Hawkeye 2000 General Specification

September 2021

PAVEMENT MANAGEMENT INTELLIGENCE

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1 ABOUT ARRB SYSTEMS

ARRB Systems Pty Ltd was founded in 2017 following the spin-off of the equipment manufacture and international operations arm of the Australian Road Research Board.

Equipment development begun in the early years at the Australian Road Research Board as a means of being able to test certain project theories in a practical sense. This led to the commercialisation of the equipment in the early 1990's, and the first survey systems were sold internationally.

Since the 1980's ARRB, and now ARRB Systems, have been a world leading manufacturer and operator of road survey equipment with scores of systems built each year, ranging from the full-scale intelligent Pavement Assessment Vehicle to the small-scale Walking Profiler.

ARRB Systems high-technology equipment meets all common international standards and has a proven record of performance and longevity under extreme conditions, all across the world. Our range of products include many features and benefits not available in other systems.

ARRB Systems has an in-house development team of 10+ engineers and software programmers, who are dedicated to delivering new technologies and data collection efficiencies to our customers. The Hawkeye software is part of ARRB Systems dedication to continual improvement and innovation, with new software released approximately every six weeks giving our clients the most up to date software and customised solutions.

Partnering and delivering systems to governmental, research organisations and FEHRL members, such as BASt in Germany and CESTRIN in Romania, requires ARRB Systems technology architecture to be flexible and adaptable while retaining precision and accuracy for custom research tool solutions.

ARRB Systems' demonstrated experience in providing customised and fully integrated survey solutions for consultants and road agencies around the world, along with its stringent quality procedures, ensures it can provide the best solution to our clients for their specific requirements.

In summary:

- 30+ years' experience manufacturing equipment and in the provision of data collection services
- Extensive experience in supply and support of equipment across all continents
- Specialist provider of innovative road survey equipment and associated software
- Large network of international partners / agents
- Access to a team of experienced data analysts and pavement assessment personnel
- Millions of Kms of experience in fully automated pavement distress surveys
- Strong track record in researching, developing, and providing innovative solutions to pavement and asset managers
- Our reputation as a trusted partner through open and transparent partnerships with our clients

2 HAWKEYE 2000 SERIES OVERVIEW

2.1 Hawkeye Platform

The Hawkeye Platform is the most complete and advanced data collection system in the industry today. Hawkeye has been built through over 50 'man-years' of steady research and development investments. ARRB Systems continues to improve and refine the Hawkeye system as the need for more data, and analysis platforms for pavement condition and performance evolves.

Hawkeye is a modular survey system which enables complete scalability and customized functionality, whilst still delivering consistent and integrated data outputs. This allows systems to range from fully automated Network Survey Vehicles ('NSVs'), to portable compliance profilers.

Using the same system architecture across the Hawkeye range allows equipment to be supplementary and interchangeable, to suit client's project needs and deliver optimal project outcomes. It also allows simultaneous and synchronized collection of complementary data such as continuous deflection, LiDAR, GPR, continuous skid resistance data and other attributes.

Figure 2.1: Hawkeye Survey Solution Platforms

ARRB Systems utilise the Hawkeye equipment to deliver data services on a routine day to day basis, for a multitude of varying clients all around the world. This is a major advantage over other manufacturers, allowing us to optimise systems to collect pavement condition under real world conditions.

Our proven track record in developing and utilising systems with the latest technology, including fully integrated high-speed deflection and friction systems, allow us to offer experienced staff, proven equipment and a superior software platform.

The Hawkeye Platform utilises a unified database structure, based on a common database primary key. The dedicated "Heartbeat" unit links the systems together and ensures accurate correlation of the measurements against the primary key. The database can then be processed or reported using time, distance, key, profile, evenness etc. and therefore provides a fully flexible and powerful survey environment.

The Hawkeye system incorporates various integrated tracking, processing and visualisation software components including:

- **Hawkeye Onlooker Live** (Onlooker)—An interactive and real-time acquisition control interface that can control and monitor all the Hawkeye module systems simultaneously.
- **Hawkeye Verifier** (Verifier)—A quality control tool that can alert both operators in the field and office field supervisors of anomalous data in near real-time.
- **Hawkeye Processing Toolkit** (HPT)—Provides full data processing, extraction, analysis and management capabilities on collected images, profile, distress and pavement data. The software allows for full control and synchronization for all raw and processed data streams collected and enables analysis down to all incremental levels and up to all aggregative levels as required.
- **Hawkeye Insight** (Insight) —A web-based application that provides users with a customizable workspace for creating data visualization and providing simultaneous viewing of synchronized pavement images.

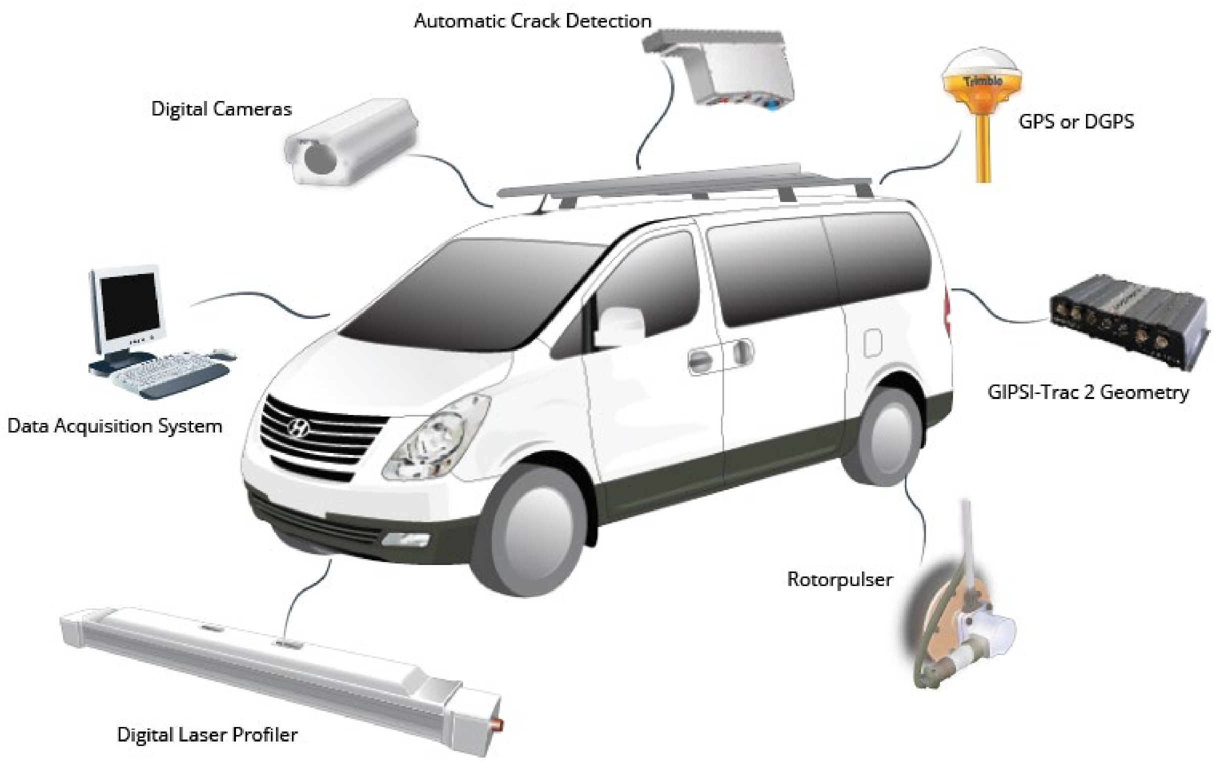

Figure 2.2: Hawkeye Network Survey Vehicle modular layout

Features and Benefits

- Modular design allows for product expansion, should your needs changes.
- Allows for the simple adoption of new technology into the platform.
- Fully integrated data collection system with common data and survey control referencing, utilising the unique Heartbeat Module.
- Safe and efficient data collection for both urban and highway surveys.
- Survey time is reduced by collecting all condition data and imagery in a single pass.

Applications

- Network and project level road and asset collection surveys.
- Automatic Crack Detection surveys.
- Routine pavement monitoring surveys.
- Roadside inventory and asset management inspections.
- Road geometry and mapping surveys.
- Quality acceptance programs.
- Contractor quality control purposes.
- Airport runway and tarmac inspections.

2.2 Host Vehicle

ARRB Systems has extensive experience installing equipment on different host vehicles all over the world. Hawkeye systems successfully operate in extreme climatic conditions from the cold temperatures of Northern America and Europe to the wet tropics of Southeast Asia and South America to high temperature deserts of the Middle East and South Africa.

ARRB Systems recommends the host vehicle is selected for their suitability in payload, engine cooling, power systems, and air-conditioning systems that are adequate for electrical needs and maintain acceptable operating conditions for operators and system equipment.

All exterior system electronics on the Hawkeye 2000 are housed in weatherproof enclosures and protected from the elements during data collection operations. The interior systems items (PC rack, GPS receiver, power shelf) are compact in design and can be installed in the rear cabin of a van or SUV.

