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Real time data acquisition and visualization software package for aerosol size spectrometer

by

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Abstract
In this report, we discuss about the design, development and implementation of the real-time data acquisition and visualization software package for the aerosol size spectrometer (TSI APS Model 3321) entitled Aerodynamic Particle Sizer Spectrometer TSI 3321 Data Acquisition and Visualization Software. The graphical user interface application software used for data acquisition, control and visualization has been developed in-house using Microsoft Visual Basic 2010.NET rapid application development object oriented programming language. The software package configures the APS 3321 and acquires its data in order to compute and display the aerosol number concentration in 52 pre-defined aerodynamic diameter bins. It also displays the real-time plot of the aerosol number, surface area or volume concentrations along with aerosol number concentration binned information for the size range: < 0.5 μm, 0.5 - 1.0 μm and > 1.0 μm. The details about the aerosol size spectrometer, data acquisition and visualization software are presented in this technical note.

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Contents

1. Introduction

Aerosols are tiny solid and/or liquid particles suspended in the atmosphere whose radii range from 0.001 to 100 μm. Aerosols of different sizes, magnitude and composition are produced by natural or anthropogenic sources and are transported to different regions depending upon the meteorological conditions. Size of aerosol is one of the most important parameters that determines its interaction with the solar and terrestrial radiation, and also affect the aerosol properties and their lifetime [3]. The aerosol size spectrometer uses the state-of-the-art technique to measure the aerosol number concentration in different size bins. The various aerosol size spectrometers available are Aerodynamic Particle Sizer Spectrometer (TSI APS 3321), Aerosol Particle Size Spectrometer (TOPAS LAP 322), Aerosol Laser Particle Spectrometer (GRIMM 1.108/1.109/EDM 180), Laser Aerosol Spectrometer (TSI 3340), Wide Range Particle Spectrometer (MSP M1000XP), etc. In the present work we will only discuss the Aerodynamic Particle Sizer Spectrometer (APS) from TSI, Model 3321.

2. Aerodynamic particle sizer spectrometer (APS)

The Aerodynamic particle sizer spectrometer (APS 3321 manufactured by TSI) provides high-resolution, real-time aerodynamic measurements of particle sizes from 0.5 to 20 μm (Figure 1-a) [2, 8]. It measures the particle number concentrations as a function of aerodynamic diameter using the principle of inertia to size particles. Aerodynamic diameter (Da) of a particle is the physical diameter of a unit density sphere that would have the identical settling velocity equal to that of the particle. It uses a patented (US Patent #561515), time-of-flight (TOF) spectrometer optical system with two partially overlapping laser beams (wavelength 675 nm) to detect coincidence as illustrated in Figure 1-b. The spectrometer measures the velocity of particles in an accelerating airflow through a nozzle by passing the particles through two laser beams (Figure 2). An elliptical mirror collects scattered light onto a photo detector, which converts the collected light pulses to electrical pulses. A particle passing through both the laser beams produce two pulses of scattered light and the time delay between the pulses is related to the velocity of the particle [5]. Using a calibration data the spectrometer converts each time-of-flight (velocity information) measurement to an aerodynamic particle diameter. The size range of the APS is 0.5 to 20 microns aerodynamic with 52 size bins (logarithmic scale) as 0.542, 0.583, 0.626, 0.673, 0.723, 0.777, 0.835, 0.898, 0.965, 1.037, 1.114, 1.197, 1.286, 1.382, 1.486, 1.596, 1.715, 1.843, 1.981, 2.129, 2.288, 2.458, 2.642, 2.839, 3.051, 3.278, 3.523, 3.786, 4.068, 4.371, 4.698, 5.048, 5.425, 5.829, 6.264, 6.732, 7.234, 7.774, 8.354, 8.977, 9.647, 10.37, 11.14, 11.97, 12.86, 13.82, 14.86, 15.96, 17.15, 18.43 and 19.81 μm.

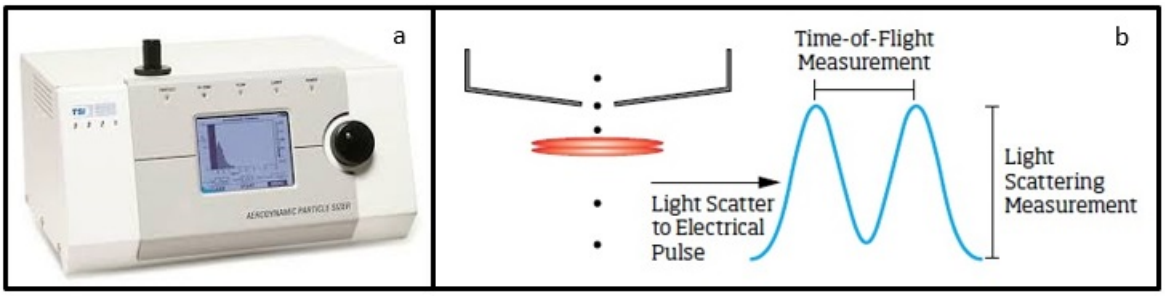

Figure 1. (a) Aerodynamic Particle Sizer Spectrometer, TSI APS 3321 (b) APS 3321 measurement technique

