Performance analysis of Mitsubishi Electric's wind lidar
in the measurement campaign at European test sites

Nobuki Kotake, Shumpei Kameyama, Yutaka Kajiyama, Masayuki Enjo

Mitsubishi Electric Corporation

5-1-1 Ofuna, Kamakura, Kanagawa, Japan, 247-8501

Email: Kotake.Nobuki@bp.MitsubishiElectric.co.jp

Tel: +81-467-41-2548   Fax:+81-467-41-2639

SUMMARY

For realizing the stable wind resource assessment, we developed the lidar system with the adaptive parameter tuning which automatically change the system parameters. In this paper, we evaluate the lidar system which has above function at several European sites.

As the result of verification, that lidar meet the NORSEWInD (NORthern SEas Wind Index Database) standard. Moreover, the data availability is increased about 30% at 430m altitude by using above function.

INTRODUCTION

Conventional wind lidar systems have an issue in the instability of performance because Signal-to-Noise Ratio (SNR) depends on the atmospheric conditions such as the aerosol density, turbulence, and so forth. For example, it is known that a measurable range fluctuates distinctly even in an hour. To overcome this issue, we developed the new wind lidar system, (named as "DIABREZZA[TM]") featuring the new function of adaptive parameter tuning for various atmospheric conditions. This function automatically realizes the best performance under the given atmospheric condition. In this presentation, we demonstrate advantageous of the above mentioned functions with the results of measurement campaign in European test sites.

SYSTEM CONFIGURATION

System configuration is shown in Fig. 1. The new components (gray squares) are added for realizing our concept to the general fiber-based CDL system[1]. The other conventional components are described as follows. Transmitted laser is modulated to be pulsed by the acousto-optic modulator (AOM), and is amplified by the fiber amplifier. The pulsed laser is transmitted to the target through the telescope and the scanner. The received light is converted to electric signal by the balanced receiver. The received signal is processed in the signal processor, where spectral analysis and accumulation are executed. Finally, the wind velocity and spectral width of each range are calculated using the accumulated spectrum. In

the previous lidar system, the constant parameters, for example, (1) laser pulse width, (2) focal range, (3) beam diameter, (4) number of accumulation, and (5) scanning speed (or method), are used for each observation. On the other hand, in this new system, the system controller calculates the best parameters of focal range and number of accumulation automatically using obtained height profile of SNR and user's request. The users request means that the "Target height" included the minimum and maximum height which user wants to observe especially.

Fig. 1. System configuration.

ADVANTAGEOUS EFFECT OF ADAPTIVE PARAMETER FUNCTION

In this section, some examples of advantageous effects for parameter tuning are shown as follows.

Optimization of signal processing parameter (Adaptive accumulation function)

The relation of SNR, focal range and accumulation number are indicated as follows[1].

$$SNR \propto \frac{\Delta R \cdot D^2}{1+\left(1-\dfrac{L}{F}\right)^2\left[\dfrac{\pi D^2}{4\lambda L}\right]^2}\sqrt{N} \tag{1}$$

where L, F, λ, D, N, and ΔR indicate range, focal range, wavelength, beam diameter, accumulation number and range resolution derived from pulse width, respectively.

In this function, accumulation number is automatically tuned. For example, when SNR becomes lower than the threshold in a specific range, this situation is recognized in the SNR

analysis, and the spectral accumulation continues until enough SNR can be confirmed. This processing can be done for each range independently. In the previous study, the number of accumulation has no relationship with the deviation between LIDAR and cup anemometer which is 10 minutes averaged[2]. This function must increase the data availability and benefit to wind resource assessment using LIDAR.

