Character Recognition of DOT Codes on Auto Tires

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What is a Tire?

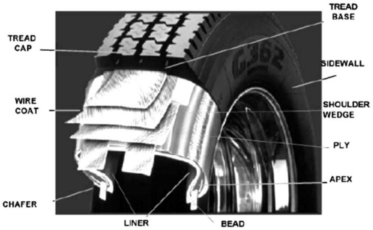
- A tire is a flexible, durable component that encloses a wheel's rim
- Provides traction, absorbs shock, supports vehicle load
- Made from a composite of rubber, fabric, and steel materials
- Approximate lifespan: 25,000–50,000 miles depending on conditions

Source: Bridgestone Tech Brief, 2022

Tire Construction Overview

- Major components:
  - Tread: contact surface for traction
  - Sidewall: provides lateral stability, houses DOT code
  - Beads: anchor tire to wheel rim
  - Plies: internal structure made of textile/steel
- Built via layered manufacturing + vulcanization at 150–180C
- Full curing cycle: 10–15 minutes per tire in industrial molds.

Source: Continental Tire Manufacturing White Paper, 2021



Materials Used in Tires

- Natural rubber: elasticity and tensile strength
- Synthetic rubber (SBR, BR): enhanced wear, heat resistance
- Carbon black (30–40%): improves strength, wear, UV protection
- Additives: sulfur (for vulcanization), oils, antioxidants
- Total weight of a car tire: 8–12 kg

Source: Goodyear Rubber Compounding Manual, 2020

Sidewall and Optical Properties

- High carbon black content = deep matte black color
- Reflectivity: $<$10% in visible spectrum
- Surface roughness: micro-texture in range of tens of microns
- Text contrast is purely geometric — depends on relief, not color

Source: ”Optical Properties of Rubber Surfaces,” Journal of Materials Imaging, 2019

DOT Code Fundamentals

- U.S. Department of Transportation code: **”DOT” + factory + size + date**
- 12 characters total; last 4 digits represent week/year (e.g., 2219 = 22nd week, 2019)
- Molded during tire curing using steel mold inserts
- Mold insert replacement: takes 30–60 seconds per changeover

Source: NHTSA Tire Safety Regulations, 2021

Why Is Reading DOT Codes Difficult?

- **Black-on-black**: no color difference
- Low reflectivity: visible light absorbed almost entirely
- Variability: code height 0.2–1.0 mm; depths vary
- Dirt, wear, and surface aging reduce readability

Source: Michelin Field Inspection Manual, 2020

Project Goals

- Automate recognition of DOT codes on tire sidewalls
- Evaluate and compare lighting configurations
- Benchmark performance in accuracy, speed, and robustness

Lighting Strategies for Visibility

- **Raking Light**: Shadow emphasis from incidence
- **Bidirectional Light**: 2 opposing LEDs at separation.
- **Polarized Illumination**: Reduces glare by up to 80%
- **Structured Light**: Stripe deformation reveals .1 mm surface changes

Source: Vision Systems Design Handbook, 2020

Advanced Imaging Techniques

- **Photometric Stereo**: 4+ angles; typical frame rate = 10 fps
- **Laser Triangulation**: Sub-mm accuracy; used at conveyor speeds 0.5–1.0 m/s
- **Depth Imaging**: Capture cycle 0.5–1.2 sec depending on resolution

Source: ”3D Machine Vision for Industrial Inspection,” SPIE Proceedings, 2018

Computer Vision Workflow

- Detection: via circular Hough transform or template match
- Enhancement: histogram equalization, gradient filters
- Recognition: Tesseract OCR or CNN-based decoding
- Validation: format pattern match; error $<$1 char on good scan

Source: "DOT Code Recognition Framework," CVPR Workshop Paper, 2021

Traditional vs Deep Learning OCR

- **Traditional:**
  - Limited to clean lighting + ideal angles
  - Recognition accuracy: 60–80% under uncontrolled settings
- **Deep Learning:**
  - CNN accuracy on trained dataset: 90–98%
  - Robust to mild occlusion and shape distortions

Source: Cognex Deep Learning Vision Guide, 2022

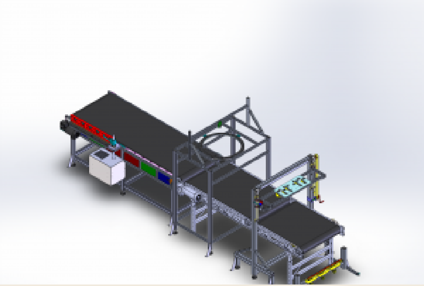
State-of-the-Art Systems in Controlled Industry Settings

