Extending inspection beyond human reach

Robotics is transforming how wind turbine blades are inspected from the inside out, giving operators safer access to hard-to-reach structures and the evidence needed to move from reactive repairs to proactive maintenance.

Wind turbine blades are becoming longer, more structurally complex and more valuable to the performance of every project. At the same time, operators are under growing pressure to extend asset life, minimise lost production and make maintenance decisions using better evidence. These objectives have made blade inspection a strategic activity rather than a simple compliance exercise. Yet one area remains particularly difficult to assess consistently: the internal structure of the blade.

External inspections using ground-based cameras, drones or rope access teams have advanced rapidly and provide essential information about leading-edge erosion, lightning damage, surface cracks and coating condition. However, the most important load-carrying structures are located inside the blade. Adhesive joints, shear webs, spar caps, internal laminates, root transitions and local reinforcements can develop defects that are not visible from outside.

A blade may therefore appear acceptable externally while an internal anomaly is progressing. As operators increasingly focus on life extension and maximising asset availability, understanding the condition of internal blade structures is becoming just as important as monitoring external damage.

Traditional internal inspection depends heavily on direct human access. Technicians enter through the root and move into the blade for as long as the available section permits. This work requires confined-space procedures, rescue planning, ventilation, communication systems and strict control of the working environment.

Even with experienced teams, access is normally limited by the reduction in blade cross-section, internal obstacles, steep gradients, surface contamination and the physical demands placed on the inspector. In practice, the inspection can stop well before the areas where certain structural defects may develop.

Reaching beyond human access

Robotics changes the access equation. A compact remotely operated platform can continue beyond the point at which human entry becomes impractical or unacceptable. It can carry cameras, lighting, distance sensors and positioning tools through narrow internal sections while the inspection team remains at the blade root or in the nacelle.

Depending on blade geometry, robotic systems may be able to inspect 75 to 80 per cent of the blade length, including zones that would otherwise remain undocumented. The purpose is not simply to replace a person with a machine. It is to expand the amount of reliable information available to engineers while reducing exposure to confined-space hazards.

Turning images into usable evidence

Coverage is only useful when the acquired evidence is clear, traceable and repeatable. The inside of a blade is a demanding imaging environment: it is dark, surfaces have very different reflectivity, dust can reduce contrast, and structural details may be located above, beside or behind the vehicle. Effective robotic inspection therefore requires more than mobility. The camera, illumination, viewing angle and operator interface must work as an integrated system.

High-resolution still images allow engineers to enlarge suspicious areas and evaluate fine indications such as cracks, adhesive discontinuities, laminate separation, resin anomalies or local deformation. Controlled lighting helps reveal surface texture and prevents important details from disappearing in shadow or glare.

A steerable camera or gimbal can examine the web-to-shell bondlines, the upper surfaces of internal structures and other areas that a fixed forward-facing camera might miss. Laser pointers and distance measurement can provide a size reference and improve the interpretation of defect size and location.

Consistency is equally important. A valuable inspection record should identify where each image was taken, the direction of view and the relationship between the observation and the blade coordinate system. Automatic image labelling, travelled-distance references and structured damage databases reduce dependence on handwritten notes and make it easier to compare findings from one campaign to the next.

When operators repeat the inspection after six or twelve months, they need to know whether an indication is stable, growing or simply being viewed from a different position.

Supporting proactive maintenance

This repeatability is central to a more proactive maintenance strategy. Many internal defects begin as relatively small discontinuities: an adhesive crack, a debonding indication, a local laminate defect or a stress-related feature around a transition.

Early detection does not automatically mean that an immediate repair is necessary, but it gives the operator options. The finding can be reviewed by a blade engineer, classified by severity, monitored at a defined interval or incorporated into the planning of a future intervention.

Without reliable internal data, maintenance often becomes reactive. A defect is discovered only after it has propagated, generated secondary damage or produced symptoms that are visible externally. At that stage, the repair scope may be larger, access more difficult and downtime harder to coordinate. By contrast, earlier internal evidence can support repairs during a scheduled low-wind period, combine several tasks in one mobilisation and allow materials, tooling and specialist personnel to be prepared in advance. The value of inspection lies not only in the defects it identifies, but in the time it creates for better maintenance decisions.

