Look Ahead Wind Field Mapping For Large Wind Turbine Rotors Using Convergent Beam Steered LIDAR

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Innovate UK
Technology Strategy Board

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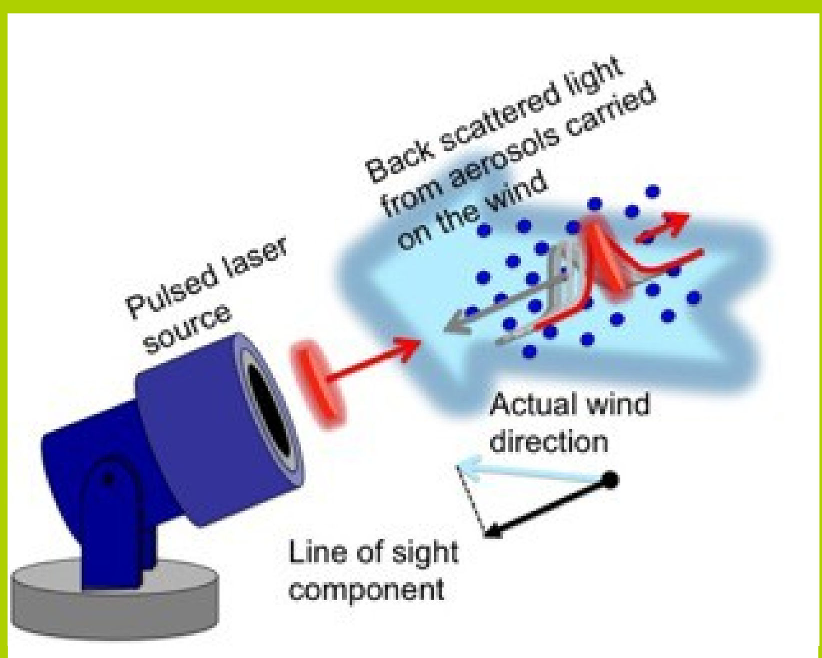
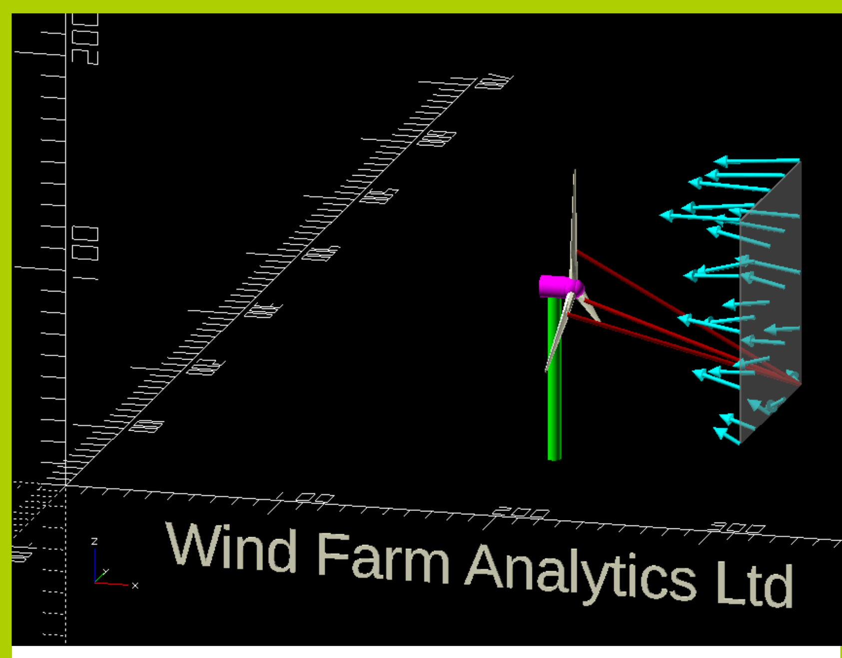
Project overview
Wind Farm Analytics Ltd, Fraunhofer UK Research Ltd (Centre for Applied Photonics), SgurrEnergy Limited and Thales UK (Optronics) Limited are working on a novel converging beam LIDAR. This technology remains in development towards a demonstrator product. Once demonstrated there are strong drivers toward commercialisation since it is possible for this LIDAR product to be incorporated on all future large wind turbines, a market widely expected to continue growing strongly until 2050 and beyond [Ref: GWEC, "Global Wind Energy Outlook", 2016]. This LIDAR design offers many mechanisms towards lowering the cost of wind energy.