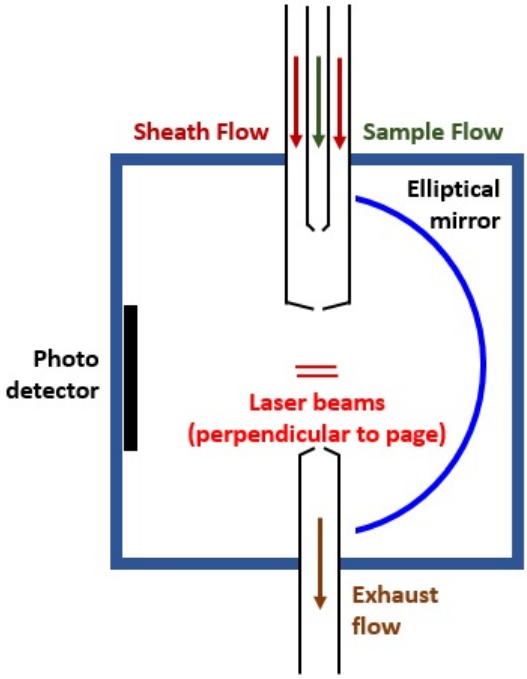

Figure 2. Schematic of the APS 3321 detector block

Table 1. Aerodynamic particle sizer spectrometer specifications

Sr. No.	Parameter	Specifications
1	Particle Type	Airborne solids and nonvolatile liquids
2	Particle size range	0.5 to 20 μm aerodynamic size 0.3 to 20 μm optical size
3	Aerodynamic size resolution	0.02 μm at 1.0 μm, 0.03 μm at 10μm
4	Maximum and minimum particle concentration	10,000 particles/cm^3 and 0.001 particle/cm^3
5	Sampling time	User programmable 1 sec to 64800 sec
6	Flow rates	5.0 LPM (Sample flow 1.0 LPM and Sheath flow 4.0 LPM)

It also records the height of the scattering peaks allowing a secondary calculation of particle size based on optical scattering over the same range, with one extra bin covering 0.3 - 0.5 micrometers ($< 0.523\ \mu$m).

The APS measures the aerodynamic diameter of particle (Da) which is related with geometric diameter of particle (Dp) as $D_p = D_a[\rho_0/\rho\ ]^{0.5}$ where ρ_0 is the unit density (1 g cm^{-3}) and ρ is the particle density (factory default value is 1 g cm^{-3}) [2]. The detailed description of the instrument is given in TSI APS 3321 instruction manual [2]. Table 1 shows the specifications of the TSI APS 3321 aerosol size spectrometer.

3. Software for APS

The spectrometer does not have any on-board memory to store the acquired aerodynamic particle number concentration. The Aerosol Instrument Manager Software for Aerodynamic Particle Sizer (APS) Spectrometers from TSI is used to collect sample data from the APS 3321 instrument [1]. The software can display the real time acquired data in graphs and tables. But it lacks to generate the consolidated daily data file with all the measured and derived parameters. We have designed and developed real-time data acquisition and visualization software for Aerodynamic Particle Sizer Spectrometer (TSI APS, Model 3321). It acquires, computes and displays (table or graph) the aerosol number / surface / volume concentration in 52 pre-defined aerodynamic diameter bins (0.5 to 20 μm) along with aerosol number concentration binned information for three size ranges: < 0.5, 0.5 - 1.0 and $> 1.0\ \mu$m. The aerosol number concentration summed up between 0.542 to 0.965 μm are put in the 0.5 - 1.0 μm bin, and the number concentration integrated between 1.037 to 19.81 μm represents the bin $> 1.0\ \mu$m. It can log the instantaneous and average, measured as well as computed data along with the APS 3321 auxiliary data. The 32-bit graphical user interface (GUI) software package is made compatible to Microsoft Windows 7/8/8.1 operating system with .NET framework for desktop computer as well as laptop.

The APS 3321 uses an ASCII-based communication protocol in the form of strings through its physical RS232 serial port. It supports four types of commands as mentioned in Figure 3 and 4: (i) Set commands, which are used to set the operating parameters of the APS (ii) Action commands, which control the system (iii) Read commands, by which the APS sends data in response to the request from the computer and (iv) Unpolled commands, by which the APS automatically output data records [2]. The software has been developed to work with these ASCII-based communication protocol.

4. Software Design and Implementation

The indigenously developed state-of-the-art data acquisition and system control program has been written in Microsoft Visual Basic 2010.NET an object-oriented programming language. It is a multi-paradigm, high level programming language, implemented on the .NET Framework which enables the rapid application development of GUI application software [4]. The asynchronous serial data acquisition is established through 'SerialPort' class in VB.NET using 'System.IO.Ports' namespace [7]. The ASCII file read and write operation have been implemented using System.IO namespace with 'FileStream' class [9]. The instantaneous dynamic plot has been implemented using ZedGraphControl class which provides a user control interface to the 'ZedGraph' class library [10]. The graphpane (plot) can be zoomed or panned by the user, either via a mouse drag operation or by the context menu commands. The timer control has been used to trigger the real-time serial data acquisition subroutine and it plays an important role in the GUI based application programming.

The APS 3321 can be interfaced with a computer using RS232 DB9 serial port or laptop through USB port (MOXA - UPort 1110, 1-port USB to RS232 serial converter [6]), as illustrated in Figure 5 as option 1 and 2 respectively. Generally, nowadays laptop doesn't come with physical serial port (DB9 port), but we can have the logical serial port using USB to serial convertor module which can be used with the available USB ports on the laptop. The APS and computer/laptop has been configured for asynchronous serial communication with the following serial port settings; 9600 baud rate, even parity, 7 data bits, 1 stop bit and none flow control. The data flow diagram for the GUI application software is shown in Figure 6. The software is initialized by disabling the unpolled operation and aerosol sampling, clearing the data buffer, and enabling the front panel APS screen. The calibration data for the time-of-flight data (Table 2) is stored in the instrument memory (EEPROM). The data acquisition is initialized by disabling the front panel APS screen, setting the sample mode & sample time for continuous sampling operation and enabling the APS sampling. The auxiliary and aerodynamic data are continuously polled in an infinite loop until the data acquisition is halted by disabling the sampling and unpolled operation and enabling the front panel APS screen.