Hawkeye hardware has been designed for very efficient power usage, and as such do not require auxiliary power units to supply continuous electrical power to on-board computer, electrical, and related subsystems. ARRB Systems has been successfully building equipment this way in hundreds of profiler units including full size NSVs.

ARRB Systems has several decades of experience building multifunction vehicles for road and off-road surveys and has built several systems that meet requirements from the clients, including ARRB Systems own international fleet of NSVs.

3 HAWKEYE 2000 NETWORK SURVEY VEHICLE

3.1 Synchronisation, Distance and Spatial Location

3.1.1 Heartbeat Module

The Hawkeye data collection equipment incorporates a purpose-built synchronization timing device called a Heartbeat module. The Heartbeat Module provides high accuracy time stamping to lock all data parameters together (i.e., does not rely on the lower-level PC clocks in the processing PCs) to ensure precise synchronization of all data delivery tables with Global Positioning System (GPS); Geographic Information System (GIS); & Location Reference System (LRS).

All data streams and reference measurements are recorded from the same original source of odometer DMI (distance) and GPS receiver (spatial coordinates). They are then aligned through the high precision Heartbeat generated primary keys to synchronize output data subsequent to road location referencing intervals.

Each sensor position is precisely located on the vehicle and defined within the acquisition software. This enables full synchronization of data output to a common reference point. This is of particular relevance where the Profiler is several meters away from the GPS and DMI and operator themselves. This functionality ensures that all sensors report their data at the same location at the same time.

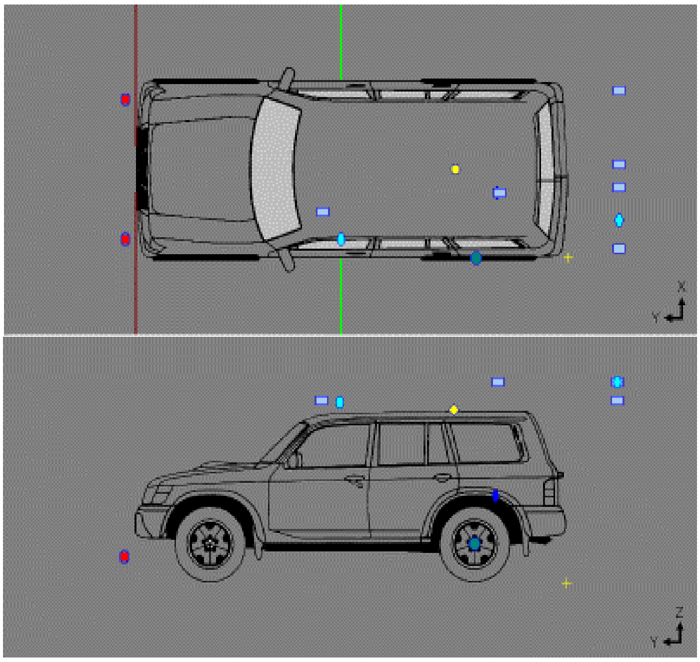

Figure 3.1 Device Location Synchronization

3.1.2 Distance measurement

The Distance Measurement Instrument (DMI) utilised on the Hawkeye System is a mechanical encoder fitted to the left rear wheel that enables referencing of all images, data, and information of the highway system.

The Heartbeat module receives the distance pulses from a high precision rotary encoder. The Hawkeye system typically uses a 2000 pulse per revolution high resolution incremental encoder as the distance measurement instrument (DMI). The Heartbeat module receives the encoder pulses and interpolates these to produce a sampling interval of at 1 mm distance, to a resolution of 0.1 mm.

The resultant accumulated distance is read by the Hawkeye odometer acquisition module and stored in a survey data file along with high precision primary key values. Primary key values are unique 64-bit values recorded with all data logged by the Hawkeye system. The purpose of the primary key values is to accurately and unambiguously align the data sets from each acquisition module. Thus, all data (including distance) is accurately aligned without dependence on GPS/IMU information.

Table 3.1: Distance Measurement Instrument Specifications.

Electrical	
Supply voltage	9 – 30V DC beat
Power consumption	≤ 0.7 W
Measuring steps	Set at 2000 ppr
Outputs	4.5 – 32V DC
Frequency range	0 – 600 kHz
Mechanical	
Shaft speed max.	9000 rpm
Moment of Inertia	6 kgm²
Shaft load max.	Radial 80 KN, axial 40 N
Shaft	Stainless steel Ø 8 mm
Code disc	Unbreakable acrylic glass
Housing	Aluminium, anodized
Weight	Approx. 300 g
Protection class	IP 67 (according to IEC 60529)
Operating temperature	-40 °C to +100 °C
Storage temperature	-40 °C to +100 °C, without package
Vibration	30 g, 10 Hz -2,000 Hz (to EN 60068-2-6)
Shock	70 g, 6 m/s (to EN 60068-2-27)

The DMI complies with ASTM E 950 and is well within the tolerance limits of a Class 1 instrument for longitudinal measurement to ASTM E1656. The DMI is Class 2 in accordance with EN 13036 travelled distance accuracy.

Due to physical factors, such as tyre pressure and thermal expansion, the overall accuracy of the Hawkeye distance measurement is defined to have an error of ≤ +/-0.1%, and subsequent bias of ≤ 0.1%.

The Hawkeye acquisition software has the capability for calibrating and validating the DMI accuracy up to 0.1% for speeds up to 110 km/h. Survey speed is determined by the DMI and reported within the acquisition system.

3.2 Digital Laser Profiler

The Hawkeye Digital Laser Profiler (DLP) is classified as a Class 1 non-contact inertial laser profiler which uses sets of paired lasers and accelerometers to obtain longitudinal profile.

A variety of lasers and laser/accelerometer combinations can be mounted on the beam in various positions such as left and right, 850±100 mm each side from the centre of the profiler, as well as the centre of the profiler itself. These positions fit within all relevant wheel path position standards and can be adjusted to meet the client's requirements.

The lasers have a sampling frequency of 32 kHz and are designated Laser Class 3B. Integrated in the inertial profiling system are ± 6 g Three axis ultra-compact MEMS integrated circuit accelerometers.

Classified as a Class 1 profiler as per EN 13036-6:2008 and ASTM E950, the DLP have a vertical accuracy of 0.01 mm, with profiles sampled every 1 mm of longitudinal travel to report longitudinal profile height at 25 mm intervals or greater in mm units to 1 decimal place. The Hawkeye DLP capable of measuring longitudinal profile wavelengths from 250 mm to 100 meters or more, at up to 115 km/h. Advanced filtering options are also available, to filter to various speciation or custom wavelength ranges as required.

Table 3.2: Laser Profiler Specification

Description	Specification
Maximum sensors	Up to 3 for longitudinal profile and/or texture Up to15 lasers for transverse profile
Profile Sampling Interval	Longitudinal profile: 1mm MPD: 1mm
Survey Speed	20 – 115kph (Note: accuracy of evenness values may be affected at speeds less than 20kph)
Laser Types	32 kHz
Laser Class	Visible 3B (<500 mW)
Longitudinal Profile Accuracy	± 0.5 mm
Longitudinal Profile wavelengths	From 250 mm to 100 m
Beam Dimensions	2000Lx500Wx 400H mm
Beam Material	Anodized aluminium
Beam Weight	Variable depending on laser configuration (30 kg – 150kg)
Operating Temperature	0°C to +50°C (32°F to +122°F)
Storage Temperature	-30°C to +70°C (-22°F to +158°F)
Data Outputs	Longitudinal Profile Evenness (IRI, Ride Number, Bump Integrator, NAASRA, HATI) Texture (Mean Profile Depth and Sensor Measured Texture Depth)

The IRI is calculated in accordance with the computer code contained in ASTM E1926 – 08, including the requirements of World Bank Technical Paper #46 with IRI calculation, reference, selection and visualisation capabilities are as per AASHTO M 328-14.

Advanced calculations such as maximum and minimum values, standard deviations and binning can be calculated. Other longitudinal profile formats such as ProVal compliant PFF, ERD and TxDOT files and additional evenness formats such as RN, HATI, NAASRA can also be generated by the processing software if required.

The DLP system lasers are stringently tested for quality control and operating conditions at the factory, undergoing hot water baths to check for leaks, and temperature cycling between -20°C and 70°C to ensure the components can operate reliably and consistently under any environmental condition encountered while surveying on vehicles anywhere in the world.

For accurate and repeatable recording of a reference point or location marker, the Hawkeye System has optical trigger capability which can generate event(s) or trigger reference point(s) during a survey. Diamond grade reflective tape is attached to the required trigger location(s) either vertically or horizontally. As the vehicle passes a trigger location marker the photocell detector, which contains both an infra-red-light source and a detector, generates an event signal. The use of optical trigger to mark the start and finish points of a DMI (distance) calibration is recommended to obtain the most accurate and repeatable calibration. This is also very valuable for research purposes.

Survey files can be setup within the system, to configure the survey setting with both operator and automated inputs relevant to the equipment configuration, conditions of measurement and information on the section(s) to be tested, as per AASHTO M 328-14 and EN 13036-6:2008 standards. The operators receive in-vehicle feedback, including calculated values, historical graphs and automatic error check messages. All automatic errors are logged with the data for future interrogation where required. Extraordinary events can be recorded during data acquisition in line with general best practice in order to identify significant events that may affect the data.