Doppler LIDAR single line of sight principle



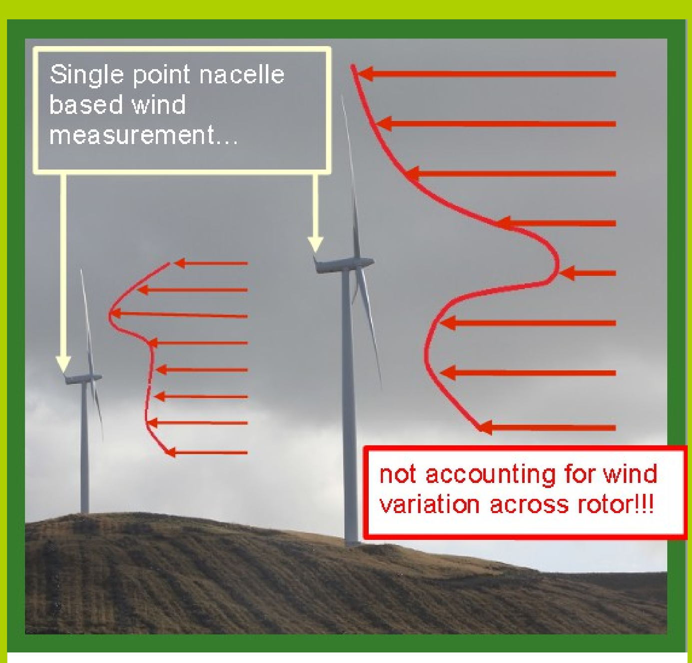
Three converging beams for 3d wind velocity

The need for forward looking LIDAR
Forward looking LIDAR can become standard on large wind turbines due to its capability to raise an alarm of imminent damaging wind conditions. Having an alarm of damaging wind conditions due to impinge on the rotor 2 or 3 seconds later will allow anticipatory protective control measures to be undertaken proactively rather than reactively, thereby reducing or eliminating a large portion of lifetime loads. LIDAR offers direct physics-based wind measurement which does not significantly alter the wind that it is measuring. Existing turbine-mounted LIDARs have been used beneficially by the wind industry but they all suffer from a number of disadvantages and have not been adopted as standard. Future LIDARs can make improved measurements by using converging beam design, and by scanning the whole rotor area to survey and map the wind field. This innovative prorammable LIDAR design will enhance the cost-benefit case so that converging beam rotor mapping LIDAR becomes standard to the benefit of the wind industry.

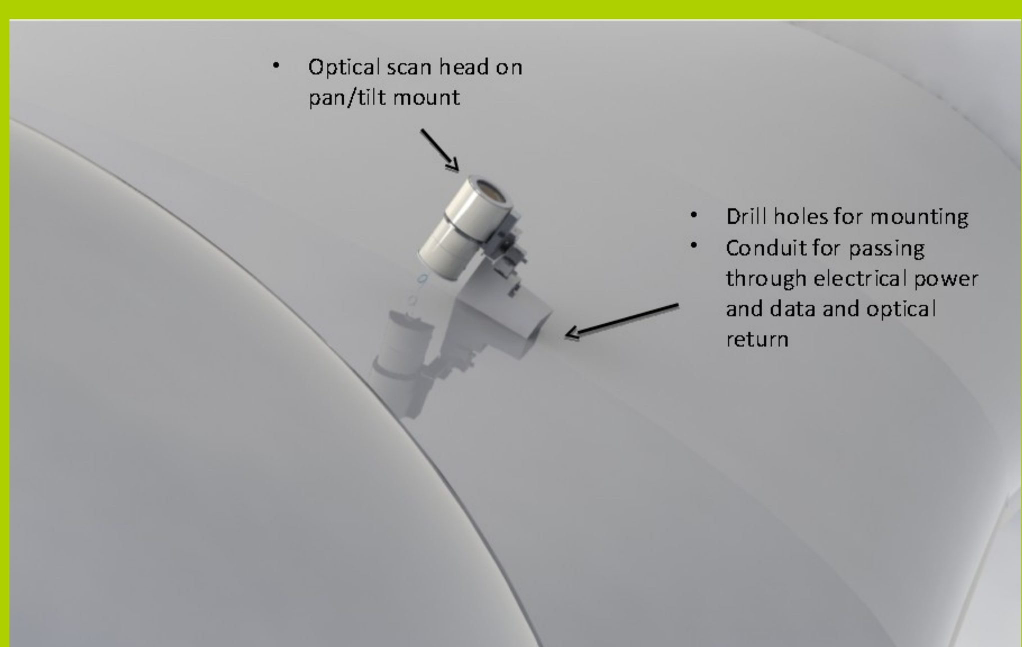
The need for converging beams
LIDAR works by measuring a Doppler shift along the laser beam line of sight in order to obtain a wind velocity component along the line of sight. Therefore to reconstruct the three dimensional wind velocity it is required to measure along at least three different lines of sight. In order to make a local wind velocity or turbulence intensity measurement it is necessary that the three lines of sight converge at the measurement point. Existing wind LIDARs use diverging beams or conical scan which combine mesurements from very far apart. This is fine if the wind velocity is uniform but in general the wind velocity is not uniform. Therefore existing diverging beam commercial wind LIDAR systems cannot unambiguously resolve the 3d wind velocity vector.

