# Instrument Control (iC) – an open-source software to automate test equipment

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## Abstract

It has become common practice to automate data acquisition from programmable instrumentation, and a range of different software solutions fulfill this task. Many routine measurements require sequential processing of certain tasks, for instance to adjust the temperature of a sample stage, take a measurement, and repeat that cycle for other temperatures. We introduce an open-source Java program that processes a series of text-based commands that define the measurement sequence. These commands are in an intuitive format which provides great flexibility and allows quick and easy adaptation to various measurement needs. For each of these commands, the iC-framework calls a corresponding Java method that addresses the specified instrument to perform the desired task. The way iC was designed enables one to quickly extend the functionality of Instrument Control with minimal programming effort or by defining new commands in a text file without any programming.

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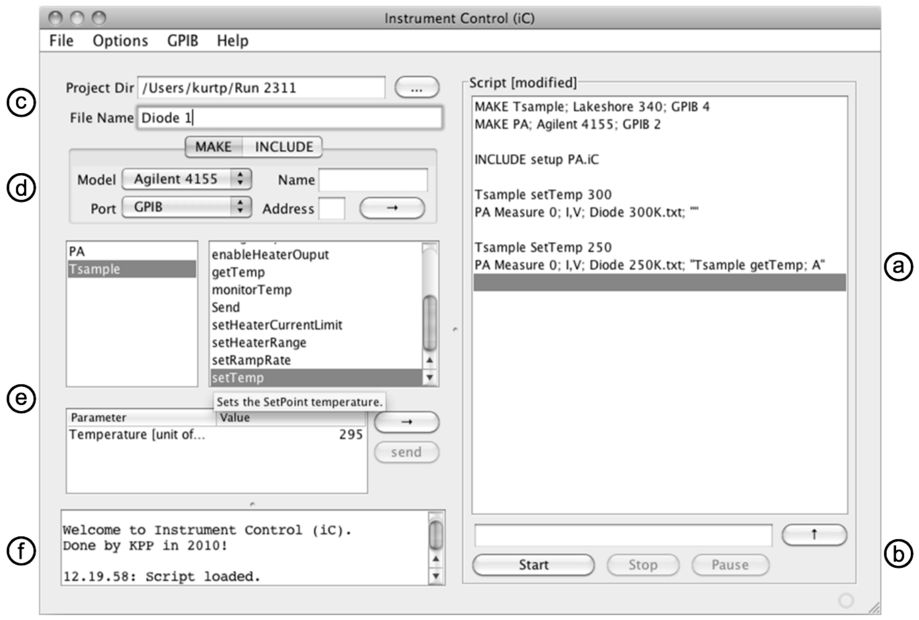
## I. INTRODUCTION

A spectrum of automation software for scientific test equipment is available, ranging from full-fledged solutions that provide data acquisition and management (e.g. LabView, VEE, and EPICS) to data visualization and calculus software with the capability to communicate with instruments (e.g. IgorPro, Origin, Matlab, Mathematica and SciLab)[8]. This article introduces Instrument Control (iC) [1][9], an open-source Java program that provides a convenient framework to automate data acquisition by processing a list of commands stored in a conventional text file. Defining the test sequence with clear text commands is one of the main advantages of iC as it enables quick and easy adaptation to different measurement needs encountered in day-to-day laboratory situations, and to store the employed measurement sequence together with the measured data for documentation purposes. Another great feature of iC is that new commands for an instrument can simply be defined in a text file which then serves as the "driver" for that instrument. Instrument Control works with General Purpose Interface Bus (GPIB) controllers [2] from major vendors (National Instruments, Agilent, Prologix), and it is prepared to support other communication protocols such as Ethernet, USB, or other proprietary protocols as well. Instrument Control uses Java Native Access [3] to access the platform-specific drivers supplied by the vendors of the communication controller (*.dll, *.dylib, *.so files), and it has been tested on Windows and Macintosh operating systems. Instrument Control is comfortable to use, easily extendable, and it is ideal for somebody already familiar with Java or a similar programming language, or when budgetary considerations or the availability of the source-code are of concern.