APS 3321 counts the ambient sampled particle (Cnt) in 32 channels per decade of particle size (logarithmic) which results in 52 channels total particle size bin. The size channel "$< 0.523\ \mu$m" has a channel width of 8 size channels which corresponds to 4 times as many particles as compared to 32. The various steps involved in the computation of number concentration $dN/dlogD_p$ are as follows:

STEP 1 : Compute the aerosol sample flow rate, FR (CC/Sec)
FR = [TF – SF] x [1000/60], TF is Total flow, SF is Sheath flow
STEP 2 : Calculate the total sampled volume, V (CC)
V = FR x time index
STEP 3 : Compute dN as, dN = Cnt / V
STEP 4 : Compute the $dN/dlogD_p$ for $D_p > 0.5\ \mu$m as (cm^{-3}), $dN/dlogD_p$ = dN * 32
STEP 5 : Compute the $dN/dlogD_p$ for $D_p < 0.5\ \mu$m as (cm^{-3}), $dN/dlogD_p$ = dN * 4

Set commands	
SCA	Set calibration for aerodynamic diameters
SCL	Set calibration label string
SCE	Set calibration environment
SCR	Set calibration resolution
SD	Set digital output
SF	Set front panel enable
SH	Set Hi concentration threshold
SL	Set laser power
SMA	Set mode for analog output
SMC	Set mode for auto cal of APD
SMT	Set mode and sample time
SP	Set pumps on/off
STU	Set time for unpolled report
SV	Set analog output voltage

Action commands	
A	Autocal the APD
B	Beep
C	Clears buffers and sample time
D	Dump command
F	Fill command
G	Go (sample)
H	Halt command
L	Laser on/off
Q	Quick concentration report
S	Sampling

Figure 3. APS 3321 serial commands summary for Set and Action operations

Read commands	
R	Read accumulator
RF	Read status flags
RI	Read input from I/O connector
RL	Read laser power
RO	Read accumulated on time of instrument
RPI	Read inlet pressure in mbars
RPS	Read sheath delta pressure in Pascals
RPT	Read total delta pressure in Pascals
RQA	Read aerosol sample flow in LPM
RQS	Read sheath flow in LPM
RQT	Read total flow in LPM
RR	Read unpolled record
RTB	Read temperature of box
RTD	Read temperature of APD detector
RTI	Read temperature of inlet
RV	Read version of firmware

Unpolled commands	
U	Unpolled operation begins
U+	Enable all records
U-	Disable all records
UA	Accumulator record
UB	SS accumulator record
UC	Correlated (paired) records
UD	Aerodynamic data record
US	SS data record
UY	Auxiliary data record

Figure 4. APS 3321 serial commands summary for Read and Unpolled operations

Table 2. Calibration data for APS aerodynamic diameters

Ch. No.	Particle size (nm)	TOF (ns)
0	487	100.00
1	523	197.09
2	562	199.05
3	604	201.25
4	649	203.78
5	698	206.69
6	750	210.06
7	806	213.86
8	866	217.98
9	931	222.33
10	1000	226.81
11	1075	231.30
12	1155	235.81
13	1241	240.35
14	1334	244.94
15	1433	249.62
16	1540	254.41
17	1655	259.34
18	1778	264.42
19	1911	269.69
20	2054	275.16
21	2207	280.90
22	2371	287.01
23	2548	293.63
24	2738	300.91
25	2943	308.97
26	3162	317.97
27	3398	328.03
28	3652	339.29
29	3924	351.90
30	4217	365.98
31	4532	381.69
32	4870	399.15
33	5233	418.50
34	5623	439.72
35	6043	462.51
36	6494	486.56
37	6978	511.55
38	7499	537.20
39	8058	563.54
40	8660	590.90
41	9306	619.63
42	10000	650.06
43	10746	682.49
44	11548	716.84
45	12409	752.75
46	13335	789.86
47	14330	827.80
48	15399	866.22
49	16548	904.82
50	17783	943.51
51	19110	982.26
52	20535	1021.04

In addition to the aerosol number concentration, the surface and volume concentration are derived as follows

STEP 6 : Compute the geometric particle diameter D_p (μm) as, $D_p = D_a[\rho_0/\rho]^{0.5}$

STEP 7 : Compute the dS/dlogD_p as, dN/dlogD_p $\times$ $\pi\times$ D_p^2 ($\mu m^2 cm^{-3}$)

STEP 8 : Compute the dV/dlogD_p as, [dN/dlogD_p $\times$ $\pi\times$ D_p^3] /6($\mu m^3 cm^{-3}$)

The measured and derived data are written into the daily generated data file in ASCII format along with station name, date, time, sample mode & sample time, and APS auxiliary data. The data stream is Station name, Date, Time, Mode & Sample time, Raw counts [52 channel data], dN [52 channel data], dN/dlogD_p [52 channel data], dS/dlogD_p [52 channel data], dV/dlogD_p [52 channel data], and Auxiliary data. The setup and deployment packages was developed using the in-built deployment tool in VB 2010.NET. The GUI application software works in Microsoft Windows 7/8/8.1 operating system with .NET framework.