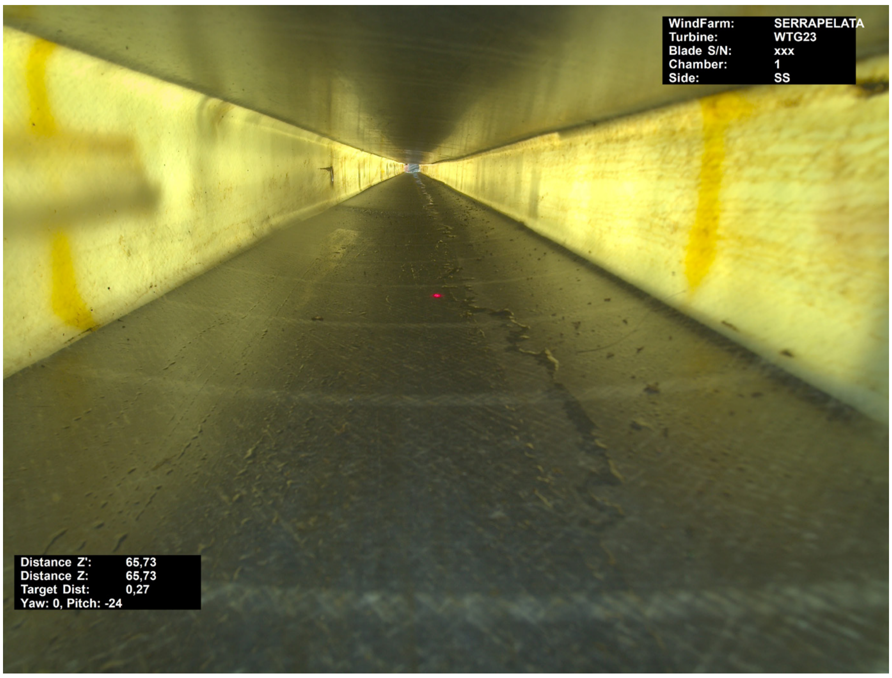
From practical experience, Windbotix has found that no single robotic configuration is suitable for every wind turbine blade. Internal geometries vary significantly between manufacturers, models and generations, so access openings, web spacing, gradients and surface conditions influence the most appropriate platform. For this reason, the company has developed complementary robotic systems rather than a single universal vehicle.

NEMO is the established platform for detailed internal inspections where sufficient access space is available. Its tracked architecture combines mobility with high-resolution autofocus imaging, adjustable illumination, laser-based measurement and software tools for structured defect documentation. Full-vision configurations provide wider visual coverage, while automatic return and optional tethered operation provide additional control during demanding inspections. The system can create detailed records of bondlines, structural surfaces and anomalies beyond normal human access.

EDGE was developed for blades with restricted passages that can prevent conventional robots from progressing. Its slim architecture allows access to narrower cavities while maintaining stability and imaging capability. Tethered power, communications and integrated sensing support operation in these environments,

helping reduce blind zones and extend robotic inspection across a wider range of blade designs.

EDGE+ develops this concept further by combining compact dimensions with increased mobility and inspection capability. Four independently driven wheels with high-torque brushless motors provide traction on demanding surfaces. Imaging and lighting systems support detailed examination of bondlines, laminates and structural interfaces, while structured acquisition of images, measurements and location-referenced information provides data that can support engineering and asset management decisions.



Robotics does not replace qualified technicians or blade engineers, and obstacles inside blades can still restrict access. Its value comes from combining appropriate robotic platforms with disciplined inspection procedures and engineering expertise. This can improve safety, extend inspection coverage and create repeatable records, helping operators move from reactive maintenance towards condition-based decision making while reducing downtime and supporting the long-term value of wind turbine assets.

For operators and service companies, the practical starting point is to define the inspection objective. Is the priority a baseline survey, investigation of a known blade family issue, monitoring of a previous finding or support for a life-extension programme? The answer determines the required image quality, coverage, measurement capability and reporting structure. It also helps establish whether a standard robotic inspection is sufficient or whether a more targeted engineering campaign is required.

As the installed fleet ages and blades continue to increase in size, the industry will need inspection methods that are safer, easier to deploy across different blade fleets and more informative. Internal robotics can reduce the need for technicians to move deep into confined spaces, expand inspection coverage beyond normal human reach and create a repeatable record that supports earlier intervention.

Most importantly, it helps shift blade maintenance from responding to visible failure towards managing structural condition with better foresight.

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