The source code including documentation, tutorial videos, and a precompiled version is available free of charge from [1]. The documentation also includes an up-to-date list of supported instruments. The most recent source code can be conveniently downloaded from the subversion server into the development environment (e.g. Netbeans) with a single mouse click, and the necessary configuration steps are described in [4]. At the time of writing, the source code comprises 7800 lines of code and more than 8700 lines of documentation, and the size of the precompiled version is 10 MBytes. In the following, a brief introduction is presented of how iC is used, as well as an overview how the iC-framework works internally. Section III shows that the functionality of iC can be extended with little programming effort. The last part explains how new commands that can be executed from the script can



Project Dir: /Users/kurtp/Run 2311

File Name: Diode 1

| Parameter | Value |
|---|---|
| Temperature [unit of... | 295 |

```
MAKE Tsample; Lakeshore 340; GPIB 4
MAKE PA; Agilent 4155; GPIB 2

INCLUDE setup PA.iC

Tsample setTemp 300
PA Measure 0; I,V; Diode 300K.txt; ""

Tsample SetTemp 250
PA Measure 0; I,V; Diode 250K.txt; "Tsample getTemp; A"
```

```
Welcome to Instrument Control (iC).
Done by KPP in 2010!

12.19.58: Script loaded.
```

Figure 1: Graphical user interface of Instrument Control (iC).

be defined in a *generic* way; i.e., in a simple text file containing the GPIB string to be sent to the instrument and a description of the input parameters for the user.

## II. USING INSTRUMENT CONTROL

Central to iC is a *script* (Listing 1) which contains a list of *script-commands*. Scripts are stored as conventional text files, and a graphical user interface (GUI, Fig. 1) implemented in iC offers a convenient way to write such scripts, although any other text editor is also sufficient. Using text files is in general advantageous because text files are universal, cross-platform compatible, unproblematic in terms of long-term readability, and can be read by essentially all programs.

The right side of iC's user interface displays the script (Fig. 1a), and it contains a line to type in new script-commands and buttons for the user to start, stop, and pause processing of the script (Fig. 1b). All measurement data are saved in a project directory and a base file name as specified in GUI (Fig. 1c). Script commands can add an extension to this base file name, e.g., the actual sample temperature when the measurement commenced. The GUI allows the user to add commands to the script that define new instruments (script-command `MAKE`) and to include sub-scripts (script-command `INCLUDE`, Fig. 1d). Label e in Fig. 1 marks a part of the GUI that lists all instruments used in the script as well as the commands each instrument supports. This part of the GUI is dynamically generated from annotations in the source code or the text file defining new script-commands in a generic way as shown below. When the user selects a command of a particular instrument, the command's parameters are shown in a table as illustrated in Fig. 1e for the command `setTemp` of the instrument with the name `Tsample`. This way, the user can comfortably add new script-commands with the appropriate parameters. The 'Send' button allows the user to send script-commands to the selected instrument while a script is being processed. This is advantageous because many instruments cannot be operated from the front-panel while they are accessed remotely. The text-field at the bottom left of the GUI (Fig. 1f) shows status messages for the user.

```
MAKE Tsample; Lakeshore 340; GPIB 4 // temperature controller
MAKE PA; Agilent 4155; GPIB 2       // semiconductor parameter
   analyzer
INCLUDE setup PA.iC              // sub-script to initialize PA

Tsample setTemp 300                 // bring sample to 300 K
PA Measure 0; I,V; _300K.txt; ""    // measure and store the I-V
   characteristics

Tsample SetTemp 250
PA Measure 0; I,V; ; "Tsample getTemp A"
                     // append current sample temperature to file
                        name
```

Listing 1: An exemplary script to measure and store current-voltage characteristics of a diode at two temperatures.

After the user starts processing the script, all script-commands are parsed to detect errors, for instance typographical errors or parameters that are out of range. This *syntax-check* is performed in the same way the script-commands are executed but without communicating with the instruments, which minimizes the programming effort when extending iC. After the successful syntax-check, the script-commands are sequentially processed. Each script-command corresponds to a Java method which is invoked by the iC-framework with the proper arguments.