5. Software functions and processes

The "Aerodynamic Particle Sizer Spectrometer TSI 3321 Data Acquisition & Visualization Software" version 3321.2014.6.C GUI application consists of five operational command buttons; (i) SETUP (ii) DATA (iii) VIEW PLOT (iv) REFRESH (v) EXIT and (vi) HELP as shown in Figure 7. The software can be configured through 'SETUP' command button (Figure 8) and the various user editable parameters are (a) Station name, (b) Data Acquisition rate (in seconds), (c) Log instantaneous data (enables to log the instantaneous data from APS), (d) Auto Run (auto enable the program once the GUI application is loaded in the computer startup program after 10 sec), (e) Email Alert (transmits system generated alert to the configured email ID), (f) SMTP server IP address, (g) Send Email To, (h) Send Email CC To, (i) Data folder, (j) Filename prefix, (k) Com port ID, (l) Com port baud rate, (m) Com port parity, (n) Data bits, (o) Stop bit, (p) APS sample mode, (q) APS sample time, (r) APS data mode, and (s) Stokes correction.The 'DATA' command button is used to view the real-time aerodynamic data in 52 size bins along with the APS auxiliary data. The 'REFRESH' button reloads and initialize the system variables and 'EXIT' command closes the ASCII setup file, ASCII data file and serial port (if exists in open state), and quits the application software.

