The long-range WindScanner system – how to synchronously intersect multiple laser beams

Vasiljevic, Nikola; Lea, Guillaume; Courtney, Michael; Mann, Jakob; Mikkelsen, Torben

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Nikola Vasiljević, Guillaume Léa, Michael Courtney, Jakob Mann and Torben Mikkelsen
How to accurately measure 3D wind speed?

Single lidar:
needs the assumption of the horizontal homogeneity of the flow

Multiple lidars system:
No assumptions
No assumptions = Multiple lidars system

- Synchronization in steering and measurements
- Pointing accuracy and repeatability of trajectories
Long-Range WindScanner

A pulsed lidar
Maximum distance 5000 m
Hardware overview

The motion control unit of LRWS

- Commands the motion of the scanner head and an execution of the measurements
- It has a crystal clock oscillator as a source for timing of moves and triggers
- Interaction with the control unit is achieved by motion programs

Crystal clock oscillator  Scanner  Motion program

```
OPEN PROG 1983 CLEAR
TriggerFrequency=10
#1(azimuth)->X
#2(elevation)->Y
TM1000
X90Y45

TM1000
TriggerPulses=10000
X90Y45

TM800
TriggerPulses=8000
X100Y50

DELAY0
CLOSE
```
How to setup a measurement scenario

Time move of 1s (1000 ms) to the position:
\(x = \text{azimuth} = 10^\circ\)
\(y = \text{elevation} = 35^\circ\)

Standstill for 1s (1000 ms) at the previous position while sending 10000 laser pulses and acquiring the same amount of backscatters.

Motion for 800 ms to the position:
\(x = \text{azimuth} = 100^\circ\)
\(y = \text{elevation} = 50^\circ\)
while sending 8000 laser pulses and accumulating the same amount of backscatters.
The long-range WindScanner system

<xml>
  <scenario>...</scenario>
  <start time>...</start time>
</xml>

Network: Ethernet, Wi-Fi, 3G, Satellite, ...
Lidar Communication Protocol (LidComPro)

**TCP Commands**
- 2100: GoHome
- 2200: GetGPS
- 2300: Synchronize
- 2400: GetConfiguration
- 2500: SetConfiguration
- 2600: GetPositions
- 2700: SetPositions
- 2800: GetScenario
- 2900: SetScenario
- 3000: Measure
- 3100: GetData
- 3200: Wipe
- 3300: GetCapabilities

**UDP Commands**
- 1100: WhoIsThere?
- 1200: Abort
- 1300: Unlock
- 1400: Stop
- 1500: GetStates
- 1600: IsBusy?
- 1700: Shutdown
- 1800: Reset

**XML message example**

```xml
<packet Client="Sterenn" PckNo="1.1" Cmd="2200" Alert="0">
  <time>080651.50</time>
  <date>270812</date>
  <lat>554134.5810N</lat>
  <long>120612.0170E</long>
  <alti>56.577352</alti>
  <msg></msg>
</packet>
```
What is our dream
Global Positioning System
Same time base

250 ns accuracy of the GPS clock
Test of the synchronization concept

- 4 hours, two measurement points, data collected after each measurement point, WindScanners monitored during the test
Two measurement points

Košava
MP1: azimuth/elevation 10°/10°
MP2: azimuth/elevation 20°/20°

Sterenn
MP1: azimuth/elevation -10°/10°
MP2: azimuth/elevation -20°/20°
How much two devices lag from each other

$T_{\text{wmoK}} - T_{\text{wmoS}}$ (milliseconds)

786 ms

TwmoK – Time when measurement occurred @ Košava
TwmoS – Time when measurement occurred @ Sterenn

Slope corresponds to the frequency difference between two crystal clock oscillators

Time (s)

2 hours
Results with “VaLé” compensator

$T_{wmoK} - T_{wmoS}$ (milliseconds)

Average lag 3.64 ms
Results with “VaLé” compensator

$T_{wmoK} - T_{wmoS}$ (milliseconds)

Threshold = 10 ms

Average lag 3.64 ms
Consequence of the maximum lag

- This lag can be considered negligible since the windscanners minimum accumulation time is 100 milliseconds
- This is minimum time needed to accumulate enough Doppler spectra in order to provide reliable radial wind speeds.
5 x LRWS in sync
WindScanner is as good as its pointing accuracy

- Determine uncertainties for:
  - azimuth (\( \phi \))
  - elevation (\( \theta \))
  - range gate center position (\( r \))

\[(\phi, \theta, r) = (\phi \pm \Delta \phi, \theta \pm \Delta \theta, r \pm \Delta r)\]
3D Plot of the intensity of the returned signal

\[ \phi(°) \] 

\[ r(m) \]
200 ns pulse length, 256 ns window size (64 point in FFT)  
CNR shape when hard target is ‘hit’ by the laser pulse
What a WindScanner can see

The top of the water tower approximately 160 m away from the WindScanner!
CNR mapper is fun
Conclusion

• The issue of synchronizing the motion control and the lidar measurements has been elegantly solved by getting the motion control unit to fire the laser and start the acquisition process as well as controlling the motors for the beam positioning.

• We have devised an architecture of a network of individual WindScanners connected through any type of network interfaces to the master computer that conducts them using the LidComPro protocol.

• The synchronization in motion and measurements among multiple WindScanners has been achieved using the GPS clock, crystal clock oscillator and the VaLé compensator with the maximum lag of 10 ms.

• We have freedom in a deployment of the system, with a possible separation among individual WindScanners of a few kilometers.

• The pointing accuracy will be assessed with the CNR mapper.
Contact: niva@dtu.dk
Videos: www.youtube.com/cadenza83