### A. An example script

Listing 1 shows an example of an iC-script to measure the current-voltage characteristics of a diode at two different temperatures. Lines 1 and 2 define two new instruments: a Lakeshore 340 temperature controller connected via GPIB at address 4, and an Agilent 4155 semiconductor parameter analyzer with GPIB address 2. To refer to these instruments later in the script, the variables `Tsample` and `PA` were assigned. Whenever a new instrument is defined, communication with the instrument is automatically established by the iC-framework to minimize the programming effort when the functionality of iC is extended. Line 3 in Listing 1 includes a sub-script, which, as an example, contains script-commands that initialize the parameter analyzer to perform the desired measurements, i.e., assign the source-monitor units, set the range of voltages measured, etc. The next script-command invokes a method `setTemp(float)` in a class which implements all supported script-commands of an instrument (*driver-class*), in this case, the class `Lakeshore340` for the temperature controller. Line 6 calls the method `Agilent4155.Measure(int, String, String, String)` which starts the measurement and stores the measured parameters `I` and `V` in a text file. The name of this file is comprised of the base file name specified in the GUI (Fig. 1c) and the extension provided in the script-command, i.e., 'Diode 1_300K.txt'. The last argument is optional and allows the user to pass an additional script-command to the `Measure()` method. This additional script-command (Line 9 in Listing 1) is processed from within `Measure()` and it's result is used to attach the current temperature to the file name, e.g. 'Diode 1_250.15K.txt'.

## III. EXTENDING INSTRUMENT CONTROL

iC facilitates two ways of extending its functionality. The programmatic way in which new Java methods are implemented is discussed next, and the generic way of defining new instrument-commands in a text file is discussed subsequently.

Listing 2: A possible implementation of a Java method to change the temperature set point and wait until the temperature is reached.

```
 1  public void setTemp(float SetPoint)
 2          throws IOException {

 4      // build the GPIB command string
 5      String str = "SETP 1," + SetPoint;

 7      // send to the Instrument
 8      SendViaGPIB(str);

10      // wait until set point is reached
11      float T;
12      do {
13          // get current temperature
14          str = QueryViaGPIB("KRDG? A");

16          // convert to a float value
17          T = Float.parseFloat(str);
18      } while ( Math.abs(T-SetPoint) < 0.1 &&
19                  m_StopScripting == false);
20  }
```

### A. Programmatic way

Listing 2 shows a possible implementation of the `setTemp()` Java method used to change the temperature set point and wait until the temperature is within 0.1 K of this set point. The main purpose of this method is to generate the GPIB strings that are sent to the instrument to perform the desired tasks, and to interpret the string which is read back from the instrument that contains the measurement data. Line 5 in Listing 2 creates the GPIB string to set the temperature set point of control loop '1', and Line 8 sends this string to the instrument via GPIB. The method `SendViaGPIB(String)` is defined by the iC-framework and handles all communication with the instruments via GPIB. The method `throws` an `IOException` when a communication error occurs, and this `Exception` is – just as all other `Exceptions` – automatically handled by the iC-framework. Therefore, new code does, in general, not require any `Exception` handling. The documentation [4] elaborates in greater detail how `Exceptions` are used to handle possible errors. In Line 14 of Listing 2, the method `String QueryViaGPIB(String)` is used to query the current temperature of input channel 'A'. When the difference between set point and current temperature is withing 0.1 K or the user has pressed the 'Stop' button in the GUI, `setTemp()` returns and the next script-command is processed.

The documentation [4] contains step-by-step instructions to implement new and extend existing driver-classes, and a reference implementation of a Java method included in the source code is recommended to serve as a template for new code. To minimize programming effort when implementing new script-commands, Java's Reflection mechanism is used to access class information at run-time. Any `public` method that is added to a driver-class is automatically recognized by the iC-framework and, hence, accessible as script-command without further programming. Java methods are allowed to start new `Threads` to enable parallel processing of certain tasks, such as to display various temperatures on a graph while a script is being processed.

Data received from instruments is in general handled by the Java methods, although a return value from a Java method can also be used in the successive script-command. Most methods that receive measurement data store the data in a text file for further processing in visualization or calculus software. Java also provides convenient ways to save data as xml files, in a binary format, or in a compressed archive which can be advantageous for large data sets. The open-source software package JFreeChart [5] is integrated in iC, making it very easy to display data in high quality graphs. iC also integrates Apache's Common Math package [6] for advanced data manipulations such as Spline interpolation of data points, statistical analysis, numerical integration, and much more.