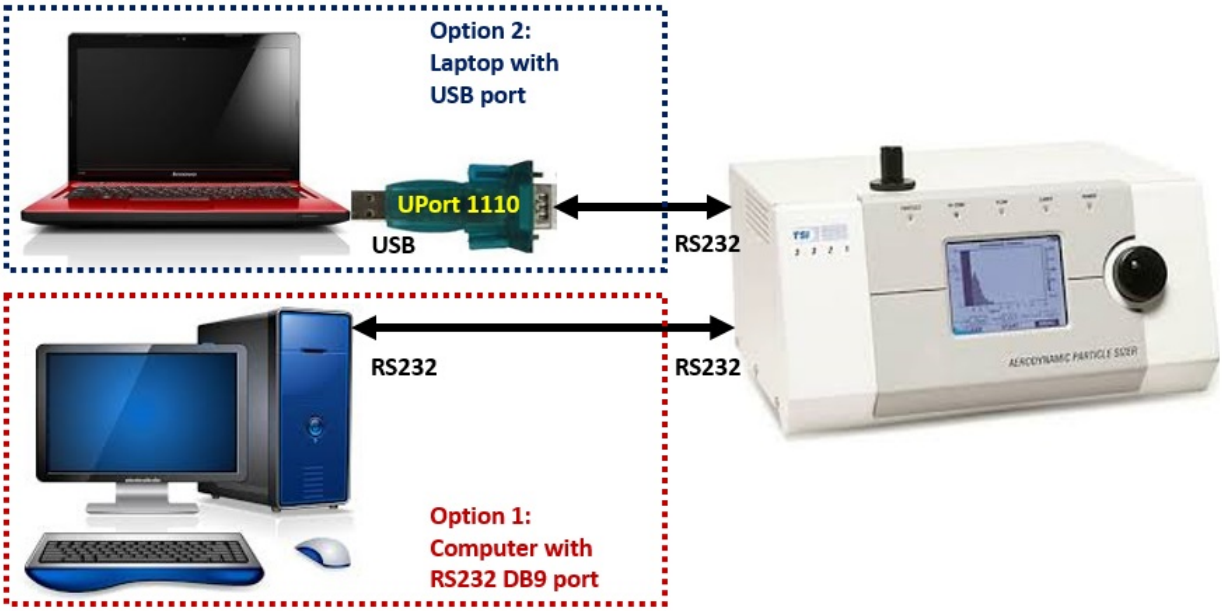

Figure 5. Schematic of APS 3321 interface with Computer and Laptop

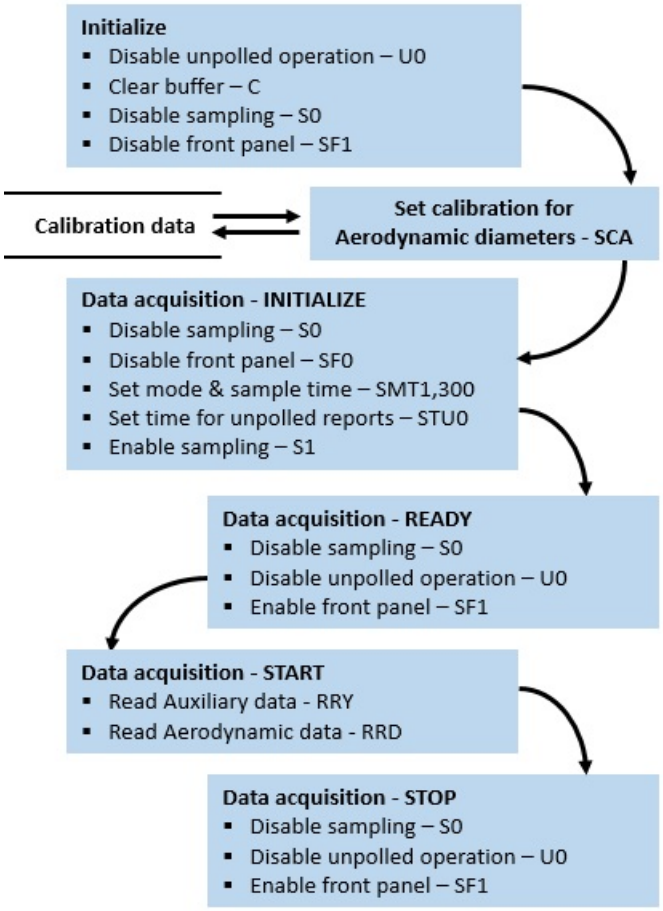

Figure 6. Data flow diagram for the GUI application software

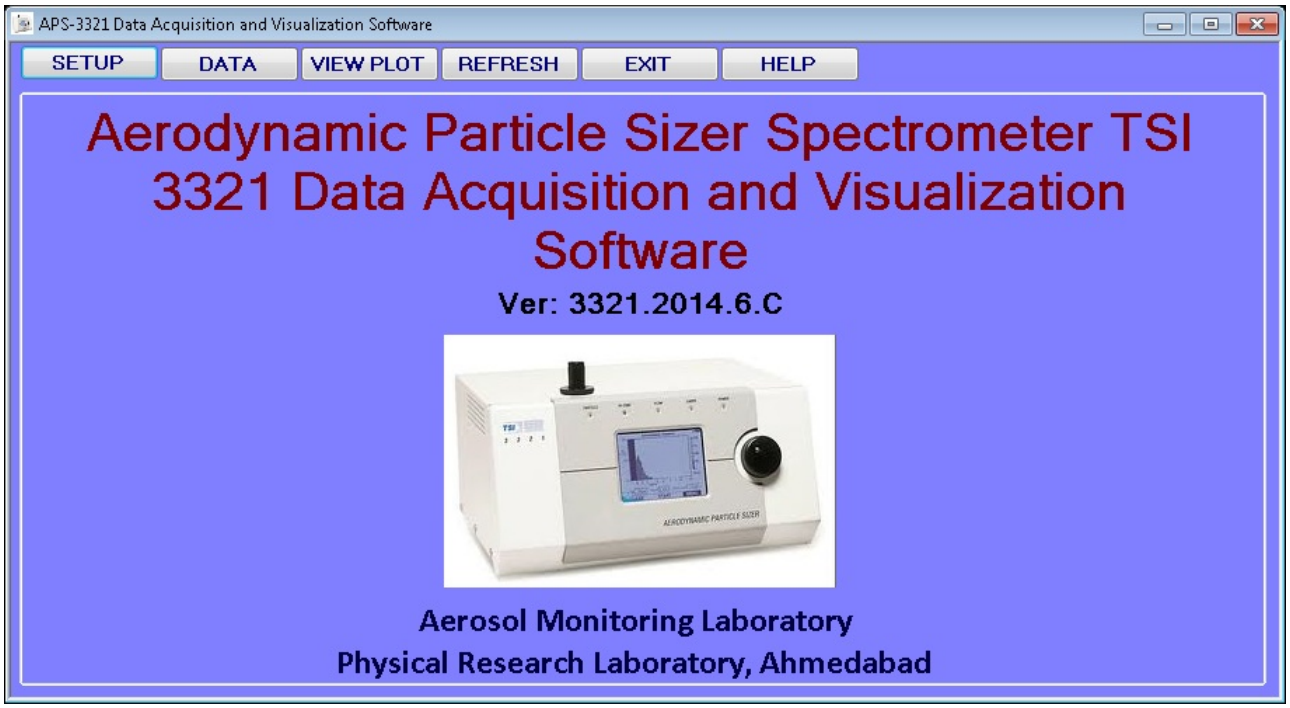

Figure 7. GUI application software for APS-3321 data acquisition software