The need for a rotor mounted system
- thanks to the wind turbine rotor yaw control a rotor mounted LIDAR always points upwind
- for a rotor mounted system the field of view is not obstructed by the rotor blades or nacelle whereas for a nacelle mounted system the field of view is reduced and impaired
- the converging beam requirement needs beams emanating from widely separated points of view so as to benefit from a "triangulation" effect in reconstructing the three-dimensional wind velocity; by employing beam steerers on or in the blades we can be sure that the converging beams are non-parallel which is a requirement for accurate unambiguous velocity reconstruction

Enabling larger rotors - the need for whole rotor wind mapping
- increase power via yaw control from better wind direction information across the entire rotor
- enabling improved control systems for reducing lifetime loads
- enables large rotors, considered to be one of the strongest drivers for lowering the cost of wind energy [Ref: BVG Associates / KICInnoEnergy, "Future Renewable Energy Costs: Offshore Wind", 2016]; as rotors get larger then variation of wind across the rotor is more important



Wind varies across large rotors

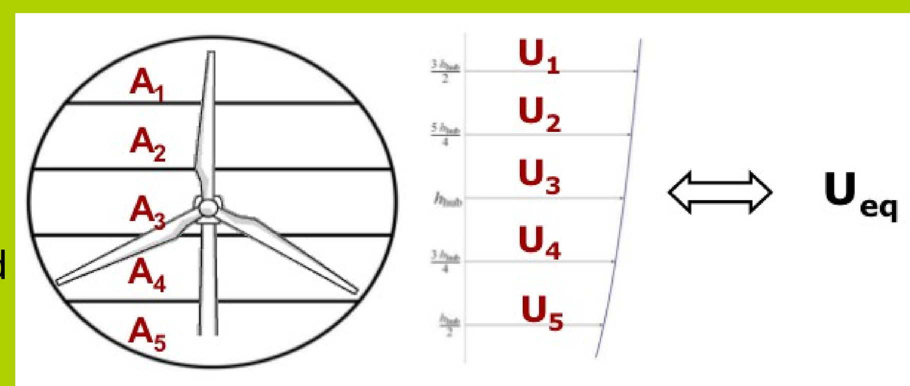


An optical head can be safely mounted to a large blade

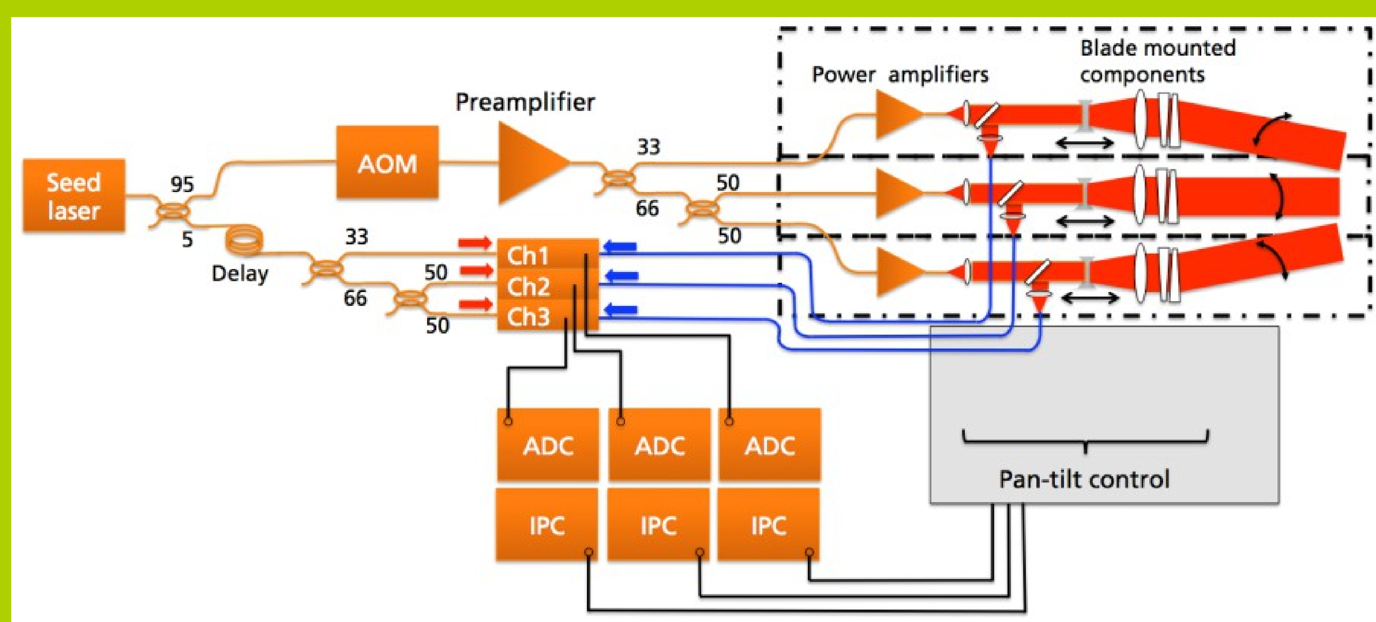
Reducing cost by wind turbine load reduction
Extreme wind conditions are associated with extreme loads and elevated fatigue loads. By providing an alarm of imminent extreme winds it is possible for wind turbine control systems to eliminate a significant portion of elevated loads from the operational lifetime. This leads to increased time between failure, longer asset lifetime, reduced O&M cost and also cheaper turbines since engineering safety factors may be lowered thanks to reduced loads. Some wind turbines have easy lives and some have hard lives. Lifetime logging of incoming wind field across the whole rotor can be used to indicate those turbines which could be due for increased O&M intervention and those which can survive fine with reduced servicing. More intelligent low wind start up and storm shutdown based on whole rotor inflow and look ahead wind measurement offers additional benefit towards reducing the cost of wind energy. Turbine design and micrositing can be optimised. Big data machine learning and human learning can combine 3d volumetric rotor LIDAR data and condition monitoring data, both onshore and offshore.