Optimization of focal range (Adaptive focus function)

Figure 2 indicates the case of decreasing SNR related to the measureable range depending on the atmospheric condition. The chain line, dashed line, and solid line correspond to the cases of (i) infinity focal range under high aerosol density condition, (ii) infinity focal range under low aerosol density condition, and (iii) focal range of L1 under low aerosol density condition, respectively. The dot line indicates the SNR threshold for correct signal detection. It is shown that when the aerosol density becomes low, there are no available data for all ranges if the focal range is set at infinity. However, this lidar recognizes this situation automatically by the analysis of SNR, and changes the focal range to the best point for realizing the best performance which is the longest measurable range in many cases. Moreover, this function can keep the observation rate fast compared with adaptive accumulation function.
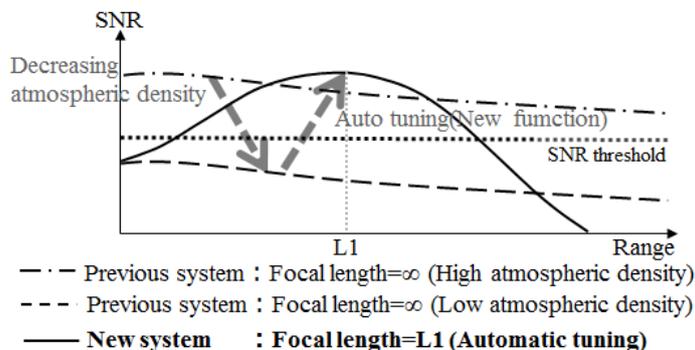
Fig. 2 Schematic explanation for the effect of the focal range tuning.

EVALUATION OF ADAPTIVE FUNCTION

We have carried out the measurement campaigns in cooperation with Dong Energy(Denmark), DTU (Denmark), EOLFI (France), ECN (Netherlands), and Ecofys(Netherlands) etc. In this section, the examples of results of our lidar's validation using above adaptive function are shown.

Validation at DTU Høvsøre test site

The measurement period is from 11th July to 7th September 2015. In this campaign, we compared the wind velocity data measured by the lidar with that measured by the anemometer installed on the IEC compliant meteorological mast. The cup anemometer and vane anemoscope installed on the 60m, 80m, 100m, and 116.5m (only cup anemometer). The new function as described above, the adaptive accumulation and focus function are turned on. Figure 3 shows the DTU test field and our lidar. Figure 4 and figure 5 shows the comparison results of wind velocity and wind direction at 100m height, respectively. The correlation coefficient R^2 of wind velocity and wind direction is more than 0.999 and more than 0.995, respectively. The coefficient R^2 on the other heights was also good result.
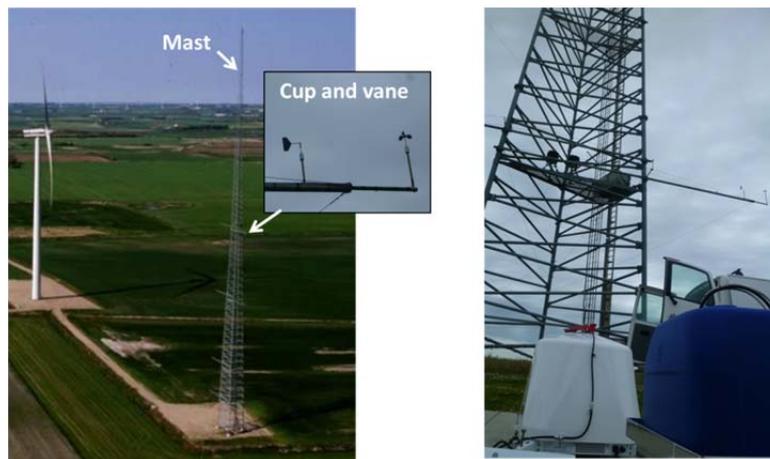
Fig. 3 Photos of the DTU test field and lidar
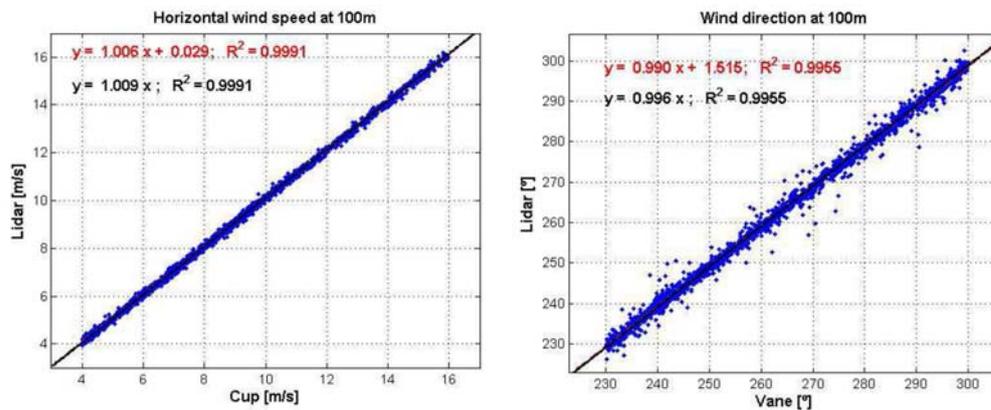
Fig. 3.   Comparison results of lidar and cup anemometer at 100m height.