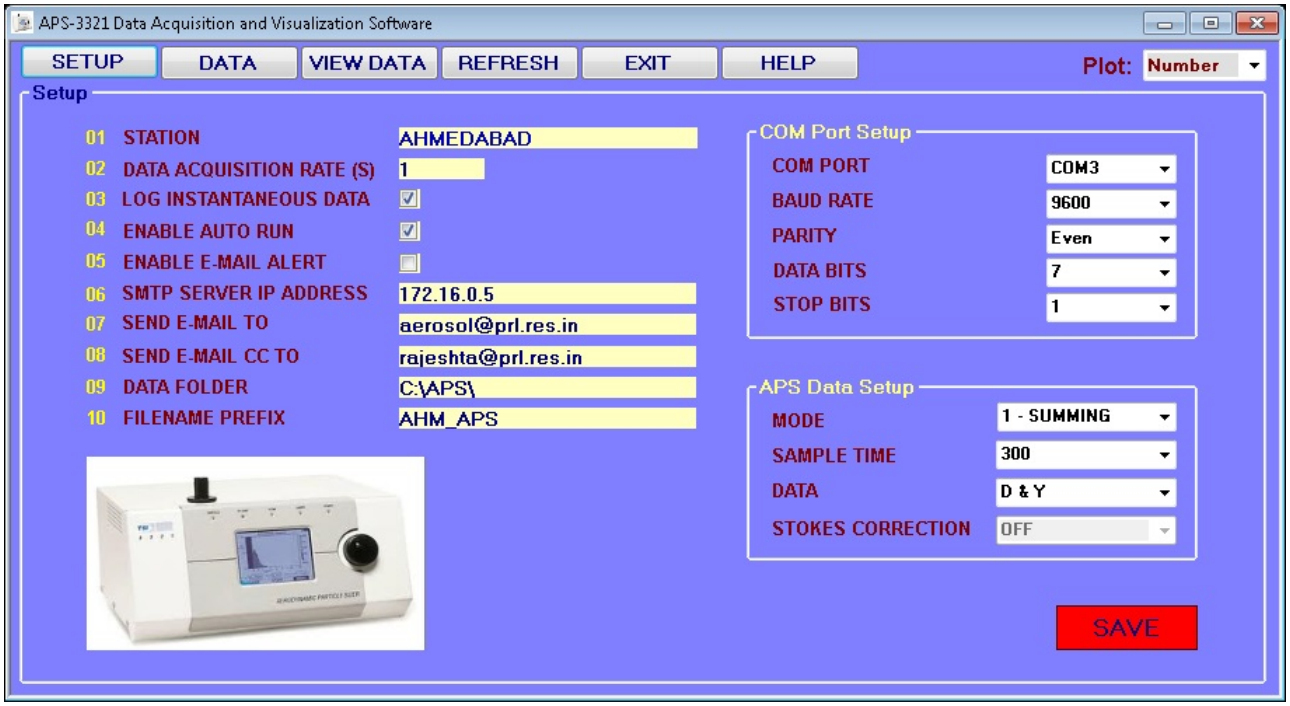

Figure 8. Setup configuration for APS-3321 data acquisition software

Figure 9. Aerodynamic data screen along with APS auxiliary data

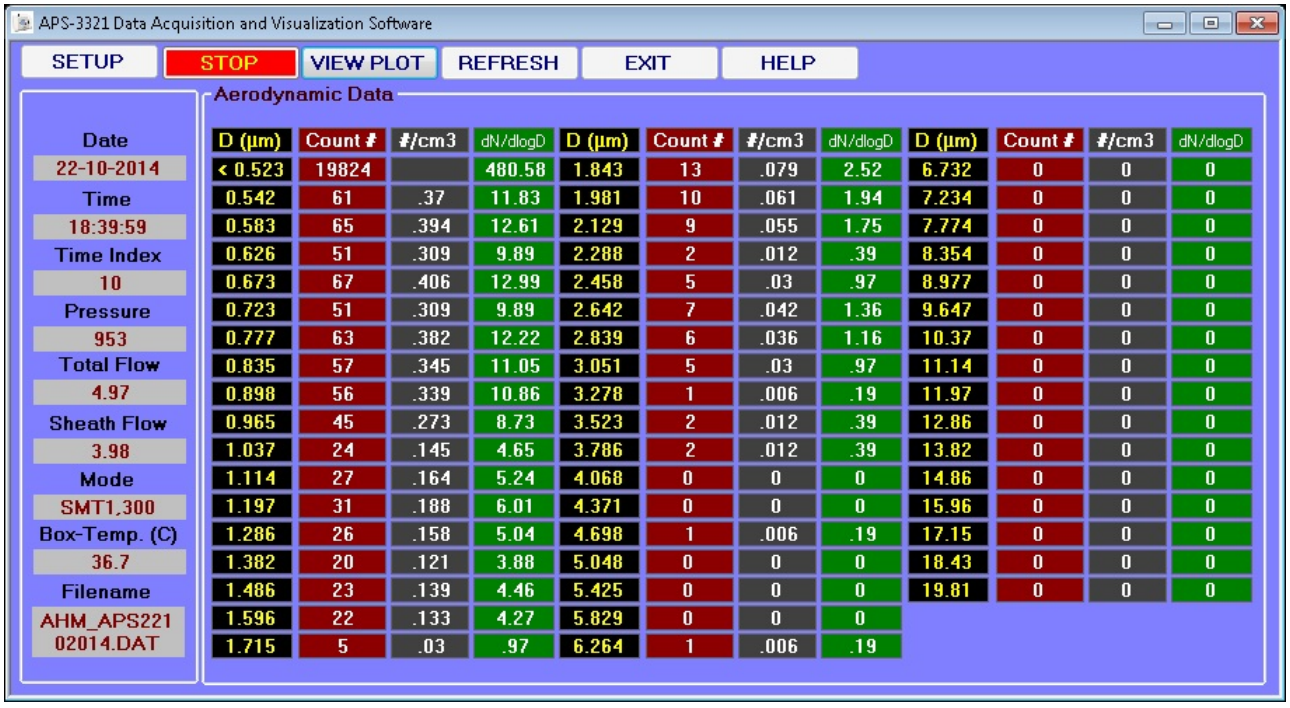

Figure 10. Aerodynamic data screen during data acquiring mode