Operating speed ranges: For longitudinal profiling the recommended operating speed range for the DLP system is between 20 km/h to 100 km/h to obtain the highest quality data. As per ASTM E950 standard, the accuracy of evenness values may be impacted at speeds less than 25 km/h, as the long wavelength component of the measured profile will be affected. It is recommended these areas are to be removed from profile for the IRI calculations, to avoid the longer wavelengths affecting adjacent sections where there is valid speed. The Hawkeye system has Stop/Go functionality to provide a result in a processed segment where there may be one of more stops or low speed areas encountered.

Longitudinal profiles from each DLP track Laser/Accelerometer combination are viewable with analytical viewing and filtering tools in the Hawkeye Processing Toolkit, as well as exportable with in PPF or ERD format. As the Hawkeye system is modular, it also has the capability of the 3D Laser System to be configured to collect and calculate evenness and IRI data independently of the DLP.

3.2.1 Macrotexture Measurement

The Hawkeye system measures the macrotexture of the pavement surface using the same three non-contact 32 kHz lasers utilized for longitudinal profile. The macrotexture is reported terms of Mean Profile Depth (MPD) in accordance to EN ISO 13473-2019, ASTM E1845, ISO 13473 determination of Mean Profile Depth, and Sensor Measured Textured Depth (SMTD) in accordance to TRL Lab Report. 639 for Sensor Measured Texture Depth. The speed of the laser is sufficient that height measurements are made every 1 mm or less at speed of 100 km/h.

The macro-texture is reported as MPD which is measured continuously along the length of the pavement in each measurement path and averaged for the selected reporting interval. Raw 1mm texture profile data can also be exported from wheel path and centre position to allow deeper analysis into the raw texture profiles for secondary processes and research purposes.

3.2.2 *Optional Line Lasers*

Two LMI Gocator 2342-3B-12 line-laser sensor units can be mounted as an option in each wheel path at 850 ±100 mm apart. The lasers have a height accuracy of 0.01 mm, and the accelerometers are capable of measuring wavelengths of 90 meters or more. The same outputs are available for raw longitudinal profile and roughness calculations. These lasers can have a tyre bridging algorithm applied to the profile to simulate tyre footprint over negativity tined concrete pavements.

3.2.3 *Compliance to Standards*

Hawkeye laser profilers meet the following international standards:

Longitudinal Profile

Standard Number	Title
ASTM E950 (Class 1)	Standard Test Method for Measuring the Longitudinal Profile of Travelled Surfaces with an Accelerometer Established Inertial Profiling Reference
ASTM E1656 (Class L111)	Classification of Automated Pavement Condition Survey Equipment
EN 13036-6:2008 (E) (Class L1111)	Road and airfield surface characteristics - Test methods - Part 6: Measurement of transverse and longitudinal profiles in the evenness and megatexture wavelength ranges.
EN 13036-6:2008	Road and airfield surface characteristics - Test methods - Part 5: Determination of longitudinal unevenness indices
ASTM E1926-08(15)	Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements
ASTM E1489 - 08	Standard Practice for Computing Ride Number of Roads from Longitudinal Profile Measurements
AASHTO M 328-14	Standard Specification for Inertial Profiler
AASHTO R 43-13	Standard Practice for Quantifying Roughness of Pavements
AASHTO R 54-14	Standard Practice for Pavement Ride Quality When Measured Using Inertial Profiling Systems
AASHTO R 57-14	Standard Practice for Operating Inertial Profilers and Evaluating Pavement Profiles

AGAM-S001-16	Specification for Pavement Roughness Measurement with an Inertial Profilometer
AGAM-T001-16	Pavement Roughness Measurement Inertial Profilometer
ISSN 0253-7494- 1986	World Bank Technical Paper 46 Guidelines For Conducting And Calibrating Road Roughness Measurements
ISSN: 0361-1981	Pavement-vehicle interaction and traffic monitoring. Transportation Research Record 1501 On The Calculation Of International Roughness Index From Longitudinal Road Profile

Transverse Profile

Standard Number	Title
AGAM-S004-16	Specification for Pavement Rutting Measurement with a Laser Profilometer
AASHTO R 87-18	Standard Practice for Determining Pavement Deformation Parameters and Cross Slope from Collected Transverse Profiles
AASHTO R 88-18	Collecting the Transverse Profiles

Texture Profile

Standard Number	Title
EN ISO 13473-1-19	Characterization of pavement texture by use of surface profiles — Part 1: Determination of mean profile depth
ASTM E1845-01	Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth
AGAM-S005-16	Specification for Pavement Surface Texture Measurement with a Laser Profilometer
AGAM-T013-16	Pavement Surface Texture Measurement Inertial Profilometer
TRL Lab Rep. 639	Sensor Measured Texture Depth (SMTD)
ASTM E965 - 15[1]	Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique

3.3 Automatic Crack Detection

The Hawkeye system incorporates a 3D Class 3B, 28 kHz frequency laser scanning system. The 3D laser system consists of two main components: a high-power spread-line laser and a high-speed 3D camera mounted off-axis to the laser light source. Together, the two 3D laser units project a laser line onto the pavement and the image is captured by the camera, allowing it to measure the transverse profile of the pavement. Half of the image is captured by each camera, which interprets the distortions to the straight laser line as variations in the

[1] 3D Laser System utilizing virtual void fill volume

vertical surface profile to obtain transverse profile measurement. As the system uses its own laser light source, it is unaffected by shadows or variations in ambient lighting and allows optimum contrast and visibility of cracks and other defects, even in full darkness.

The 3D imaging scans the pavement with 4000 measurement points across the transverse profile over a nominal 4 m width resulting in a 1 mm transverse resolution, to a 0.1 mm profile depth resolution with a depth accuracy of 0.25 mm. It does this at a 28 kHz sampling rate which equates to one transverse profile being recorded every 1 mm of longitudinal travel at 100 km\h survey speed.

Hawkeye software can utilise the string line and straightedge models, calculating both the severity (mean rut depth and standard deviation) and extent for both wheel path and lane rutting in millimetres to 1 decimal place. Advanced calculations such as maximum and minimum rut depth can also be calculated by the software, as required. The rutting results are produced every 1 m and aggregated to produce a value for the given report interval e.g., 1 m, 10 m or 100 m.

The high resolution of the transverse profile allows the system to identify other features such as edge drop off by detecting the relative height measurements towards the edge of the rut profile and the intensity values can identify the presence of line marking. These features can be used to limit the rut measurements to the lane itself or ignored, if required.

With the addition of inertial measurement units (IMU) to accurately track the laser units position and orientation, the 3D scans can be corrected to negate the effect of vehicle motion. From this combination of data, geometry information such as curvature, slope and crossfall gradient measurement can be determined to ± 0.15% accuracy.

The ACD system will capture a picture of the road surface by combining sequential transverse profiles. There are three types of 'images' created, both range and intensity profiles which are merged to produce, clear, high resolution 3D digital pavement images, in a continuous format, that represent the width of transverse road section up to 4m wide.

Additionally, line markings can be identified automatically by the processing software, through the intensity information in the images.

Using this information, the Hawkeye ACD system can assess the cracking extent area at a fixed distance from the line, thus removing the potential errors that can result from variations in driver tracking. This will improve the repeatability of the results.

- **Intensity** - Is a realistic view of the road surface without the 3D integration of the lasers. The intensity images are used to identify line marking, sealed cracks and surface type.
- **Range** – Displays different shades when the laser detects drops in the profile. Range images are used to identify rutting and image depth.
- **3D** – Is similar to Intensity but it has more detail, it incorporates the laser profile (depth) into the image. The 3D image is used to extract cracking, potholes and other surface defect characteristics.

The pavement images are synchronized to all other data streams and location spatial information, and can be displayed as one uninterrupted continuous pavement image ribbon for the entire survey file. The pavement images can also be provided as individual 5 m long by 4 m wide images that can be zoomed in and out to show detail, as well as toggle on overlay information to view crack map overlays and other defects. The image can also be singularly, and batch exported into high resolution JPEGs, or without associated header information as required. Along with the image export the processing toolkit creates an image database, listing the image identifier, section reference, distance and spatial location coordinates of the image exports.

The pavement images are collected in conformance with AASHTO R 86-18 Standard Practice for Collecting Images of Pavement Surfaces for Distress Detection, with the processing of the images, separated into two distinct phases. First, the raw data is processed into crack maps, which is done by the proprietary Pavemetrics software algorithms. The data for the "crack maps" are stored in an XML format.

These XMLs can then be analysed using ARRB Systems own proprietary algorithms to classify, weight and aggregate the cracking information into multiple formats as required, such as AASHTO R 85-18 Standard Practice for Quantifying Cracks in Asphalt Pavement Surfaces from Collected Pavement Images Utilizing Automated Methods.

