

## **AC 2009-530: AUTOMATED DATA ACQUISITION AND DATA ANALYSIS FOR PLASMA DIAGNOSTICS IN PUPR-MC PLASMA MACHINE WITH WEB CAPABILITIES**

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Carlos M. Serrano was born in Arecibo Puerto Rico, receiving his elementary education from San Juan Bosco private school graduating with honors and earning the medal San Juan Bosco, the highest Medal of Honor in that institution. During high school years, Carlos was recipient of many awards for excellence in almost all subjects, being awarded 7 medals upon graduation, including the Medal of the Pontifical Catholic University of Puerto Rico, in recognition of his high moral and academic performance. Carlos obtained a Bachelor Degree in Electrical Engineering at Polytechnic University of Puerto Rico. Intrigued by technology and innovation, he specialized in electronics, communications and control system. Carlos participated in three summer work experiences with Abbott Laboratories as part of his professional development. Because of his contribution to the company he was allowed to participate for three consecutive summers, when one was the established rule. During his last year of college he was offered the opportunity to work at the Plasma Engineering Laboratory at Polytechnic University of Puerto Rico. His capstone design final project in the electrical engineering program, was to create a computer program to perform the processes for measuring and analyzing plasma parameters. This application is currently used at this laboratory. This work obtained first prize in the poster presentation and third place in the oral presentation in the Senior Engineering Student Design Contest sponsored by the Puerto Rico Engineering and Land Surveyors Board (Colegio de Ingenieros de Puerto Rico). Carlos is currently working at Honeywell Division of Engineering and Technology in the area of defense and space.

# Automated Data Acquisition and Data Analysis for Plasma Diagnostics in PUPR-MC Plasma Machine with Web Capabilities

## Introduction

Polytechnic University of Puerto Rico (PUPR) Plasma Engineering Laboratory (Figure 1) features a plasma machine built to study RF and microwave heating of steady-state plasmas. The Plasma Laboratory also features an interdisciplinary undergraduate research program sponsored by NASA Puerto Rico Space Grant Consortium, to give engineering and science students a first experience on experimental research. This program receives students of all branches of the engineering and sciences. Hence, many of those students are totally untrained in using measurement equipment. To study the confinement, stabilization, production losses, macro and micro instabilities, and other plasma phenomena, it is necessary to diagnose the plasma density ( $n$ ), electron temperature ( $T_e$ ), ion temperature ( $T_i$ ), and plasma potential ( $V_s$ ). The Plasma Engineering Laboratory uses electrostatic probes for this purpose. Electrostatic probes are generally excited by injecting a ramp voltage  $V$  to the probe, and collecting the current  $I$  supplied by the plasma in which the probe is immersed. Then the current  $I$ - $V$  characteristic is analyzed to extract useful information from it and determine the plasma parameters. In order to acquire and analyze the data from the probe, the precise operation and control of various elements is required. The operator must be trained in various topics before he (she) can perform these operations satisfactorily. This poses a problem in a predominantly undergraduate institution using the regime of 12 weeks terms. The students had to spend about one term just getting trained to perform a simple diagnostic. To expedite the realization of the experimental work, an automatic diagnostic system was needed. The main objective of this project was hence, to design software that automatically obtains the data from various electrostatic probes in use at PUPR Plasma Engineering Laboratory, performs the calculation of the desired plasma parameters, and store the results in a well suited location. Another objective was to develop a user friendly interface that allows any inexperienced user to perform measurements with very little training. The application also was required to communicate with the Human Machine Interface (HMI) software in place at the Laboratory (Wonderware<sup>TM</sup>). In this work, the development of that piece of software is described.