Operational power curve performance monitoring, insurance and warranties
Large electricity utility companies, medium wind farm investors and single wind turbine owners all need to know the performance of their assets. Whilst SCADA system power curve data is useful there are presently limitations to its use, mainly because the wind speed measurement from the nacelle instruments is subject to energy extraction and turbulence from the rotor, as well as streamline flow effects of the wind around the nacelle. Asset owners suffer from uncertainity of performance and warranty conditions. Wind turbine manufacturers cannot give the same performance warranty under extreme wind conditions as for benign normal wind conditions. Therefore, formal power curve testing is undertaken which may involve expensive met mast installation and extended data taking requirements. Wouldn't it be better if the owner and asset manager had reliable power curves all the time? Wouldn't it be better if the turbine manufacturer or insurer had access to full wind conditions historic data including turbulence history, wind shear, wind veer, non-horizontal inflow angle and other important wind attributes in order to know whether the deployment of a given turbine has been subject to abnormal wind conditions outside of its design envelope, and that the correct class of turbine is deployed?

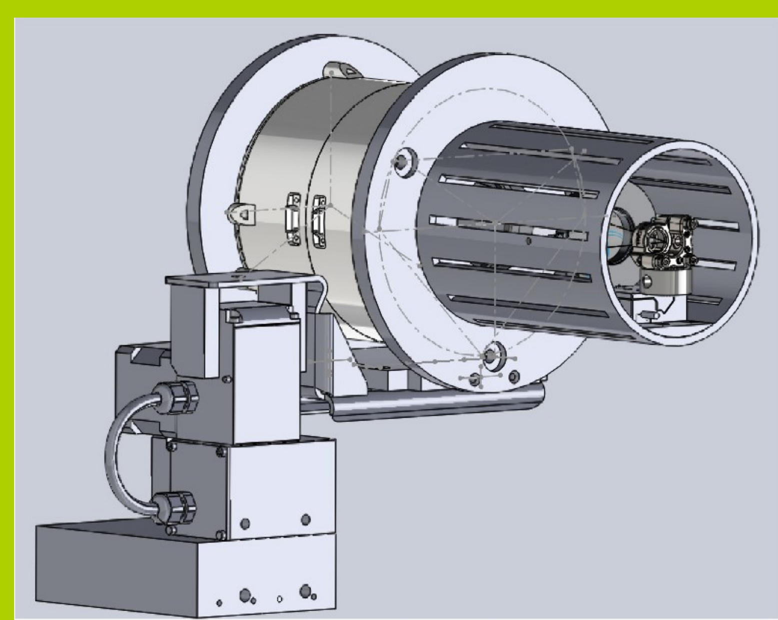
Rotor equivalent wind speed
Rotor equivalent wind speed methods may account for variation in height such as wind shear and wind veer. It is suggested that rotor equivalent wind speed power curves are superior for performance monitoring compared to traditional power curves based on single point nacelle height wind speed. The rotor mapping converging beam LIDAR is best placed to offer the option of rotor equivalent wind speed by measuring at different heights across the rotor, without ambiguity or false assumptions of horizontal wind flow. Rotor mapping converging beam LIDAR can extend the rotor equivalent wind speed concept to account for left-right imbalance and other attributes.