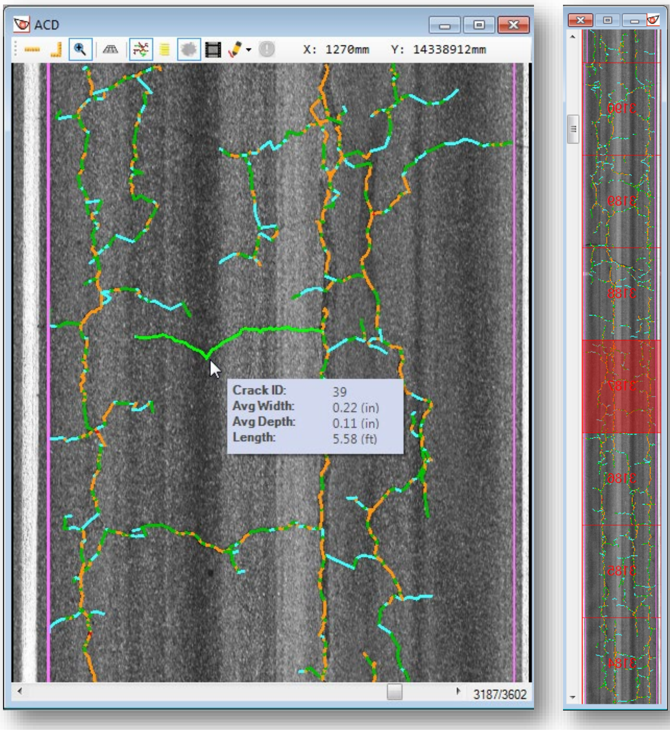

Figure 3.2 ACD Crack Map (left) and Continuous view (right)

"Straight line" cracks (joints, induction loop cuts, etc.) and other "false positives" are removed from the analysis by our custom developed algorithms. In ideal conditions, the minimum crack width measurement is 1mm and the reasonable minimum crack width automatic detection threshold is 2.5 mm, but cracks are visible in the images down to 1mm.

Flexibility is a key element of the Hawkeye automatic crack detection system that has the ability to identify Cracks, Potholes, Line Marking, Curb, Drop off, Texture, Rutting, Ravelling and Seal types, and Lane marking which are all synchronized to all other data streams, distance and spatial information. By using all this information, the Hawkeye system can produce comprehensive reports that can be tailored to any client.

Features

- Crack Percentage – Hawkeye's automatic crack detection allows for improved crack percentage calculations. Since the length, width and depth can all be detected accurately, no block estimation of the percent area is required.

- Wheel Path and non-Wheel Path Cracking – The AASHTO (AASHTO:55-10) and HPMS field manual wheel paths are standard but are completely customizable if required. This allows for improved flexibility when dealing with different vehicle types.
- Surface type detection – The Hawkeye system automatically identifies different surface types, which allows for tailored detection algorithms to be used. This is extremely useful when dealing with concrete roads.
- Concrete Joint Detection – When concrete roads are detected both longitudinal and transverse joins can be detected automatically. Once these joins have been detected they can be incorporated into any reporting format.
- Line Marking, Curb and Drop off detection – Detection of these road objects allows for improved crack detection repeatability. Knowing the position of the line marking allows the AASHTO wheel path bands to always be in the centre of the lane, hence removing vehicle tracking. (note: this is also customizable).

Table 3.3: ACD operational specifications

Description	Specification
Number of profiles	2
Sampling Interval	28,000 profiles per second
Minimum Process Intervals	1 m
Profile Spacing	2 mm (adjustable)
Survey Speed	1 – 100 kph
Transverse Profile Depth Accuracy	0.1 mm
Transverse Profile Resolution	1.0 mm
Depth range of operation	250 mm (adjustable)
Data Outputs	Crack rating Rut depth Ravelling Potholes
Operating temperature	Capable of operating up to 50 degrees C
Measurement Width	Up to 4m
Laser Types	Pavemetrics Laser Crack Measurement System (LCMS) 2
Beam Material	Rugged, anodized aluminium
Weight	10kg per unit
Dimensions	Laser units: 428L x 139W x 265H mm Mounting frame: 2500L x 2000W x 1000H
Mounting Location	Rear of roof rack

Customized Reporting

- ARRB Systems has a number of reports that have been based on different standards around the world (i.e. Japan, China, Australia, USA - AASHTO). These reports can also be tailored to any client upon request.

- Cracking distresses can also be measured at each severity level, according to the Distress Identification Manual for the Long-Term Pavement Performance Program and/or AASHTO R 55-10 "Standard Practice for Quantifying Cracks in Asphalt Pavement Surface".
- ARRB can also collect and report the total percent of asphalt pavement area cracked and Percent of Slab Cracking for PCC pavements in accordance with US Federal HPMS reporting requirements.

The 3D system measures transverse profile every 1 mm of longitudinal travel, allowing for the short wavelength (high frequency) content of the pavement to be measured at any point across the pavement. To be able to measure the long wavelength (low frequency) content of the pavement each sensor is also fitted with an accelerometer.

Combining the output of the accelerometer, which determines the inertial frame of reference of the 3D system, with the height of the ground relative to the accelerometer (measured using the sensor spot directly under the accelerometer) and sampling both together at a constant interval, allows the longitudinal profile of the pavement to be measured over the IRI waveband.

Measurements are made in each wheel path, the locations of which are defined by the user. In this way the 3D system operates in exactly the same way as a typical inertial laser profiler and is able to export longitudinal profile in a given format.

It can also detect transversal and longitudinal joint faulting in concrete pavements. The position, the length, perimeters and the faulting value of each transverse joint are reportable. The 3D sensor mounted IMU accelerometers can also provide slope and cross fall geometry data.

Testing has been undertaken to show that the system meets the flowing standards:

- Class 1 requirements of ASTM E950 Standard Test Method for Measuring the Longitudinal Profile of Travelled Surfaces with an Accelerometer Established Inertial Profiling Reference,
- IRI to ASTM E1926-08.
- AASHTO R 56-14 Standard Practice for Certification of Inertial Profiling Systems.
- AASHTO M 328-14 Standard Equipment Specification for Inertial Profiler.

The traditional way to measure texture is via dedicated high frequency texture lasers, however there is an alternative method to measure texture via the 3D System. The 3D system applies inbuilt algorithms to measure mean profile depth (MPD) and/or mean texture depth (MTD) in accord with the requirements of the following two standards:

- ASTM E1845 - 01 Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth.
- ASTM E965 - 15 Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique.

With 3D texture, it is also possible to report both macro-texture measurements for each of the 5 AASHTO bands across the lane. This enables texture to be reported across the full lane width.

3.4 Digital Imagery

The Hawkeye 2000 series Asset View imaging package is an advanced video acquisition system that utilises the latest in digital camera technology. Cameras are optimized for high and varying speed road collection, to produce crisp high-resolution image quality in all road conditions.

All digital Images have a positional accuracy of less than 0.5 m and measurement accuracy of less than 0.25 m. The images are high-resolution and the set-up of the cameras easily allows the reading of lettering less than approx. 100 mm high. The viewing software's zoom function allows even smaller lettering to be read.

Figure 3.3 Example of Hawkeye Image Export

Each High Definition ethernet camera can collect images every 5 m, with the captured high-resolution, high definition 1920 x 1080-pixel image easily allowing lettering on passing signs of less than 100 mm high to be read. The viewing software's zoom function allows even smaller lettering to be read. The images themselves are high in resolution and the set-up of the cameras allows a positional accuracy of less than 1 m and measurement accuracy of less than 100 mm. Optional 4K (9MP) resolution cameras can be fitted that allow for higher resolution and deeper zooming, however the trade-off is significantly increased file size and require more data storage.

Captured images are referenced for position linearly (in relation to road location information) and geospatially (latitude and longitude), along with a continuous camera calibration grid enabling real-time and post, checking of calibration alignment and azimuth during a survey. This allows for accurate measurement of inventory information, complete with a unique geo-referenced position, thus making it possible to measure and locate defects or features on the network by chainage and spatial reference.

Inventory data can then be imported into a GIS, which can then be used as a tool for the management of existing assets on the network. Even if other existing asset assessments are not required at the time, the recorded information can still be used to note inventory or condition at a later date.

Images are captured, compressed and synchronized in conjunction with sensor and location data and stored in to AVI format to streamline playback and searching capabilities. Hawkeye

Processing Toolkit has both single and batch export capabilities to export high-definition images in JPEG format, along with header meta-data options to imbedded header information into the images where required.

Having collected millions of kilometres of imagery, ARRB Systems is highly experienced in the collection and development of hardware and software to collect the highest quality image that is both efficient and adapts to constantly changing road conditions encountered during a network survey. The Field of View (FOV) has been specifically selected to optimally match the camera CCD/CMOS sensor size to minimize barrel distortion at the image edges, prevent poor image quality and increase consistency for calibration for on screen measurement and geo-referencing accuracy. The cameras are built specially for the road environment, and are optimized for high-speed road collection, with adaptive lenses and software-controlled exposure levels, enabling superior performance in constantly changing light conditions of a network survey. This enables the cameras to recover from rapid changes in lighting conditions (bright sunlight, dark shadow) in less than 25 m of travel.