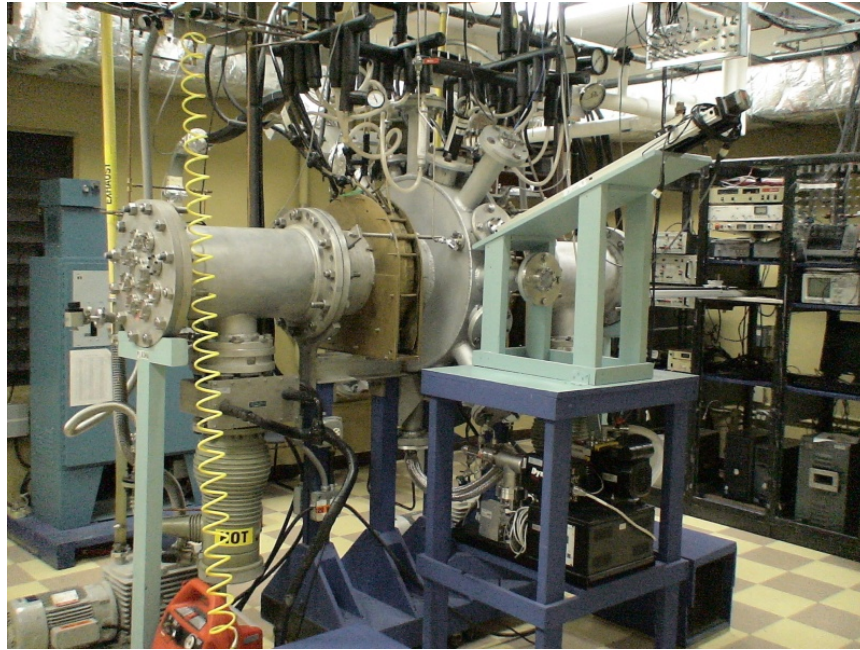


Figure 1: Plasma Engineering Laboratory

## Description of the Software

A conceptual schematic of the system is shown in Figure 2. Most of the electrostatic probes in use at the Plasma Engineering Laboratory share the same physics principles to perform diagnostics. However, each one of them uses a different method of measurement. Each probe is then considered to be the measurement element of an instrument, while the software developed by this project is the element to extract and transmit the information from the measuring element to the end user. The measuring elements considered are the Single Langmuir probe, the Double Langmuir probe, the Emissive probe, and the Ion and Electron Energy Analyzers<sup>1,6</sup>. The circuitry and software was developed using National Instruments LabView and some basic electronics. The software was designed to save the processed data to a database already in place in the laboratory.

The analysis for the automated measurement was designed using the relationships described by Leal-Quirós<sup>6</sup>. The software was designed as virtual instruments (*vi*) using Labview<sup>4</sup>. A *vi* works as independent objects that can be called and used by other programs and objects. This object oriented programming helps the developer to design very complex applications in a structured and ordered fashion. The software created is intended to help a user non trained in plasma physics, to perform plasma diagnostics and obtain results in a fast and reliable way. The application is required to control at least two Keithley 2400 source-meters<sup>5</sup>, and a Velmex MN10-0600-M02-21 Bislid positioning system<sup>3</sup> (referred to as probe driver in this document) using either a GPIB bus or a RS-232 serial interface.