Rotor equivalent windspeed for vertical shear



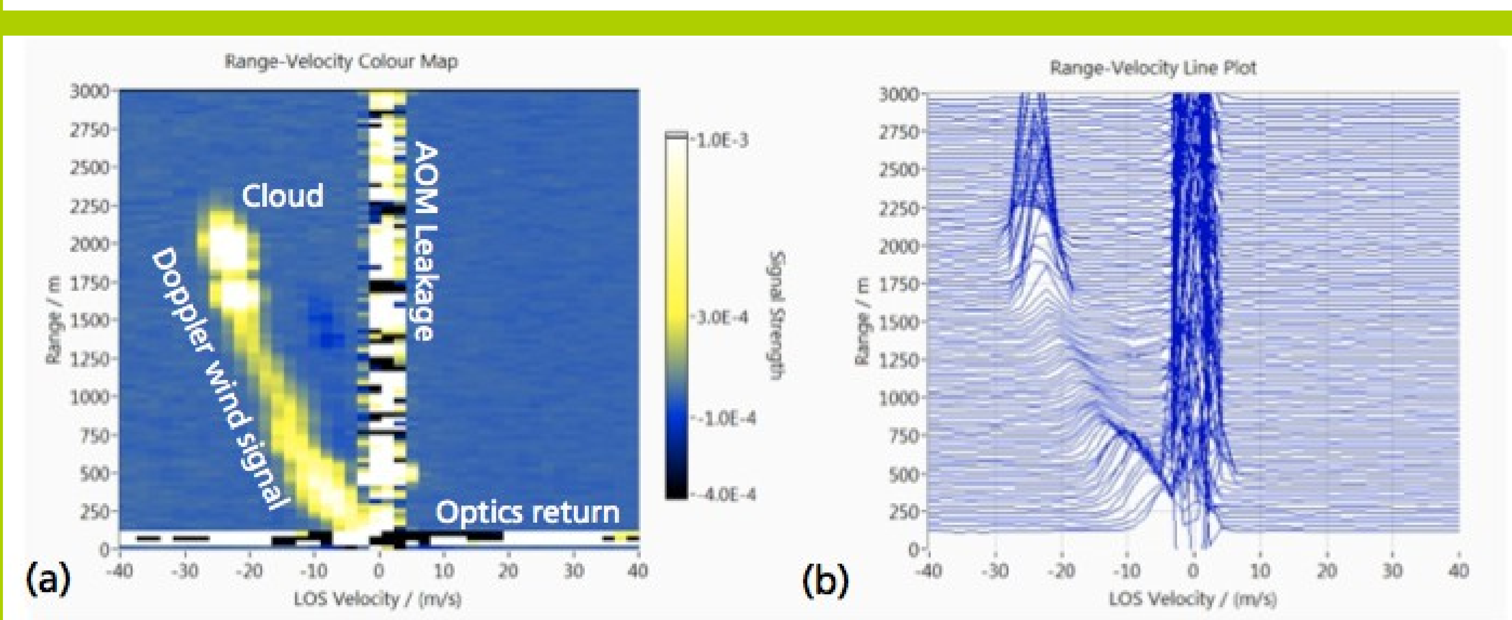
Triple beam LIDAR design


Optical head CAD design


Boresight alignment testing

Technology current status
At the present time this LIDAR remains under development with ongoing system refinement and ground based testing. It is planned to undertake rotor based testing in the near future. Design and testing work includes system ruggedisation and testing at environmental test chambers to ensure a robust system capable of enduring harsh operational environments.


Environmental test chamber



Initial ground based measurements were made out to 2 kilometres and beyond

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