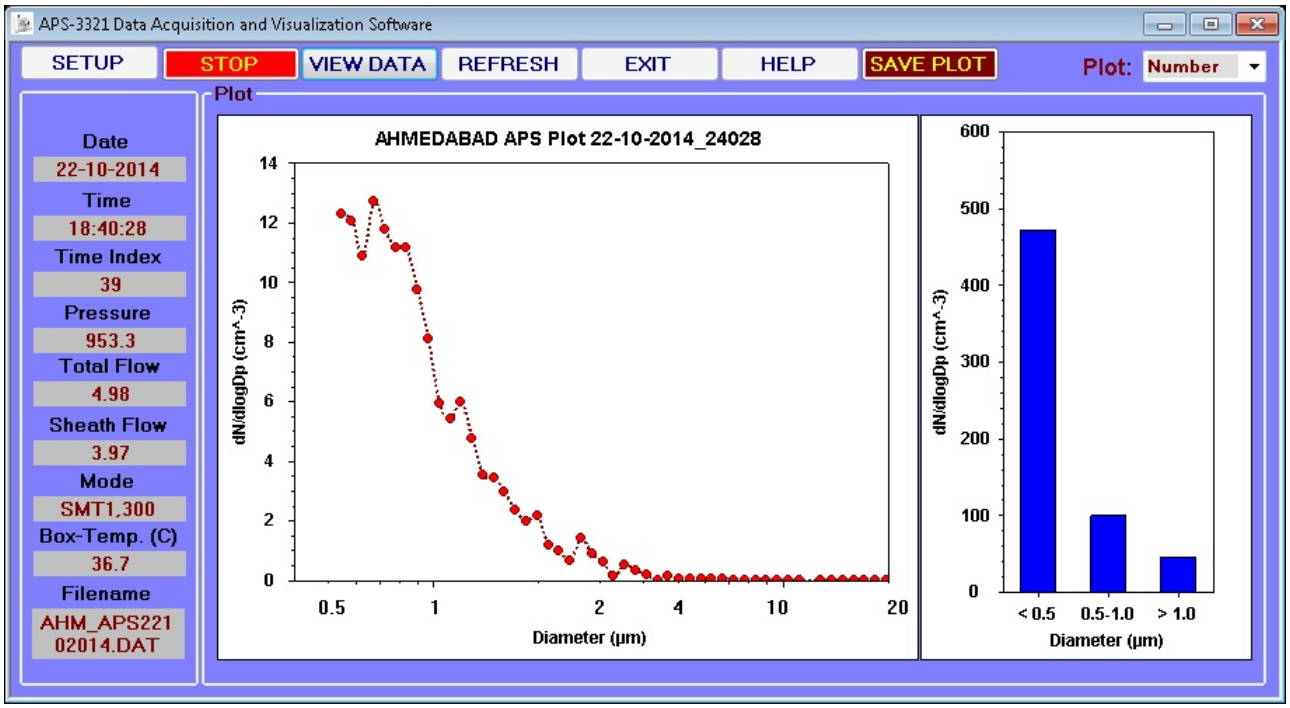

Figure 11. Real-time aerosol number concentration plot in the APS-3321 data acquisition software

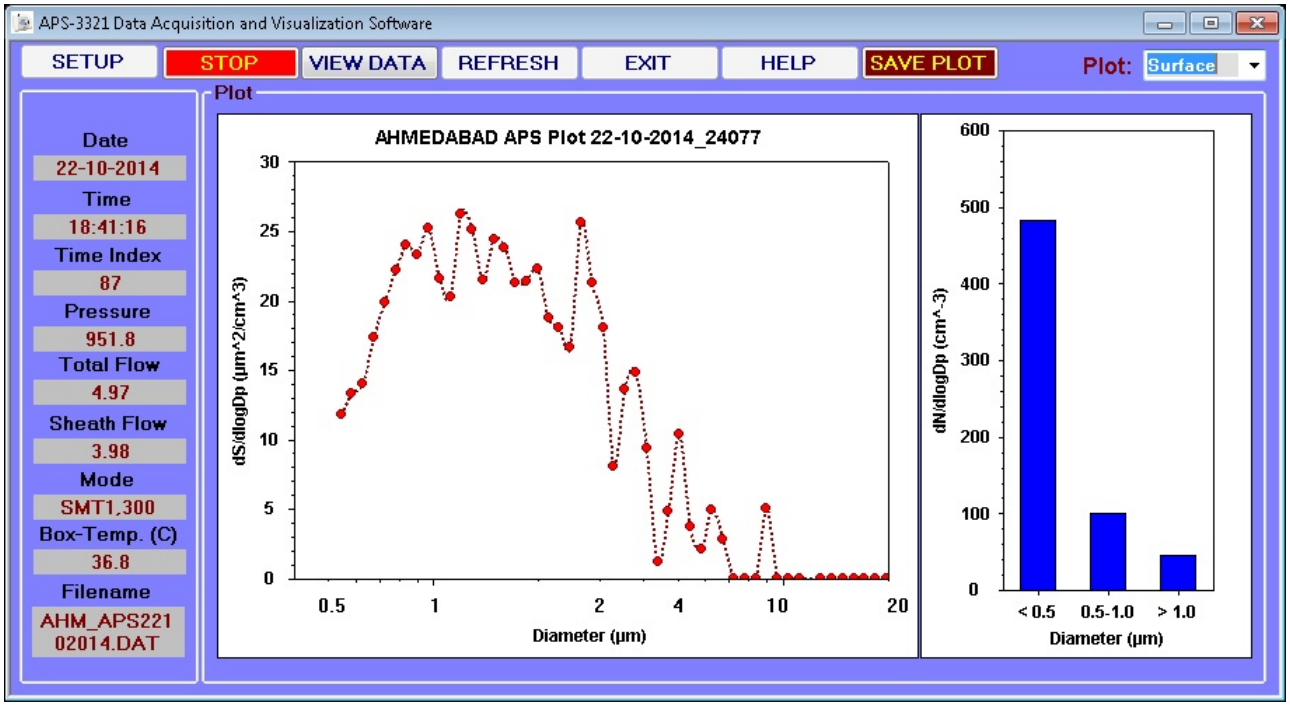

Figure 12. Real-time aerosol surface area concentration plot in the APS-3321 data acquisition software