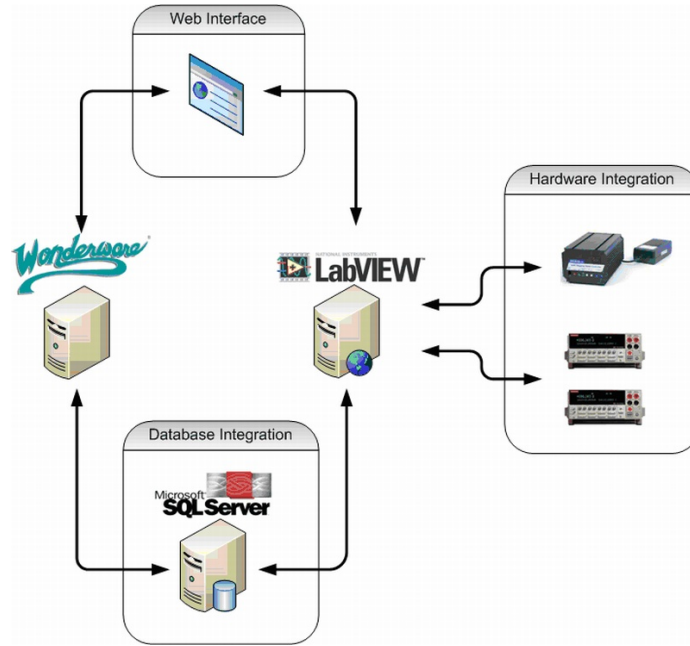


Figure 2: Schematic of Automatic Data Acquisition System

For both interfaces, the application uses the ASCII Standard Commands for Programmable Instrumentation (SCPI) protocol. Additionally, the application has the capability of triggering a store procedure to send the data acquired during operation to a database. To perform communication with the instruments, actuators, and database, special *vi* blocks had to be developed, adopting a modular design to enable future modifications. The LabView Database Connectivity Toolkit<sup>2</sup> was used to develop the communication with the database. A Web based interface was also developed to allow user remote access to the measurements and enable future remote collaborations.

The application uses the characteristics of the I-V characteristics for each probe for computing the plasma parameters<sup>6</sup>. For the Single and Double Langmuir probes, the first step is to identify the exponential portion of the I-V curve. This is performed by identifying the floating potential using

$$I_i = I_e = 0, \quad (1)$$

and the plasma potential  $V_s$  using

$$\left[ \frac{dI(V)}{dV} \right]_{V=V_s} = 0. \quad (2)$$

With this information the exponential portion of the I-V characteristic is isolated, and the plasma electron temperature was computed using

$$kT_e = \frac{e}{\frac{d \ln |I|}{dV}} \quad (3)$$

where  $kT_e$  is the electron temperature,  $e$  is the elementary charge,  $I$  is the current collected at the probe and  $V$  is the probe voltage.

The plasma electron density was calculated by identifying the electron saturation current and using

$$n_e = \frac{-I_{es}}{eA\sqrt{\frac{kT_e}{2\pi m_e}}} \quad (4)$$

with  $n_e$  the electron density, and  $I_{es}$  the electron saturation current. Equation 2 was also used for the analysis of the data acquired from the Ion Energy Analyzer, along with

$$kTi = -\frac{e}{\tan \theta} \quad (5)$$

with  $kTi$  the ion temperature, and  $\theta$  the slope of the I-V characteristic, given by

$$\theta = \frac{\ln I(V)}{V} \quad (6)$$

For the electron energy analyzer, equation 2 was used, together with equation 3.

## Design Specifications

The objectives outlined for this work are:

1. Design and development a software to enable automatic data acquisition and measurements for Langmuir Probes and Energy Analyzers.
2. Design and development of a user friendly interface that allows any user to take measurements from the Plasma machine.
3. Communicate LabView with Wonderware and a SQL server for data acquisition and storage.
4. Create a Web Interface for the Automated Measurement System enable remote access of the measurements.

## Results

The resulting application performs a number of functions to help unexperienced students to perform plasma diagnostics, organized in six different tabs. Each tab contains various

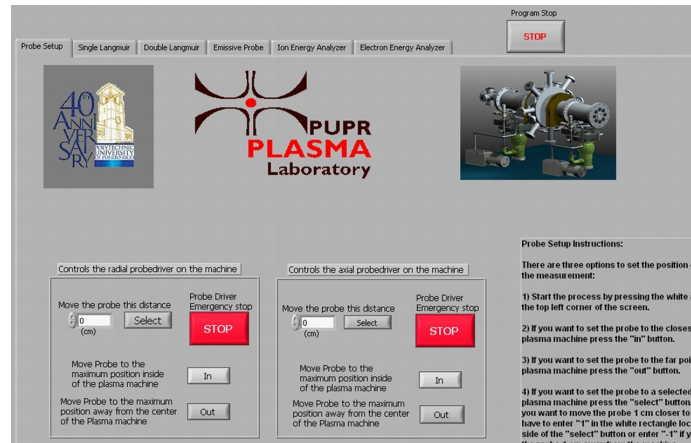


Figure 3: Probe Driver Setup Tab

text fields, controls, and buttons to setup the corresponding measurement and evaluate the results, and a help area with instructions for the user. Figure 3 shows the first of the tabs. This tab is called *Probe Setup* and enables the user to program the probe driver to move the measuring element or a experimental sample to a convenient or required position inside the plasma chamber. The probe setup tab also has a security option (available from all tabs) to exit the application if something unexpected occurs.

