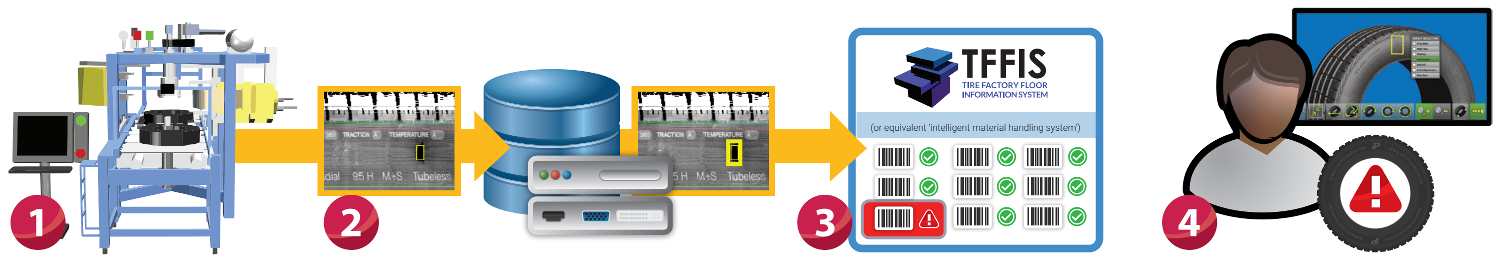


In this example, predefined rules were established to flag any area 0.4 mm below the sidewall surface as a defect.

Defects such as pits or blemishes from curing mold contamination, gouges or similar damage from tire handling equipment, unwanted pin vents or flashing, and damage from improper processing by upstream equipment, such as grind appearance issues, can all be detected using intelligent rules-based algorithms employing statistics and thresholds to differentiate pass from fail.

Visual Inspection Layout in a Factory Setting

Let's review how our Visual Inspection System can be adapted to a typical factory's final finish area:



1 - Tire is processed normally at each testing machine, which includes a tire geometry system.

2 - The System uses a combination of rules-based algorithms and Anomaly Detection deep learning models to identify potential defects from the geometry images.

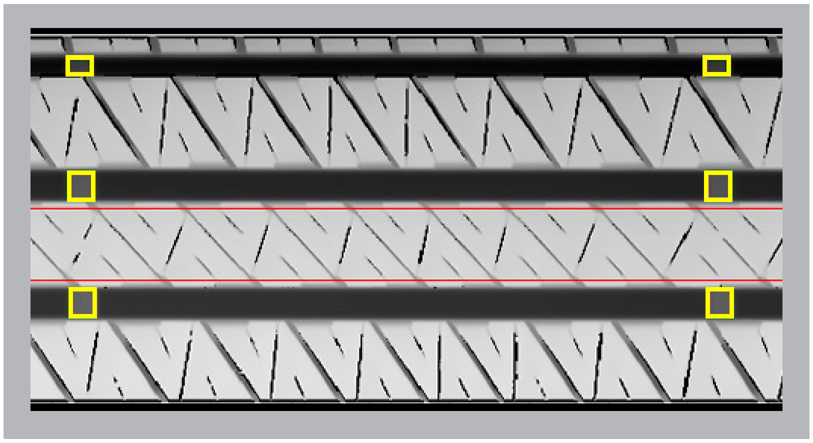
3 - An intelligent tire handling system (like CTI's TFFIS) diverts any tires with potential defects away from the warehouse to an area for further classification.

4 - Potential defects are confirmed, labeled, and classified at Kiosks using our 3D tire model. This feedback from the Kiosks is used to train an Object Detection deep learning model. Once the accuracy of the model is validated, our Visual Inspection System is updated to begin using it to detect and classify defects, skipping the Kiosks and routing those tires to the appropriate reject or repair area.

Additional Object Detection models can be implemented

Outside of detecting and classifying visual defects, our Visual Inspection System has additional Object Detection models, giving it even more value. Such models locate and read the DOT Tire Date Code, and when using tread lasers with a large field of view to measure the entire tread width, they measure the amount of rubber removed from force or runout grinding and even locate and measure the height of the treadwear indicator bars.

Once these deep learning models are trained, they could even run directly on the geometry systems, classifying any defects, reading the DOT Tire Date Code for correctness, measuring the height of the treadwear indicator bars, and even checking grind appearance. It could make those tasks part of the final tire grade. It could even call for extra clean up grinding from the machine controller if grind appearance shows it is needed.



Object Detection : locating and highlighting tread wear bars

Benefits of a Software Based System

Since our Visual Inspection System is mainly software, it can be quickly updated and continually re-trained to find problematic visual defects or to support new 3D images from updated laser profile sensors.

Think of it like Tesla's® Autopilot feature. Even the older model Tesla's® can be updated to the latest Autopilot features, including their latest deep learning models trained on the feedback from the ever increasing amount of Tesla's® on the road, with the future goal of adding full self-driving capability.