Figure 3.4: Example of three cameras stitched image

Systems are typically equipped with four HD digital imaging cameras, three facing forward, and one rear facing. This arrangement of individual cameras along with each camera's field of view will allow for visually identifying, measuring and locating road and roadside features accurately at highway speeds. Optional arrangements can include six cameras (up to eight) three forward and three rear to provide a full 360-degree view of the roadway.

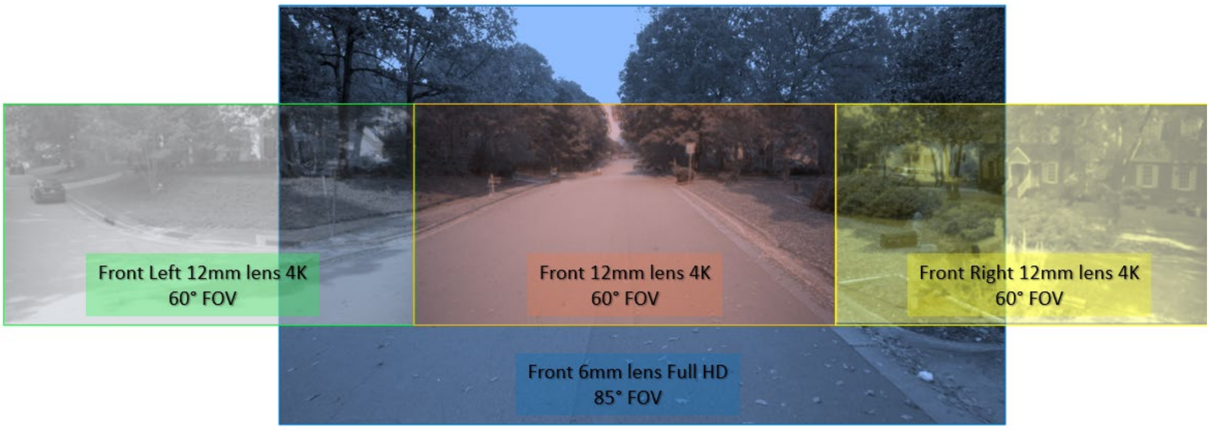

Figure 3.5: Example FOV with Full HD and 4K cameras with 6 mm and 12 mm lens options

All cameras are roof mounted on anti-vibration mounts to provide unlimited perspective view flexibility. They are operable in -10 °C to +50 ° temperature ranges and enclosed in waterproof IP rated housings, with distortion free light transmission through high optic quality glass windows to eliminate fogging and condensation in high humidity conditions.

Table 3.4: Camera Specifications

Description	Specification Full HD	Specification 4K
Image position accuracy	Typically, 0.1 m with DMI distance sensor	Typically, 0.1 m with DMI distance sensor
Sensor type	1/1.3" CMOS Sony sensor Global shutter 30 fps	(1") CMOS Sony sensor Global shutter 12 fps
Camera format	IP camera (Basler BIP2-1920-30c)	GigE camera (Basler acA4096-11gc)
Picture size	1920 x 1080 pixels (Export size is 1920 x 1184) 2.2 Megapixel	4096 x 2168 pixels 9 Megapixels
Colours	Full colour, MJPEG, 0.2 lux	Full colour, MJPEG
Survey speed	Zero to full highway speeds	
Frame rate	Able to capture frames at 5 m intervals while travelling at maximum survey speed of 100 km/h	
Frame rate configuration	Software configurable, based on time, distance or external trigger operation	
Compression	Adjustable (3 - 30x compression)	
Lens options	Lens option A: 6 mm fixed iris, fixed zoom at 85 degrees FOV	Lens option A: (best for single FOV) 8mm fixed iris, manual focus (no zoom) / ~85 Degrees
	Lens option B: DC-iris, variable FOV	Lens option B: (best for triple FOV) 12mm fixed iris, manual focus (no zoom) / ~60 Degrees
Storage format	MJPEG (compressed)	
Operating temperature	-10°C to 50°C	
Camera housing dimensions	400L x 100W x 300H mm	
Mounting Location	Roof rack on vehicle	

A 5 to 10 m sample interval will ensure that information detail is not lost between subsequent images and 10 m interval is a good balance of data storage and provides the optimum image and image quality for asset image identification and collection of roadside assets as guardrails, guardrail terminals, signs, pavement markings and unpaved shoulders. Captured images are referenced linearly and spatially when exported along with other sectional and time meta data.

3.5 Gipsi-Trac2 Spatial Positioning System

The GIPSI-Trac 2 is a next generation GNSS + INS (Global Navigation Satellite Systems + Inertial Navigation System) geometry module. The GIPSI-Trac 2 is a Hawkeye compatible module using dead-reckoning sensors and dual GNSS antennas to collect position and road geometry information with an GPS update rate of 20 Hz.

Figure 3.6: GIPSI-Trac 2 - Global Navigation Satellite Systems + Inertial Navigation System

This combined system provides a far greater update rate and supports more satellite systems than previous GNSS offerings, including SBAS Egnos and Omnistar HP/XP/G2.

It boasts real-time fused GNSS/INS outputs in all survey conditions, including periods of GNSS outage to provide sub-metre geographical location accuracy. The data can be post processed to achieve centimetre level accuracy.

The System can export positional data, synchronized and referenced to the individual sensors on the system, a 3 axis X-Y-Z spatial data coordinates every 1.6 m at 120 km/h at a resolution of 3 decimal places.

The system records and combines inertial data from a 3-axis gyroscope, 3-axis accelerometer and a distance sensor with dual GNSS positional information. The built-in dead-reckoning allows for position data to be recorded when in tunnels, under bridges and locations with little or no GNSS coverage to maintain a sub-meter accuracy after 1 minute of satellite outage. This ensures greater than 95% of all records have an accuracy of sub-meter or better.

Gipsi-Trac 2 is an ARRB Systems' built component and therefore have full control over the outputs and compatible satellite systems in communication with the GPS and GLONASS satellites.

Applications

- Provides road geometry and position for complex 3D highway mapping
- Estimated speed and travel times
- Advisory signage for road users
- Locate potential sites for rainfall ponding
- Conformance to geometric road design specifications

Table 3.5: Gipsi-Trac2 operational specifications

Description – GPS	Specification
Output Data Rate	H2000 250 Hz (post processing option available) 1000 Hz (post processing option not available) H1000 500 Hz (post processing not available)
Operating speed	Zero to highway speeds
Data Outputs	Grade Vertical and horizontal curvature Cross slope Dead reckoning position data
Accuracy	Grade: <0.2% (0.1 degrees) Cross slope: <0.2% (0.1 degrees) Horizontal position accuracy: 1.2 m Vertical position accuracy: 2.0 m Horizontal position accuracy SBAS: 0.5 m Vertical position accuracy SBAS: 0.8 m Horizontal position accuracy with post processing: 0.008 m Vertical position accuracy with post processing: 0.015 m
GNSS Specifications – Parameter Value	Supported Navigation Systems • GPS L1, L2, L5 • GLONASS L1, L2 • GALILEO E1, E5 • BeiDou B1, B2 Supported SBAS Systems WAAS • EGNOS • MSAS • GAGAN • QZSS • Omnistar HP/XP/G2 Update Rate 20 Hz Hot Start First Fix 3 seconds Cold Start First Fix 30 seconds

4 HAWKEYE SOFTWARE

4.1 Acquisition Software – Onlooker Live

Hawkeye Onlooker Live software is an interactive and real-time acquisition control interface that is capable of controlling and monitoring all of the Hawkeye systems simultaneously. The software runs on a dedicated computer in the vehicle.

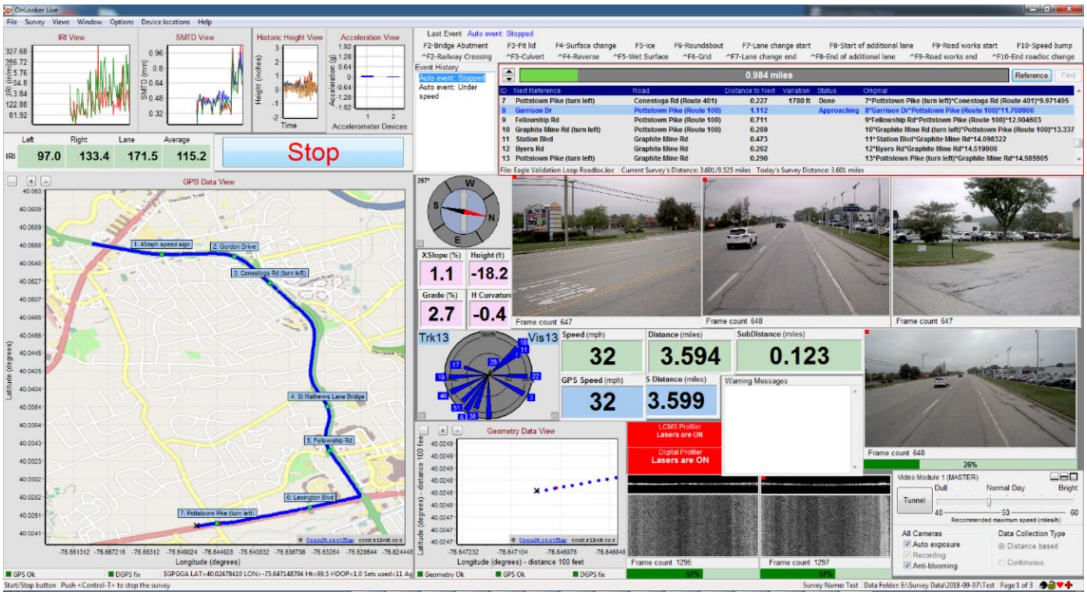

Figure 4.1: Example Hawkeye Onlooker Live data collection user interface.