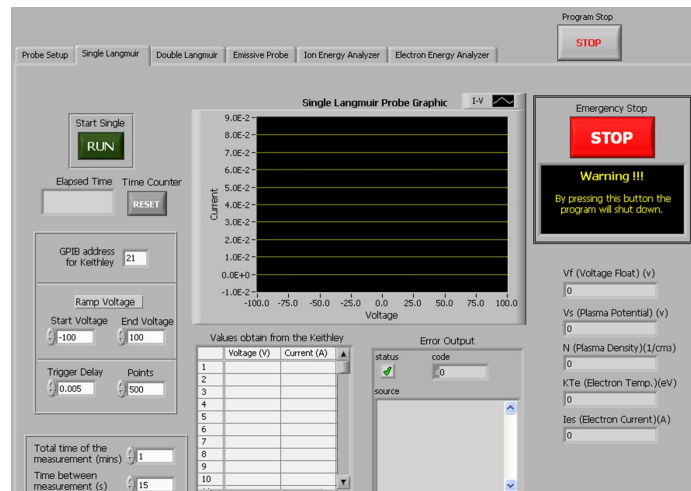


Figure 4: Single Langmuir Probe Tab

The next five tabs (Figure 4 shows an example) are used to control five different measurement instruments included in the software. These tabs are generally featured with a x-y chart displaying the acquired data, text boxes to input the number of measurements and interval between them, text boxes to input the range of the voltage ramp, a table displaying

the acquired data in a tabular form, start and stop buttons, and display labels to output the value of the plasma parameters.

There is a tab for each type of probe, the Single Langmuir Probe, the Double Langmuir Probe, the Emissive Probe, the Ion Energy Analyzer and the Electron Energy Analyzer. The algorithms for data gathering and analysis are different for each probe. Nevertheless, the measurement procedure is the same for all of them. First, the software obtains, shows, and stores the raw data (Figure 5) from the probe. After applying a zero phase low pass filter (Figure 6), it analyzes the data computing the plasma parameters and displaying the results of the analysis on screen. If the data is not adequate to perform a measurement, the program displays an error message indicating so. Finally the application is able to archive the results of the analysis of the raw data in a database giving the users the ability to open and analyze the archived raw data and results at a later time.

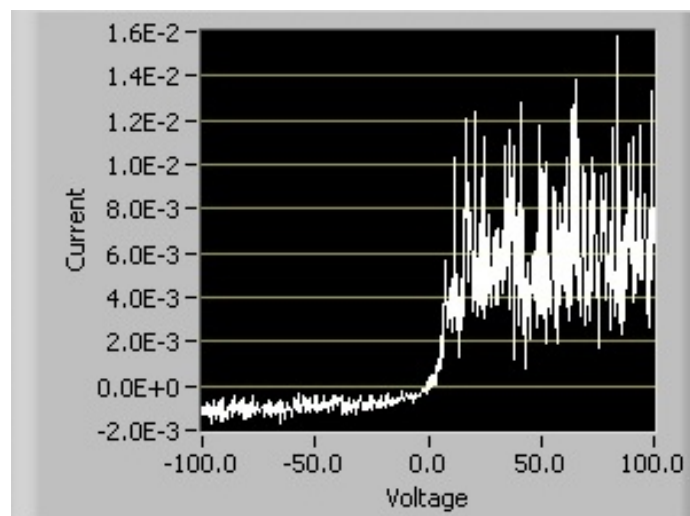


Figure 5: Single Langmuir Probe Measurement before filtering

Figure 7 shows the main algorithm to obtain measurements from any of the probes included in the design. The application has two modes of operation. The administrator is able to view the block diagrams and make changes to the algorithm of the application. The user is only able to perform measurements. This security feature was implemented to ensure that inexperienced users would not accidentally change the operation of the application.