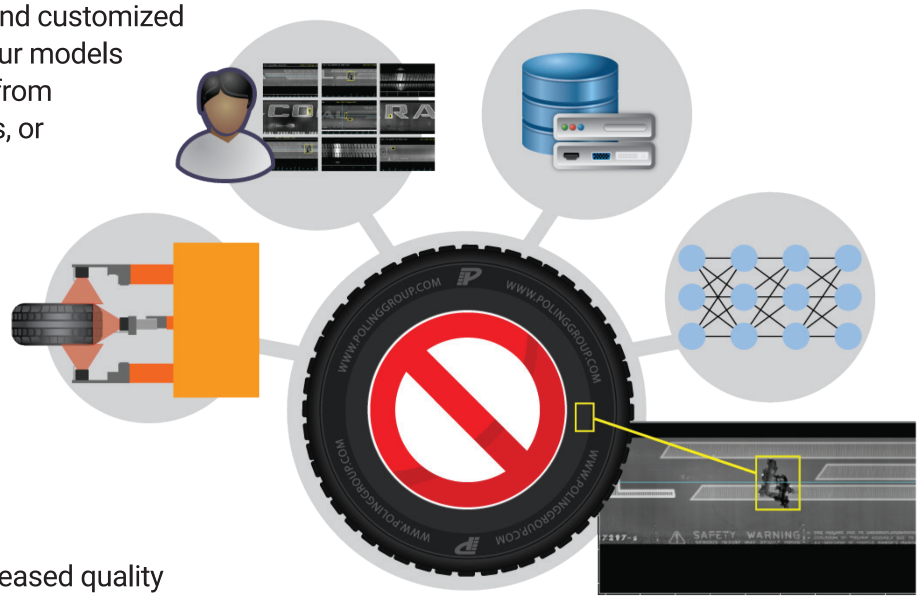
Summary of our Visual Inspection System

Using images provided by the existing geometry systems, tire manufacturers can prevent tires with visual defects from reaching their customers. Tire factories state that about 1% of tires have curing defects and about 10% of those defects are missed by the human inspectors. Because of these missed defects, factories also report that they re-inspect 5% of their tires.

Our Visual Inspection System uses a combination of rules-based software algorithms, which can provide good results for identifying defects with repeatable features, and Anomaly Detection deep learning models, which are better for high variability and subjective inspection to identify visual defects. With the existing classifiers or secondary inspectors confirming and classifying the potential defects at our Kiosks, an expansive dataset can be created for training an Object Detection deep learning model. This model would continue to receive feedback, even across multiple factories within the same organization, continually re-training itself to be more accurate. This model identifies and classifies defects, allowing those tires to be routed directly to a repair or reject area, without further intervention from the labor force.

Additional Object Detection deep learning models could be trained and implemented to locate and read the DOT Tire Date Code, locate and measure the treadwear indicator bars, and other objects desired by a factory. With the new governmental penalties in place for incorrect DOT Tire Date Codes, reading those codes with our Visual Inspection System can stop tires with incorrect dates from leaving the factory.

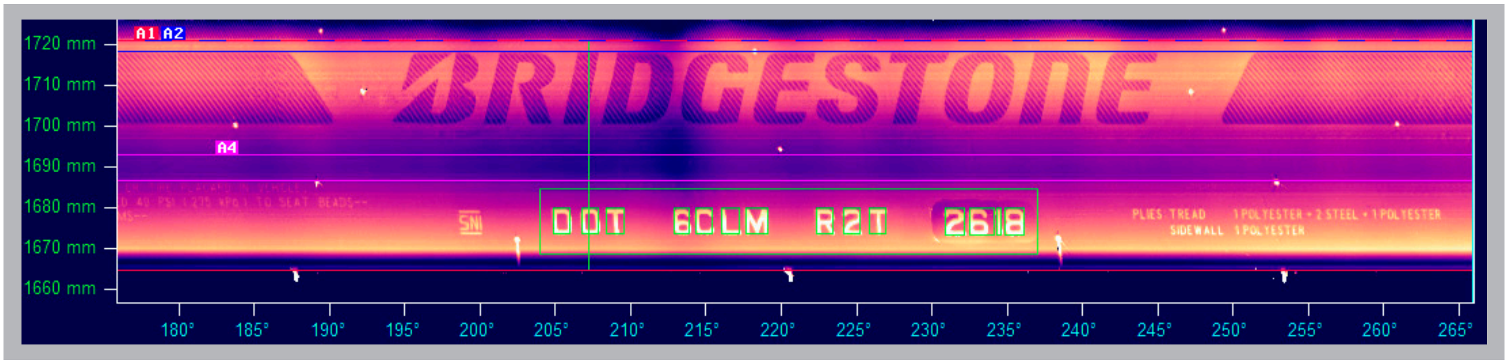
Our Visual Inspection System can be scaled and customized to exactly how your factory processes tires. Our models can run on a large server, processing images from multiple machines with tire geometry systems, or they can run directly on the tire geometry systems, using their results to further enhance the tire's final grade.



For a small investment, a factory can add our Visual Inspection System to detect and classify defects identified in their already-collected tire geometry images. This allows a factory to gain even more value from its prior large investment in tire geometry systems.

Our Visual Inspection System guarantees increased quality from the plant floor to the tires on the road.

Our Visual Inspection System can also be trained to detect other objects, such as the DOT (as shown below) and the treadwear indicator bars. Once detected, it can read the DOT Tire Date Code and measure the height of each treadwear indicator bar. It would provide higher-quality assistance to a classifier or secondary inspector, or replace the most mundane aspects of their work, freeing them up to process many more tires.



Visual Inspection Software can locate and read DOT Tire Date Codes

Visual Inspection Kiosk

A key element of our Visual Inspection System is its Kiosk, which makes use of a large, high-resolution touch panel to display an interactive 3D tire model, stitched together from the sidewalls and tread geometry images. Potential defects are highlighted (as shown here).

Although Kiosks can be integrated into the existing classifier or secondary inspection stations on the plant floor, they could also be located in an office environment because the interactive model could replace the actual tire.

Our Visual Inspection System provides its results and the 3D high-resolution geometry images to a Kiosk from multiple machines containing tire geometry systems. At a Kiosk, an inspector can manually classify each defect by selecting the appropriate classification from a dropdown list, including the ability to dismiss a defect that has been