The easy-to-use interface features a fully flexible layout that can be customised to individual operator and survey requirements. The network control interface enables real-time results reporting and the flexibility to progressively add new Hawkeye systems without the need for additional software. Additional plug-ins are available to enable advanced operations and can provide advanced mapping systems, real-time IRI calculation and customised QA tools.

Hawkeye Onlookers modular system allows the Operator to choose to conduct measurements with only one or multiple data acquisition modules.

The on-screen interface includes Route details both distance log and spatially mapped GPS coordinates, Real-time measurement outputs including IRI, geometry and speed, Views of both ROW cameras and 3D images perspectives, Disk space utilization and everything required for the operation and monitoring of the equipment to obtain quality data.

Features and Benefits

- Real-time fully graphical Windows data acquisition software
- Seamless upgrades as systems are added
- Customisable screen layouts to suit operator needs
- Single software interface for management of multiple computer system
- Survey navigational aids e.g.: compass, location reference points, events etc.
- High resolution camera views
- Digital display of:
  - speed (High resolution DMI and GPS data)

  - distance (High resolution DMI and GPS data)
  - geometry (X-fall, Slope, grade, and curvature)
- Graphical display of:
  - GPS maps, compass and satellite locations
  - inertial geometry map
  - road profile information
- Tabular display of:
  - road location reference points
  - predefined and real-time event point marking
  - user defined survey notes tool

4.2 Processing Software – Processing Toolkit

The Hawkeye Processing Toolkit is a professional office-based data processing, analysis and reporting tool that enables accurate processing of all parameters, in an easy-to-use interface featuring an integrated image viewer and database interface to review, chart, locate and map survey data.

Hawkeye Processing Toolkit software provides full data processing, analysis and management capabilities on all imaging, profile, distress and pavement data collected. This software allows for full control and synchronization for all raw and processed data streams collected, enabling analysis down to all incremental levels and up to all aggregative levels, as required.

Toolkit has advanced mapping capabilities with integrated Google background maps and GIS layer export capabilities such as ArcGIS, MapInfo or ESRI layer formats. Processed condition and inventory data can be tagged with a Hawkeye URL (hURL), a tool to launch the Hawkeye software that will direct the user to the location of the road where the condition assessment has taken place. hURLs can also typically be attached to any GIS layer, spreadsheet, document or Windows object. This allows for ease of viewing imagery from other third-party software packages or documents. The hURL acts as a bridge to connect collected spatial data to the video image by automatically opening to the Hawkeye software, which allows a more in-depth analysis of the particular road section. This ensures easy access to the image relating to the data provided in a GIS layer or spreadsheet.

The Hawkeye Processing Toolkit is an integrated graphical user interface (GUI) that compiles the collected survey data and allows the user to 'virtually drive down the road' to review and record rating information as needed. The viewer can be used to review and rate individual video frames against chainage and GPS, save images to file and zoom-in to inspect areas of interest.

Asset view video images can be stitched to allow for measurement across images in a panoramic view. This professional yet user friendly image stitching feature has all the functionality you need to stitch panoramic views, rotate camera views, scale images up and down, and adjust brightness and contrast. Multiple images can be reviewed simultaneously, and the road can be 'driven' at a rate selected by the operator

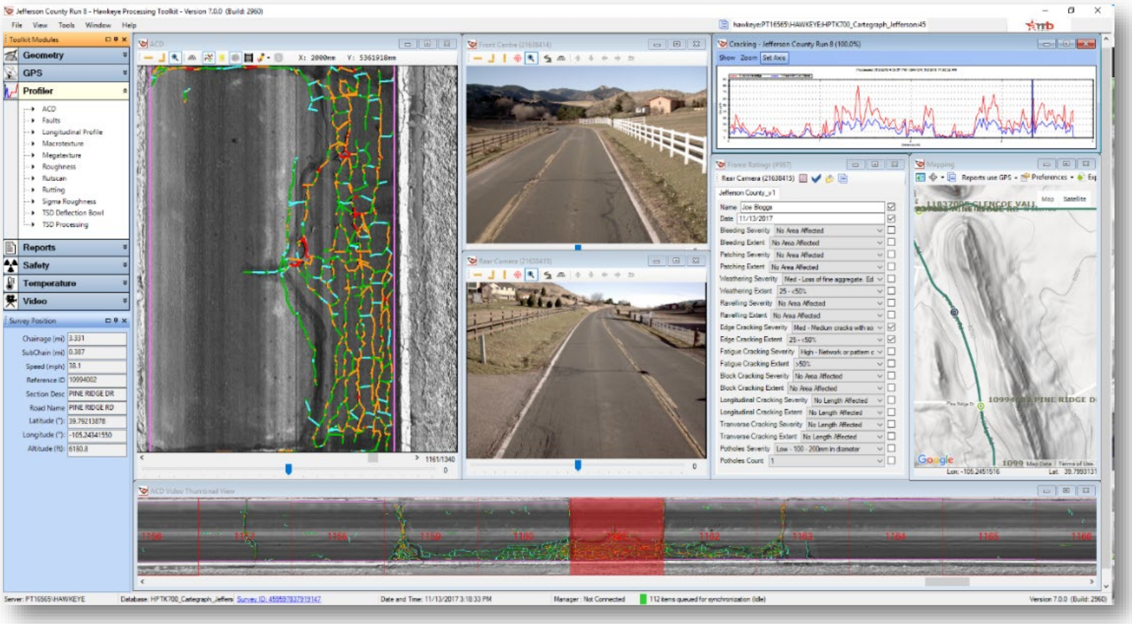

Figure 4.2 Hawkeye Toolkit example showing cracking views and outputs

Hawkeye Toolkit processing and reporting functionality includes but is not limited to:

- Longitudinal and Transverse profile, from both profiler and 3D Laser System, to report:
  - Evenness IRI to ASTM E 1926,
  - Rutting to ASTM E 1926,
  - MPD macrotexture to ASTM E 1845 and ISO 13473-1.
- Geometry, to report;
  - Grade (longitudinal slope),
  - Cross fall,
  - Horizontal curvature,
  - Vertical curvature.
- "Defects reporting" to report;
  - Cracking to AASHTO R 85-18,
  - Crack ratio,
  - Ravelling Index,
  - Potholes.
- Features and Benefits
  - Easy-to-use fully graphical Windows interface allowing synchronised viewing of data, results and video,
  - Seamless integration with Hawkeye databases,
  - Extensive analysis and reporting capability for geometry, GPS, profiler and video,
  - Mouse and/or configurable keyboard operation for efficient data review,
  - Export capability to popular PMS and HDM-4 programs,
  - User configurable ratings forms,
  - Graphical display of

        - survey route with reference points and events,
        - profiling data and geometry,
    - Rubber banding and editable reference points,
    - Export tools to: CSV, PDF, MS Word, MS Excel, RTF, ERD, PPF,
    - Synchronised viewing of data, results and video,
    - Advanced mapping with integrated Google background maps,
    - Centralised databases to allow multiple users to process the same survey data simultaneously,
    - Multi-lingual language support: Chinese, Russian, Japanese, Arabic and Spanish,
    - Survey search filter,
    - Batch processing,
    - Windows 10 compatible,
    - Windows launching.