- **Inline Structured-Light Systems** (Micro-Epsilon identityCONTROL TID):
  - Capture cycle: 1 tire every 2–3 seconds
  - Accuracy: $>$99% in factory settings
- **Trevista Dome Lighting**:
  - LED flashes from 6–8 directions
  - Processing time: 1 sec per acquisition
- **Cognex Systems**:
  - Read time: $<$1 second with high-speed industrial cameras
  - Updatable with new training sets every 3–5 minutes
- **Handheld Laser Scanners**:
  - Operator-guided scan: 5–10 seconds per tire
  - Data uploaded to cloud in real time

Sources: Micro-Epsilon White Paper, 2021; Trevista Product Manual, 2020; Cognex Tire ID Solutions, 2022

Laser-Based 3D DOT Code Scanning (1/2)

- Utilize laser displacement or structured-light sensors to capture 3D profiles of tire sidewalls, revealing embossed text by height differences
- Characters are identified from the 3D scan data, achieving very high read rates (often $>$99% accuracy) even under tough production conditions
- The Inmess DOT system rotates the tire 360° under a laser line scanner; software automatically locates and reads the TIN and DOM from the 3D height map



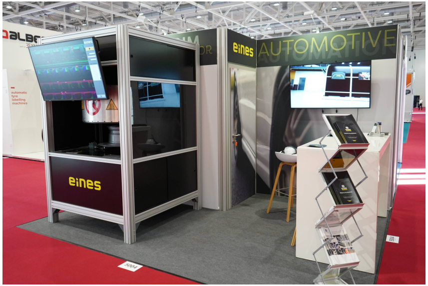
Laser-Based 3D DOT Code Scanning (2/2)

- Typically integrated in manufacturing lines; one scan per tire takes 1 second and results can be automatically logged or verified in real-time
- Eliminates the contrast problem—text is revealed by height, not brightness
- Suitable for high-volume, in-line verification or warehouse sorting

Source: Inmess DOT Scan System Datasheet, VAIA Technologies, 2023.

2D Vision & Deep Learning OCR Systems (1/2)

- High-resolution cameras with optimized angled lighting (like LED ring lights) capture tire sidewall images for OCR
- Modern systems use AI-based vision to detect and read low-contrast embossed DOT text using deep neural networks
- Eines Vision’s Auto DOT Reader uses multiple cameras and deep learning OCR to achieve 100% in-line inspection



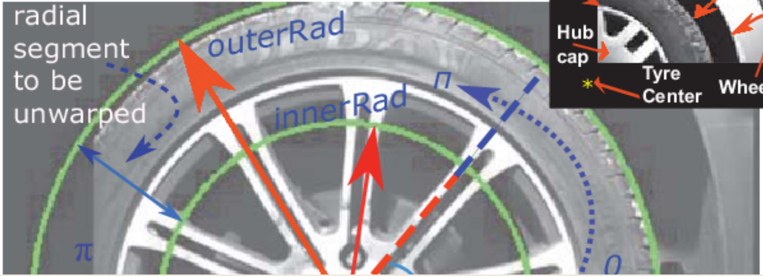
2D Vision & Deep Learning OCR Systems (2/2)

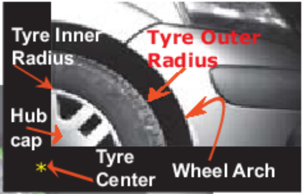
- Cognex tire OCR tools adapt to text variations and orientations on moving tires using pre-trained models
- Works well under controlled lighting but may degrade in bright outdoor or dirty conditions
- Often used in factory or bay setups

Source: Eines Vision Systems, ”Automatic Tire DOT Code Reader,” Technical White Paper, 2022.

Drive-By Tire Code Recognition (1/2)

- Specialized systems read DOT codes from vehicles in motion (like low-speed lanes)
- Uses high-speed cameras + strobe lighting to freeze motion and capture multiple sidewall images
- Unwarps curved tire view, then detects DOT code using CNNs





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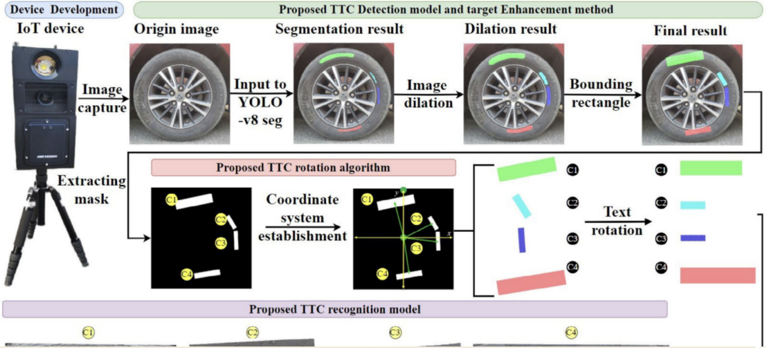
Drive-By Tire Code Recognition (2/2)

- Reported character accuracy: up to 73–80% in clear conditions
- Drops sharply in presence of water, mud, or shadow (14% worst case)
- No public dataset—researchers created synthetic and real-world training sets

Source: Kazmi, W. et al. ”Vehicle Tire Detection and DOT Code Recognition Using Deep Learning.” *IEEE Transactions on Industrial Informatics*, 2020.