(Source:DTU Wind Energy LC I-078 (EN))

Verification at Test Site Lelystad

The measurement period is from 2nd March to 2nd May 2016. In this campaign, we also compared the wind velocity data measured by the lidar with that measured by the anemometer installed on the IEC compliant meteorological mast. The used cup anemometer to compare is which installed on the 80m, 100m, and 120m height. Figure 4 shows that the photos of the Ecofys test field and lidar. Figure5 shows that the correlation between two instruments, and the deviation of the wind velocity obtained by cup and lidar. This indicates that the good correlation and regression is obtained. Furthermore, figure 6 indicates that the results for each height meet the NORSEWInD (NORthern SEas Wind Index Database) standard [3].
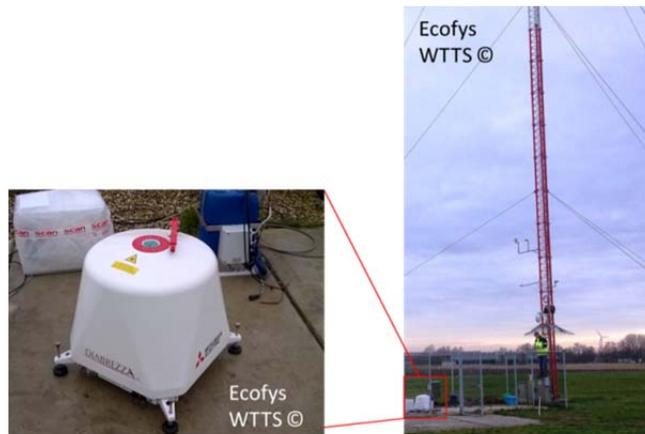
Fig. 4 Photos of the Ecofys test field and lidar
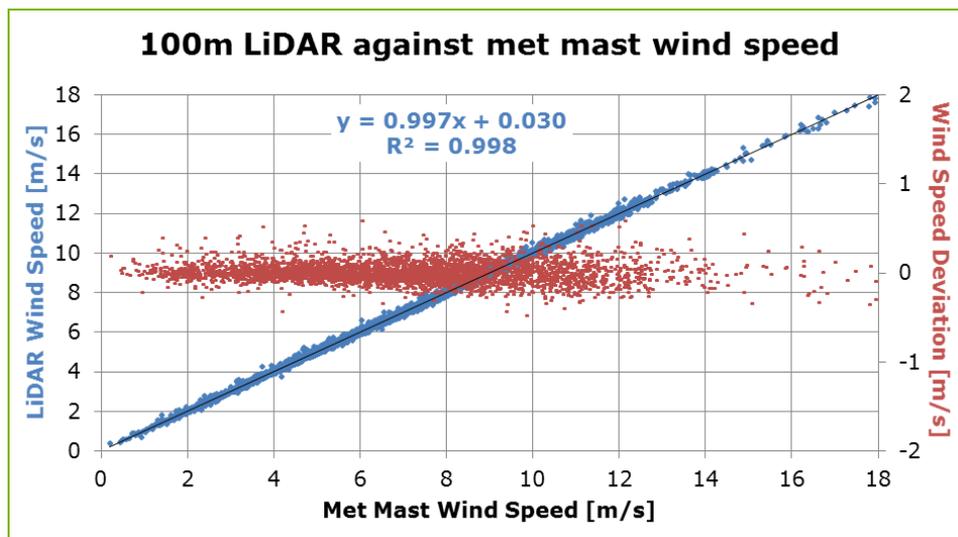
Fig.5 Comparison results of lidar and meteorological mast data at 100m
(Source:20160606_REP_MELCO_VER_DIA_LiDAR_V02_FMo)