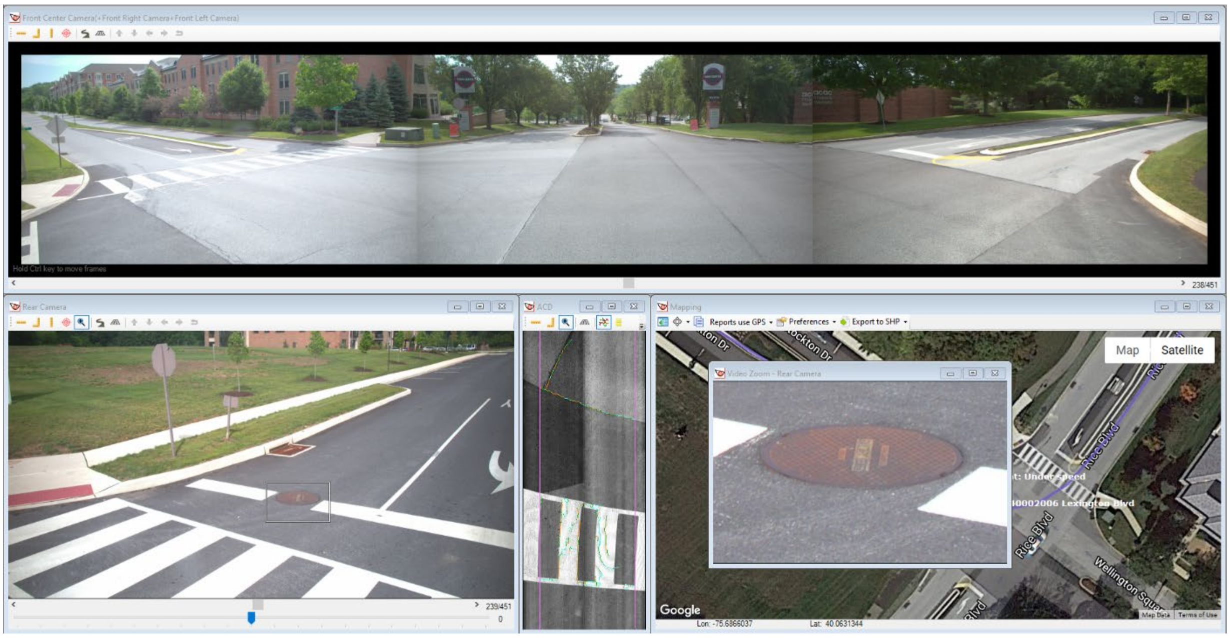

Figure 4.3 Hawkeye Toolkit example showing 9MP camera views and ACD

- Video
    - Zooming tool to inspect areas of interest,
    - Distance measurement tool:
        - measure lane widths,
        - distance of object from centreline,
        - crack lengths.
    - Area measurement:
        - crack area,
        - pothole area,
        - assets size measurement,

  - Save images to file,
  - Fast navigation and scrubbing features ,
  - Multiple images can be reviewed simultaneously, and the road can be "driven" at real-time speed or at a rate selected by the operator.
- Profilometry
  - Roughness/Evenness – IRI and HRI calculation,
  - Texture – SMTD, SPTD and EN ISO texture (MPD) calculation,
  - Rutting,
  - Longitudinal profile export.
- Data formats
  - Exports printable reports in Adobe PDF, Microsoft Word and Excel format,
  - Exports data in Microsoft Excel-compatible CSV format,
  - Exports longitudinal profile in PPF and ERD format.
- Professional image stitching and enhancement
  - Onscreen line and area measurements can be conducted across images
  - Multiple asset view image stitching capabilities,
  - Various image enhancement features including scaling brightness and contrast ,
  - Measurements can be copied directly to rating forms.
- On-screen Asset Location
  - Powerful geo-referencing feature ,
  - Create an inventory of roadside assets such as signs, guard rails, etc.,
  - Reference image against GPS co-ordinates and can be converted to UTM,
  - Simple point and click operation,
  - Identify multiple objects in the same video window,
  - Simple calibration technique,
  - Field co-ordinates saved to individual rating forms.

4.2.1 Distributed Processing System

Hawkeye Processing Toolkit has powerful and flexible batch processing capabilities. Multiple survey files from one day, to tens of thousands of kilometres of data over several weeks, can be simultaneously and automatically processed to calculate evenness, texture, cracking and other defects, for any chosen, defect type, segment or length.

Features

- Significantly decreases 3D imagery and crack processing times.
- 'Hawkeye Data Processor' can be installed on multiple PCs within the network.
- Automatically discovers any Hawkeye Data Processors on the network.
- Utilises the in-active processing power of a PC network.
- Speeds of approximately 200 km of data per hour can be achieved.
- In a 24-hour period over 4500+ km can be processed.

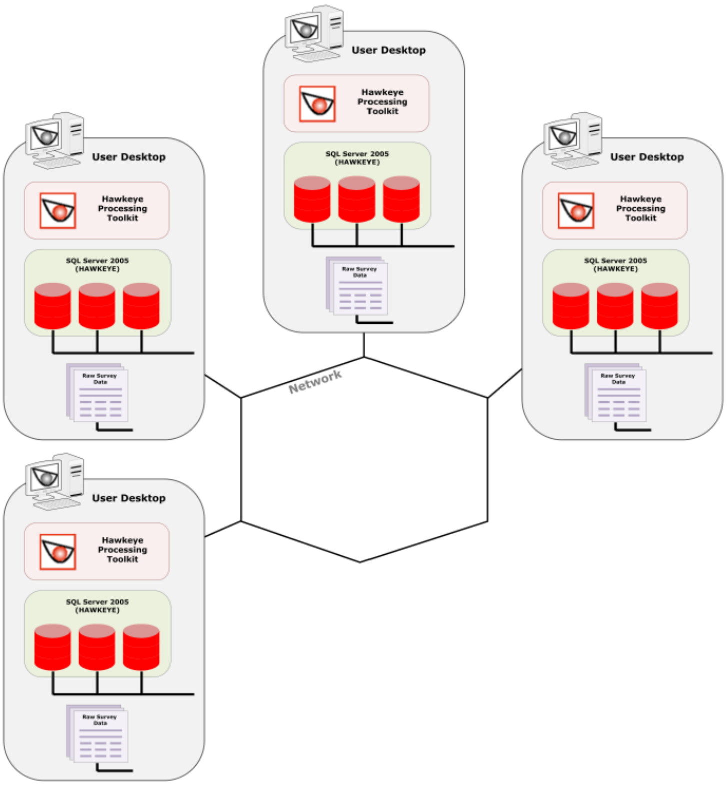

Figure 4.4: Distributed Processing Architecture

The Hawkeye ACD system is very flexible in its outputs and ARRB Systems has developed algorithms that can be used to emulate or exactly replicate other crack system assessments.

Templates can be created to allow for batch or individual processing of data files to ensure there is consistency with outputs and reporting. This includes the ability to choose and set the processing method for each type of data. For example, both inertial profiler and 3D profiler texture and evenness can be processed together, or individually with same parameters, or different parameters, to the data processing technician's discretion.

The high flexibility of the Hawkeye Processing Toolkit allows for multiple parameters to be set and saved in template form. As the raw data is not modified in any way, multiple processing types, setting the parameters, interval reporting lengths and configurations such as kerb detection andcrack seal settings, can be applied and changed to suit client requirements. If required, multiple variant reports with differing output parameters and settings can be processed simultaneously from the same raw data.

5 VEHICLE ENGINEERING AND SAFETY

A Hawkeye System consists of a host vehicle fitted with pavement measurement sensors to the front, rear and underneath the vehicle, along with equipment towers, various computing equipment and electrical power systems, within cabin of the vehicle.

In the modification of an OEM vehicle to fit a Hawkeye system, the main engineering regulation and safety considerations are the overall dimensions, mass, airbag deployment, structural modifications, weight and positioning of equipment and anchorage methods used in upholding the comfort and safety of vehicle occupants and others.

Modifications are designed and implemented with following considerations:

- Ergonomic impacts to vehicle occupants and system operators.
- Installations will not affect the frontal airbag deployment sensors.
- OEM factory body mounts are used wherever possible both in the interior and exterior of vehicle.
- Penetrations to the vehicle body are kept to a minimum with use of existing OEM penetrations and are considered to have minimal effect on the structural integrity of the vehicle .
- Clearances are maintained such as driver field of view and Supplementary Restraint Systems (SRS) compatibility with screen attachments.
- The centre of gravity of the equipment and mounting has been kept low and the weight evenly distributed left and right.
- Installation is within the perimeter of the vehicle dimensions wherever possible, with any extrusions within the allowable dimensional and overhang requirements.
- Roof mounted equipment is fitted using existing roof rail attachment points within the roof loading allowance of the vehicle.
- Anchorage and fitment of all equipment is secure, and all cabling is secured and supported.
- Gross vehicle mass limits are not exceeded.
- Clearance lights, warning lights and outline end outline markers are fitted where required.
- Equipment fitted to the exterior and interior of the vehicle has been assessed as having met the design regulations relating to occupant and pedestrian impact.

ARRB Systems' products are tested in both workshop and field conditions to ensure operational performance and safety criteria are met. The Hawkeye systems have been 3rd party certified as compliant to relevant Design Rules and vehicular compliance standards, as well as certified to have satisfactorily addressed secondary safety aspects.

5.1 Laser Safety

ARRB Systems follows all laser safety protocols to protect workers and the general public against laser optical radiation exposure in the system design, build and operation.

This includes limiting all laser power emittance to Class 3 or below. Directive 2006/25/EC and Class 3B laser safety protocols require that the laser emittance is automatically stopped if the speed falls too low below 5 km/h or the vehicle is stationary. Override systems with keyed hardware lockouts and software locks are in place that can enable operation under controlled conditions for calibration at diagnostics where laser safety protocols are followed.

5.1.1 Optional Low Speed Safety Interlock

Collecting data in a dense, urban environment at low speeds has always been a trade-off between operating the equipment productively and safely as well.

ARRB Systems has developed a safe, low risk option to enable low speed collection of ACD data using the LCMS laser. We use object identification technology and include a Hawkeye human detection module which allows '0 speed' (actually 0.5 km/h and above) collection of ACD data from LCMS units.