The user friendly interface has safety and control integrated into it. The first control feature is the impossibility of activating two probes at the same time, since all of them share the same measuring element (Keithley 2400). The second feature is the emergency stop button, that if pressed will cause the current measurement to be stopped, the Keithley 2400 to be reset, and the application to exit. This interface also allows communication with the

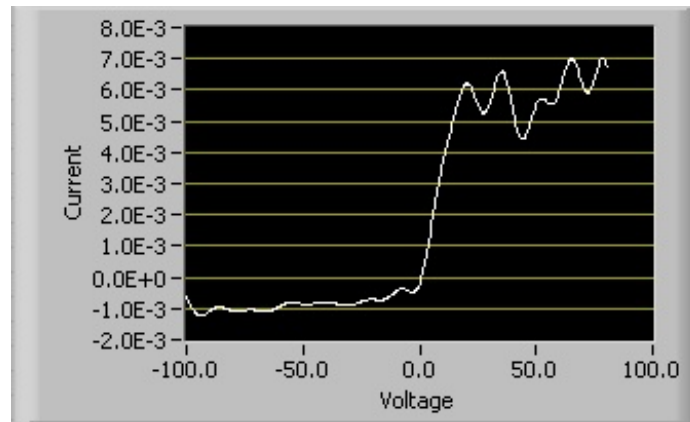


Figure 6: Single Langmuir Probe Measurement after the filter

Wonderware<sup>TM</sup>, the Human Machine Interface (HMI) software used to control the start up and shut down of the plasma machine. It also provides the ability to communicate with a database (SQL server) to keep historic records of the operations.

Summarizing the capabilities of the system

- Probe Setup
  - Control the position of the probe or energy analyzer.
  - Exit the program after finishing the experiment.
- Electrostatic probes and energy analyzers
  - Obtain and show raw data acquired from the probe.
  - Archive raw data obtained from the probes.
  - Analyze raw data obtained from the probes and compute the plasma parameters.
  - Display the results of the analysis on screen and display an error message if there is something wrong with the measurement.
  - Archive the results of the analysis of the raw data.
  - The ability to open and analyze archived raw data.
- User friendly interface
  - Communicate with Wonderware through the web interface.
  - Communicate with the database (SQL server).
  - Run as an executable program.
  - View the obtain graphics and results through a web interface.



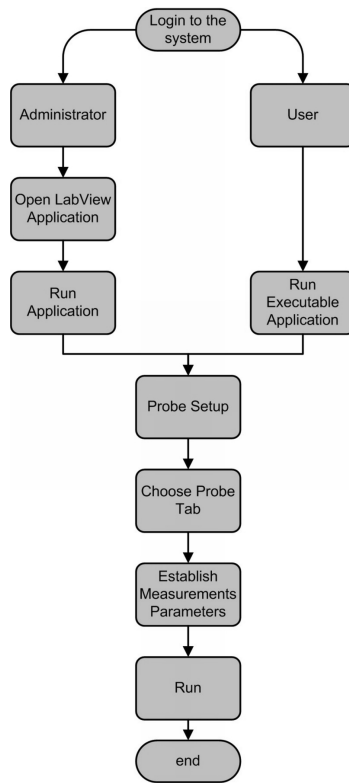


Figure 7: Main algorithm for the application operation

## Conclusions

An application for diagnostics of plasma parameters using electrostatic probes was developed for the Plasma Engineering Laboratory at Polytechnic University of Puerto Rico. The objectives outlined for the design of the software were accomplished, providing a tool for students of any of the branches of the engineering and science to perform experiments at the laboratory with relative ease and minimum training. The application is able to compute plasma density and temperature depending for 5 different probes, is able to communicate with an HMI to provide information during its operation, can be controlled remotely from the HMI, and is able to store the data acquired into a database for further studies on plasma diagnostics and other areas of the physics. This application provides the researchers of PUPR with a tool to speedup the experiments developed at the Plasma Laboratory, and decreases the amount of work to be performed for each experiment.

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