Portable IoT & Handheld DOT Readers (1/2)

- Low-cost portable systems enable on-site tire scanning by mechanics or fleet techs
- 2025: YOLOv8-based model used in an IoT vision device processes tire image in 200 ms with 97% character accuracy
- Automatically aligns, detects, and OCRs code on device or sends to cloud



Portable IoT & Handheld DOT Readers (2/2)

- Earlier devices used internal laser/camera units in sealed housings (e.g. patent WO2017074759A1)
- Designed for consistent results regardless of ambient light
- Ideal for depot inspections, salvage yards, or remote compliance checks
- Limitations: Needs 1-1.5m standoff and vehicle speed $<$5m/s and wont capture worn/tilted/densely packed characters. Dataset is not publisehd, so no reproducibility

Source: Zhang, Y. et al. ”A Portable IoT System for Tire Text Code Identification Using YOLOv8.” *Computer-Aided Civil and Infrastructure Engineering*, 2025.

Smartphone-Based DOT Code Recognition (1/2)

- Uses phone camera + onboard or cloud AI to scan and read DOT text
- SDKs like Anyline, Scanflow provide real-time guidance and OCR even in low contrast
- Michelin's API offers automatic lookup from tire image

Smartphone-Based DOT Code Recognition (2/2)

- Works well when user provides clean, focused, well-lit image (min 800px height recommended)
- Easily scalable to fleet or retail settings—apps in use at Discount Tire and others
- Most do not publish datasets; training sets are proprietary

Source: Michelin Digital Services, ”DOT Code API Reference Manual,” 2022.

Advanced AI & Multimodal Approaches (1/2)

- Systems combine 2D and 3D sensing with deep learning for high robustness
- Mech-Mind's solution uses laser profiler + AI to recognize worn or faded codes with $>$99.99% accuracy
- CNNs trained on synthetic and real tire image datasets

Source: Mech-Mind Robotics, "Tire Surface 3D OCR Using AI Vision," Product Brief, 2024.

Advanced AI & Multimodal Approaches (2/2)

- Benefits: tolerant to harsh lighting, dirt, font variation
- Some models deploy on edge hardware for fast inference
- Research trend: enhancing OCR by fusing surface geometry and visual features

Pain Points and Associated Costs

- **Manual DOT Code Reading**
  - Time: $\sim$2–4 minutes per tire for human transcription
  - Errors: up to 15% transcription error rate in field surveys
  - Cost: At scale, $\sim \$50,000+$ annually for a fleet of 10,000 vehicles due to labor inefficiency
- **Safety Risks**
  - Missed recalls/expired tires linked to $\sim$738 fatalities in the U.S. (NHTSA, 2019)
  - Delayed recall compliance: average 25% of tires untraced in first 6 months
- **Proposed Solution:** Automated DOT OCR with optimized lighting & deep learning
  - *Benefits if solved:* 90–99% read accuracy, $\sim$20–30s per vehicle scan, reduced liability, improved compliance

Objectives and Tasks

- **Objectives**
  - Automate accurate DOT code recognition outside controlled factory settings
  - Compare and benchmark lighting methods for embossed text visibility
  - Improve safety by enabling rapid detection of aged/defective tires
- **Tasks**
  - Literature survey of tire materials, optics, and DOT processes
  - Build image acquisition setup (cameras, raking/bidirectional lights)
  - Develop computer vision pipeline (detection $\rightarrow$ OCR $\rightarrow$ validation)
  - Benchmark against ground truth dataset (stationary & moving tires)

Proposed Approach

1. **System Development**
   - Prototype lighting rigs: raking, polarized, structured-light
   - Capture dataset: stationary tires under varied lighting, moving tires at < 5 m/s
   - Implement OCR pipeline: classical methods + CNN (YOLOv8 + Tesseract baseline)

2. **Testing & Validation**
   - Metrics: character accuracy (%), read success per tire, average processing time
   - Compare with manual transcription (baseline cost/time/error)
   - Stress tests: dirty, wet, aged tires

Time Plan (Sept 30 – Dec 7, 2025)

- **Week 1–2 (Oct 1–12):** Finalize literature review & acquire hardware (cameras, LEDs, polarizers)
- **Week 3–4 (Oct 13–26):** Build image acquisition rig, capture initial dataset (stationary tires)
- **Week 5–6 (Oct 27–Nov 9):** Implement baseline vision pipeline (classical + Tesseract OCR)
- **Week 7–8 (Nov 10–23):** Train deep learning models (CNN/YOLOv8), evaluate on dataset
- **Week 9 (Nov 24–30):** Stress tests: degraded tires, moving tire capture
- **Week 10 (Dec 1–7):** Final benchmarking, report preparation, slide deck polishing

Deadline: Completed by Dec 7, 2025 (week before Dead Week).