Listing 3 illustrates the mechanism used to dynamically generate the part of the GUI shown in Fig. 1e and also how the syntax-check mechanism is implemented. The Java language allows to define annotations in the source code which can be evaluated at run-time. Instrument Control uses this technique to automatically build a GUI at run-time by defining an annotation `@AutoGUIAnnotation()` (lines 1-5 in Listing 3) with fields that provide a detailed description of the method's purpose (tool-tip in Fig. 1e), the names of it's input parameters, the default values, and the tool-tip texts for each parameter.

Instrument Control uses a second annotation `@iC_Annotation()` (line 6 in Listing 3) which declares that the method performs a syntax-check. If a syntax-check is implemented, the method should `throw` a `DataFormatException` if a parameter is not allowed (lines 11-12 in Listing 3), and the method must return without any communication when the program is in syntax-check mode (lines 15-16 in Listing 3).

Listing 3: Annotations used by iC to define part of the GUI in the source code, and to declare if a method implements a syntax-check.

```
1  @AutoGUIAnnotation(
2      DescriptionForUser = "Sets the SetPoint temperature.",
3      ParameterNames = {"Temperature [unit of SetPoint]"},
4      DefaultValues= {"295"},
5      ToolTips = {"Define tool-tips here"})
6  @iC_Annotation(MethodChecksSyntax = true )
7  public void setTemp(float SetPoint)
8          throws IOException, DataFormatException {

10     // perform Syntax-check
11     if (SetPoint < 0 || SetPoint > 500)
12          throw new DataFormatException("Set point out of range.");

14     // exit if in Syntax-check mode
15     if ( inSyntaxCheckMode() )
16          return;

18     // continue as in Listing 2
```

## B. Generic way

The programmatic way of implementing new script-commands offers great versatility but requires re-compilation of the source code and some programming skills. Defining new script-commands in a generic way using text files requires neither of these and is, therefore, ideally suited for quick testing or implementing simple functions. An example of a generic instrument definition for a SRS Lock-In amplifier is given in Listing 4. The file name (without extension) is taken as the name used in the MAKE commands (e.g. MAKE lia; SRS SR810; GPIB 8). Every line contains a definition of a new script-command and comprises the following tokens: (1) the name of the script-command; (2) the GPIB string where %d, %f, %s (and other format specifiers [4]) are placeholders for integer, double and string values which will be replaced by the values specified in the script; and (3) and (4) specify the parameter names shown in the table of the GUI (Fig. 1e). As illustrated in line 3 of Listing 4, the tokens can also include tool tip texts (enclosed in curly braces) as well as a minimum and maximum numerical value (enclosed in square braces) and a default value for the GUI (enclosed in round braces). If a method name (token (1) in Listing 4) starts with 'get' or 'save', the instrument is addressed to talk and the result of this query is made available to the next script-command. If the method name starts with 'save' the result is additionally stored in a text file and the last parameter is interpreted as a file extension (token (5) in Listing 4). The text files defining new generic GPIB instruments need to reside in a particular directory (<user home>/iC/Generic GPIB Instruments/), and the file name must contain '.GPIBinstrument' to be recognized by iC. If the file name matches the name of an existing instrument (e.g. Agilent 4155.GPIBinstrument), the generically defined commands are added to the existing commands of that instrument. All generic GPIB instrument definitions are read when iC starts, which makes it very easy to write new "instrument drivers" or extend existing ones without any Java programming.

Listing 4: Example for a generic definition of script-commands for a SRS SR810 Lock-In amplifier. These definitions are stored in a text file named 'SRS SR810.GPIBinstrument.txt' and automatically recognized by iC at start-up.

```
1 // (1)    (2)          (3)           (4)
2 setAUX | AUXV %d,%f | AUX channel | Voltage
3 getAUX | AUXV? %d | AUX channel {can be 1..4} [1,4] (1)
```

```
saveIDN | *IDN? | File Extension
//                (5)
```

## IV. SUMMARY

Instrument Control (iC) is an easy to use open-source software to automate test equipment which uses intuitive script-commands stored in a conventional text file to quickly adapt to various measurement needs. It is very easy to extend the functionality of iC by either implementing new Java methods in a driver-class or by defining generic instrument definitions in a text file. Instrument Control works with GPIB controllers of major vendors on various operating systems, and it is prepared to support other communication protocols as well. Instrument Control is made available as open source to follow a call to publish computer code [7] and in the hope that it will serve the scientific community.

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[8] Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the Na-

tional Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

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