'HELP' button shows the software user guide and contact information. When the GUI software is run for the first time in a computer/laptop, it will prompt to configure the application setup and the setup parameters are saved in 'APSSetup.txt' file in the configured folder. The GUI is programmed to detect the available serial port (physical or logical) and enumerate the com ports in the com port setup frame. The software reads the system setup and configures the computer/laptop serial port and the system variables. When the data acquisition operation is initiated it configures the APS 3321 as per the user setup (Figure 9) and then starts acquiring the data (Figure 10). It displays the instantaneously measured aerosol number concentration data in the tabular format (Figure 10) and using the 'VIEW PLOT' button it displays the aerosol number concentration plot along with aerosol number concentration binned information for the size ranges: < 0.5 μm, 0.5 - 1.0 μm & $>$ 1.0 μm (Figure 11). The aerosol surface concentration plot can be configured through the 'Plot' drop down combo box for Number, Surface area and Volume in order to display aerosol number (Figure 11), surface (Figure 12) and volume (Figure 13) concentration respectively. It logs the instantaneous as well as averaged data into ASCII file on daily basis. The software can also be configured to upload the daily data file and system alert (if any) to the user configured email address through SMTP server. The aerodynamic data in the tabular shows the particle count #, particle concentration (#/cm^3) and particle distribution dN/dlogDp as a function of aerodynamic particle diameter D_p (μm). The left frame shows the APS 3321 auxiliary data like spectrometer inlet pressure (mbar), total flow (LPM - litre per minute), sheath flow (LPM), internal box temperature (Celsius) along with system date, time, APS data acquisition mode and the software generated data filename.

6. Summary

The real-time data acquisition and visualization software has been designed, developed and successfully implemented for Aerodynamic Particle Sizer Spectrometer (TSI APS, Model 3321). The user can configure the APS 3321 and acquires the measured real-time aerosol size distribution data. It computes and displays the aerosol number concentration in 52 pre-defined aerodynamic diameters bins (0.5 to 20 μm). The aerosol number, surface area or volume distributions along with aerosol number concentration binned information for the size ranges: < 0.5, 0.5 - 1.0 and > 1.0 μm can be displayed in real-time. The instantaneous and average, measured as well as computed data along with the APS 3321 auxiliary data are logged into files daily in ASCII format. The software package is made compatible to Microsoft Windows 7/8/8.1 operating system with .NET framework for desktop computer with physical serial port as well as laptop with logical serial port (using USB to serial convertor). The GUI application software is made available in the installer setup and deployment format.

Acknowledgements

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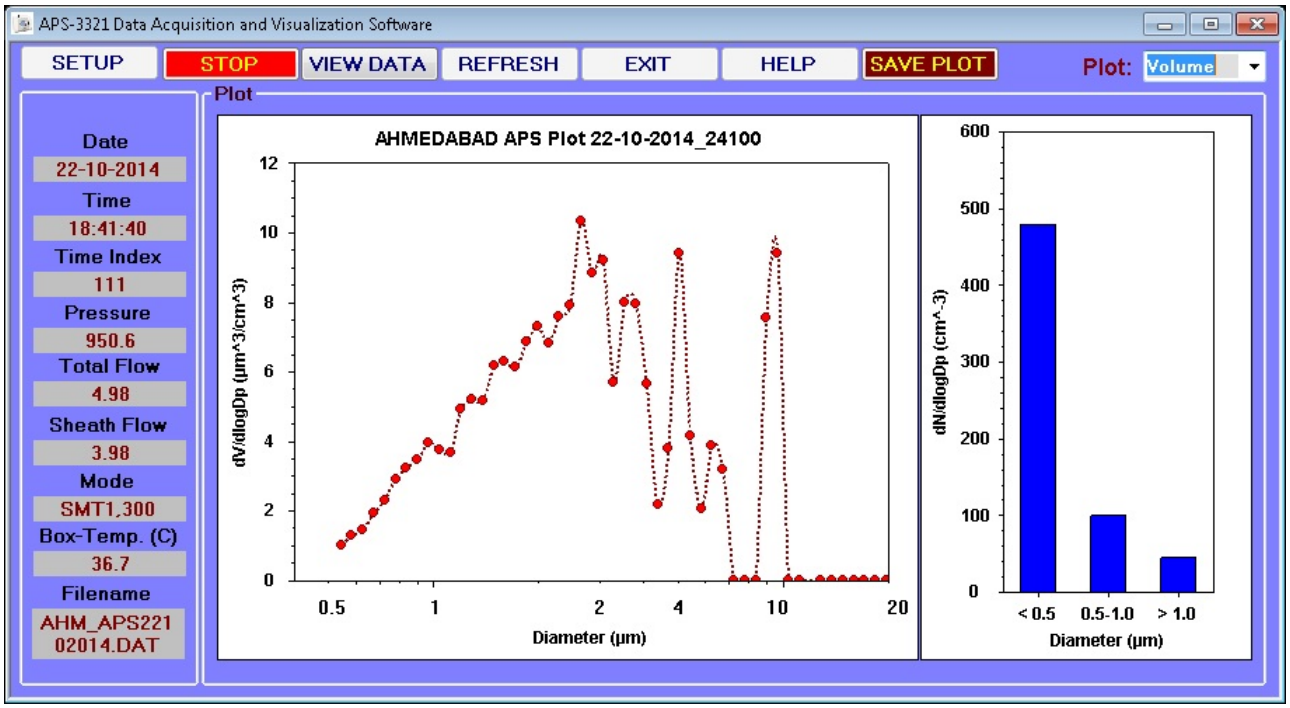

Figure 13. Real-time aerosol volume concentration plot in the APS-3321 data acquisition software

PRL research encompasses the earth the sun immersed in the fields and radiations reaching from and to infinity, all that man's curiosity and intellect can reveal

पीआरएल के अनुसंधान क्षेत्र में समविष्ट हैं पृथ्वी एवं सूर्य जो निमीलित हैं चुंबकीय क्षेत्र एवं विकिरण में अनंत से अनंत तक जिन्हे प्रकट कर सकती है मानव की जिज्ञासा एवं विचारशक्ति