6 SYSTEM COMMISSIONING

The Hawkeye system will be commissioned and validated in accordance with client's requirements at the client premises or local validation site. This includes client's observation and acceptance of laser calibration processes, bounce test limits and validation data. A written report will be supplied that documents the local validation measures undertaken and analysis of results.

Acceptance testing to client's requirements for the verification of calibration 3D Laser System will be conducted and results documented in a Validation report. Tuning and adjustment trial runs for Profiler, Distance measurement instrument, Defect detection system, Road geometry and Macrotexture will be conducted at the client's location to client's requirements and satisfaction, including checks to the measurement of macrotexture, IRI and geometry using the 3D Laser System.

Commissioning of the Hawkeye system onto the vehicle is generally carried out by two experienced technicians for a total of five (5) days. Training takes place the following week for a total of five (5) days with one technician, comprising both desk-based and practical training components.

Training operators for the Hawkeye system will include the safe, productive, and efficient operation of the pavement condition data collection system by client personnel. Topics include system operation, validations, calibrations, trouble-shooting items, survey technique, and data processing. In vehicle and on the road training is included in the program.

Tuning and adjustment trial runs for Profiler, Distance measurement instrument, Defect detection system, geometry of the road, measurement of macrotexture, measurement of macrotexture, IRI and geometry using the 3D Laser System, will all be conducted in the origin country of the client and to the client's requirements and satisfaction. This includes calibration processes, speed dependency tests, test threshold limits and repeatability runs, with documentation of the measures, analysis and statement of compliance with a written report

7 QUALITY ASSURANCE

The quality and integrity of data collected is dependent on the host vehicle, the sensors and recording equipment, the training of the staff and their compliance with set protocols. All Hawkeye 2000 systems undertake the quality checks below for all individual equipment.

- Calibrations
- Validations and repeatability
- Precision and accuracy tests

ARRB Systems has extensive experience in delivering large-scale projects of high complexity, and in doing so has developed methodologies, project management methods, and procedures to deliver these projects efficiently and effectively. These processes and methodologies have been developed and refined over the last several decades and have been implemented over hundreds of projects, on both international, national and state level projects.

The proposed workflow for the project is illustrated in Figure 7.1 with the detailed tasks associated with the project plan approach outlined in sections below.

Figure 7.1: Project plan flow

7.1 Quality Assurance Procedure

Project planning

- Project scoping
  - Upon award follow procedure - Order Processing and Timing
  - Define project scope
  - Prepare draft schedule, resource plan
  - Ensure production and delivery staff have the required training as per training matrix
- Kick off meeting
  - Prepare questions on issues to be clarified/resolved
  - Develop agenda items
  - Discuss and document any ambiguities

  - Communication protocol defined, agreed and followed
- Project preparation
  - Contract and payment terms finalized
  - Handover meeting with Project and Production team
  - Build and Commissioning schedule finalized
  - Development requirements defined
  - Safety and risks assessed with team briefed and signoff

Production

- Bill of materials (BOM)
  - Follow procedure - BOM Creation and Modification
  - Bill of materials (BOM) created
  - Develop product requirements list
  - Select order part from stock inventory
- Assembly
  - Follow procedure - Production Assembly and Testing
  - Issue of stock from store inventory, with serial numbers assigned to product
  - Assemble and wire components
- Equipment verification
  - Assembly Check
  - Firmware Testing
  - Production Testing
  - Instruments are fully calibrated
  - Equipment is road tested
  - Equipment runs factory repeatability and accuracy of measurement checks
  - Equipment assessed in accordance with acceptance criteria
  - Sign off by Validation Manger

Commissioning

- Shipping
  - Follow procedure - Assembly, Commissioning and Training
  - Ship Product
- Vehicle build
  - Follow procedure - Assembly, Commissioning and Training
  - Commission equipment as per build instructions, and relevant configuration/wiring drawings
  - Check to ensure the system is fully operational per the customer requirements.
- Acceptance testing
  - Repeatability and accuracy of measurement runs
  - Equipment assessed

    Sign off by customer

Delivery

- Equipment handover
    - Follow procedure - Assembly, Commissioning and Training
    - Handover equipment
    - Complete Handover Document

Training

- Follow procedure - Assembly, Commissioning and Training
- Training schedule
- Deliver training
- Training Certificate issue

Project close out

- Project de-briefing with all project management, operational and delivery teams
- Project close out meeting
- Customer sign off on equipment, training & warranty
- Customer Satisfaction Survey
- Document lesson learnt and draft amendments to Project plan for any subsequent projects

8 HAWKEYE CLIENT LIST

Country	Client	Year
Australia	ARRB Group	1990 - 2021
	Australian Surface Testing	2002,2014
	Boral	1997, 2006, 2007, 2011
	Department of Defence	1998, 2004
	Department of Transport SA	1996, 2011, 2012
	Downer EDI, Western Australia	2017
	Geospatial Data Services	2008
	Main Roads Western Australia	1990
	Pavement Management Services	1990, 1995
	Queensland Department of Main Roads	2000, 2006, 2009, 2010
	Roads & Traffic Authority NSW	2004, 2007, 2009, 2010
	Sensis	2009, 2010
	State Asphalt Services	2007
Bangladesh	FERBA Instrumentation Logistics	2012
Brazil	Consulpav	2000
Chile	Index S.A.	1997, 1998, 2012
	National Highway Administration	1999
	APSA	2004, 2010
China	SE University, Nanjing, China	2004
	Gao Yuan Highway Maintenance Technology	2004
	Guiyang-Xinzhai	2003
	Guizhou Highway Bureau	2006
	Hebei Highways	2008, 2011
	Henan Province	2007
	Jiangxi Provincial Highway Bureau	1995
	Nanjing Province	2004
	Ningbo City Traffic	2007
	Pudong Highway Bureau	2013
	RIOH	2002
	Shandong Highway Testing Centre	2003
	Shanghai Highway Bureau	1996, 2008, 2010, 2013, 2015, 2018
	Xiamen Highways Bureau	2006, 2008
Columbia	Evaltec S.A	2012
	Geotecnica Y Cimentaciones S.A	2013
	JVR	2014

Country	Client	Year
Croatia	IGH	2015
	Rijeka University Croatia	2015
	RoTehnologija	2020
Czech Republic	University of Brno	2012
Ecuador	Ecuatest	2011
Ethiopia	Ethiopian Road Authority	2021
Fiji	Worley Consultants	2000
	Department of National Roads	2006
France	CETE De Nord	2012
Germany	BASt	2017
Greece	National Technical University of Athens	2002
Hong Kong	Hong Kong Polytechnic	2007
India	Central Road Research Institute	2006, 2009, 2012
	Indian Road Survey & Management	2009, 2011, 2015
Indonesia	DG of Civil Aviation	2008, 2012
	DG of Highways	2010, 2012, 2013
	DG of Land Transport	2011
	IRE Bandung	2008, 2010, 2012,2014
	Jasa Marga	2018
	Jabodetabek	2018
	STTD	2013, 2018
	Tegal Polytechnic School of Transportation	2013
Israel	Geokom	2006, 2012, 2017
	Isotop Ltd	2006
Japan	TOA Road Corporation	2013
Jordan	ACES	2012
Kenya	Ministry of Transport and Roads (World Bank Project)	2012
Korea	Korea Highway Corporation	2005
Malaysia	Double Trans Pte Ltd	2013
	Gamlite	2009, 2012,2015, 2017
	Kumpulan IKRAM	2000, 2003, 2008, 2015
	Selia Selenggara	2001, 2008, 2013, 2015
	Belati Wangsa	2015
	CMS Group	2015
Mexico	Institute of Transport	2012
	Proyecto Civil Mexico	2014, 2016
New Zealand	Info 2000	1996, 1998

Country	Client	Year
	Shaw's Consulting	2008
	Terralink International	2007
	Downer EDI	2014
	Roadscience	2019
Oman	BCL	2009, 2012
Portugal	Consulpav	1997, 2010
	Norvia	2019
Romania	Cestrin	2007, 2018, 2020
Saudi Arabia	Al-Ayuni	2013
	EST	2013
	Jubail RCJY	2011
	Saudi Road Traffic Authority	2004, 2008
	Ministry of Transport	2020
Serbia	CPL	2018
Singapore	Samwoh	2004, 2010
	Hexagroup	2012
	United P&E	2019
South Africa	Africon	2009
	VNA Consulting	2011, 2012, 2015
Spain	Geotecnica Y Cimientos S.A	1997
	RACC Foundation	2007, 2012
Sri Lanka	Road development Agency	2008, 2019
Taiwan	Apex Science	1996
Thailand	STS Engineering Consultants	2006, 2007
	Thammasat University	2006, 2011
	Department of Highways	2020, 2021
	Chulalongkorn University	2008
UAE	Dubai Municipality	2006
	Ghantoot Transport	2003
	Sharjah Municipality	2007
	Road Traffic Authority	2020
United Kingdom	PTS	2019, 2021
United States	City of Los Angeles	1998
	Federal Highways Authority	1999
	ARRB Group Inc.	2015, 2021
	Michael Baker International	2019
Vietnam	Research Institute for Science & Technology	1999
	University of Transport Technology	2012

Country	Client	Year
Yemen	SMEC	1997