Criteria	Category	NORSEWInD Acceptance Threshold for Replacement of IEC-compliant Cup Anemometry	120m	100m	80m
Number of valid data points	4-8 m/s	>200	1,753	1,920	2,109
	8-12 m/s	>200	1,389	1,205	988
	ALL	>600	3,903	3,944	3,962
Absolute error		<10%	0.3%	0.2%	0.3%
Linear regression slope	4-8 m/s	0.98-1.01	1.0015	1.0015	1.0100
	8-12 m/s	0.98-1.01	1.0012	1.0007	1.0099
	Variation in slope	<0.015	0.0003	0.0008	0.0001
	ALL	0.98-1.01	1.0016	1.0009	1.0100
Linear regression – R^2	4-8 m/s	>0.98	0.9940	0.9920	0.9919
	8-12 m/s	>0.98	0.9834	0.9853	0.9845
	ALL	>0.98	0.9984	0.9984	0.9985
Overall PASS/FAIL			**PASS**	**PASS**	**PASS**

Fig. 6 Result of NORSEWInD performance criteria analysis

(Source:20160606_REP_MELCO_VER_DIA_LiDAR_V02_FMo)

Evaluation of data availability using adaptive accumulation function

The data was obtained for 17 days. Lidar observed with adaptive accumulation function and without that function, simultaneously. Table 1 and Figure 7 show that the data availability at each height. The effect of that function can be seen from data availability at higher altitude, especially.

Table1. Availability for each height

Height(m)	availability(%)	
	With adaptive	Without adaptive
50	**100**	99.42
100	**99.85**	98.12
150	**98.95**	98.22
250	**97.30**	94.64
350	**89.07**	77.00
430	**84.28**	55.92
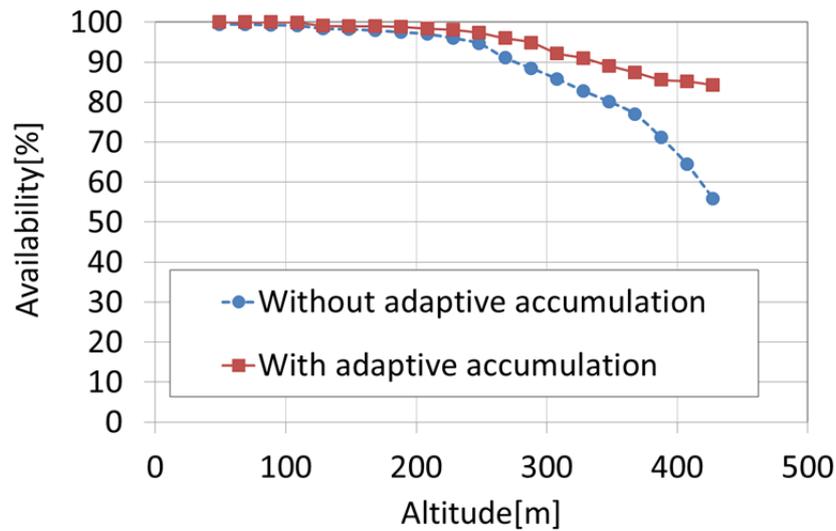
Fig. 7 Effect of adaptive accumulation (Dataset:Courtesy of EOLFI)

CONCLUSION

We developed a new concept of wind lidar system with automatic adapting parameters function. Moreover, we have carried out the measurement campaign in Europe. Consequently, the good results in accuracy and data availability have been obtained for each campaign. We could confirm that these functions provide the lidar performance which fits best to the user's needs. Especially, this function is very powerful to keep high data availability even in severe atmospheric conditions for lidar (for example, low aerosol density conditions). Therefore, it could contribute the stable measurement for wind resource assessment.

REFERENCES

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