4. DATA ACQUISITION

The DAS comprises integrated hardware and software components to acquire, interpret, record, display, correct, and archive data from the suite of transducers installed on the PCCV model. The basic data acquisition requirements were specified by NUPEC and, after discussions with the NRC and SNL, a detailed DAS Plan [29] was developed and approved. The DAS Plan specified the objectives, performance requirements, and basic architecture of the DAS. A DAS QA Task Plan [30] specified and documented the detailed procedures that guaranteed the DAS satisfied the operational specifications. The key elements of the DAS Plan and QA Task Plan are summarized in this chapter.

4.1 Objectives

The primary program objectives the DAS must satisfy included the following.

1. The DAS must be fully functional, verified, and approved at the time of model prestressing. This means that the output signal from all operational sensors can be read, that the source and location of all output signals was known with certainty, and that the output signal can be converted to accurate engineering measurement units within the tolerances specified in the Instrumentation Plan.
2. During prestressing operation, the DAS must:
   a. be capable of monitoring all instruments, including all strain gages, displacement transducers, and T/Cs, except those gages in the uncompleted portion of the basemat,
   b. provide a real-time display of selected sensor output (especially load cells and tendon gages) in engineering units to monitor prestressing operations, and
   c. retain a record of final data after prestressing as initial conditions for subsequent readings.
3. The DAS must be capable of periodic data acquisition between prestressing and testing phases.
4. During low and high pressure testing, the DAS must be capable of scanning all active sensor data and storing dynamic data and data of record (DoR) data. The DAS must be capable of providing real-time displays of any sensor output (uncorrected) in engineering units and facilitating comparison with pretest predictions to guide the conduct of the test. The DAS may also be integrated with other systems controlling and monitoring the test, such as the pressurization system, acoustic monitoring system, visual monitoring system (video and still photography), lighting systems, and audio systems.
5. The DAS must record the data in a manner that facilitates timely and accurate correction of the raw data after the test is complete.

4.2 Hardware Description

The PCCV hardware configuration for both the instrumentation system and the DAS is shown in Figure 4.1. A more detailed schematic is provided in Appendix F. This schematic not only graphically "maps" all component classifications important to the data acquisition effort, but also provides details on where documentation pertaining to each component of the system may be found. This documentation includes installation, wiring, and quality control information. For the PCCV tests, there were approximately 1500 instruments mounted on the model. Each of these gages had lead wires extending from the gage itself to a terminal board. From the terminal board, the gage's signal was carried to a specific channel on a card located in a mainframe. The channel location defined the General Purpose Interface Bus (GPIB) address for that gage. This address was used for acquisition, tracking, and recording of the gage's data. There were 13 mainframes located in a DAS trailer. From the mainframes, a fiber optic cable carried the signals from all of the gages to the data acquisition computer located in the control room (9950). The hardware from the gages to the front side of the terminal boards made up the instrumentation system. The remaining hardware (shown on the right of Figure 4.1) made up the DAS. The data acquisition computers stored the data on redundant media and also made the data available to the display computer. The display computer allowed test personnel to track the behavior of the gages in real time. The stored data were protected and used for posttest data analysis.

The primary hardware component involved in the data gathering was the Hewlett Packard 75000 Series B system, which included the HP1302A VXI Mainframe and its associated 5 ½ digit multimeter (HP1326B). Analog signals from the instruments were sent to plug-in cards installed into the mainframe housing. An analog bus jumper connected the signals to the digital multimeter where the analog-to-digital (A-D) conversion occurred.

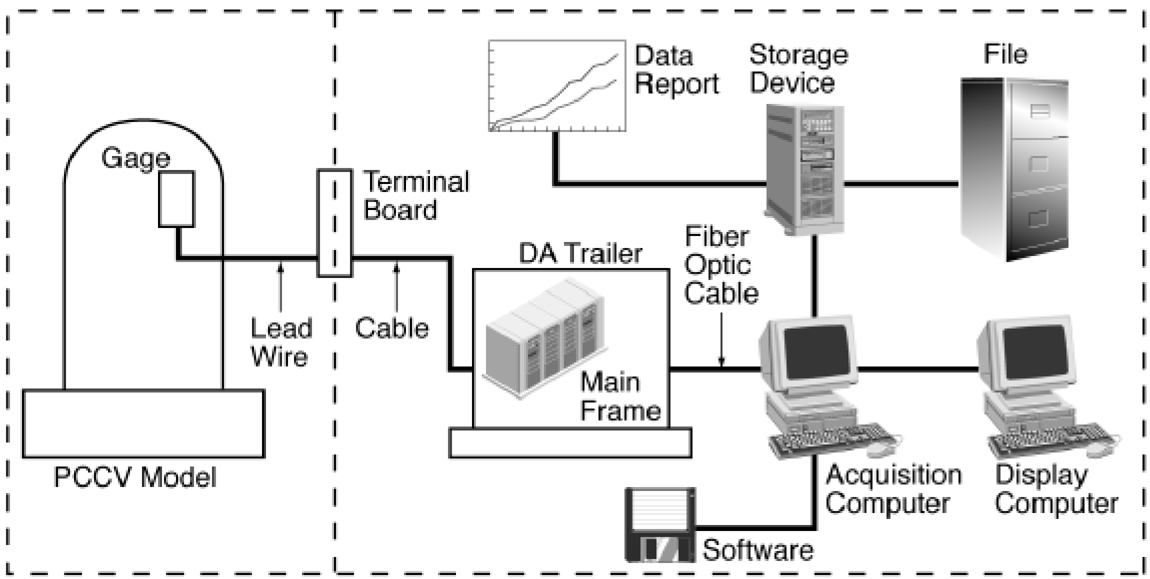

Figure 4.1 PCCV/DAS Hardware Configuration

Data were then stored in input/output (I/O) buffers dedicated to the multimeter, or in the RAM of the mainframe, for eventual transfer over a standard GPIB cable to the data acquisition computer. The mainframe was able to manage the channel switching and data transfer operations as well as respond to controller commands over the GPIB. In addition, the status of the data transfer operations was monitored.

The digital multimeter can be used as a stand-alone device through the VXI bus. However, for this test, it was connected through the analog bus jumper to a series of relay multiplexers. It measured and converted five types of input signals: DC voltage, RMS AC voltage, 2-wire resistance, 4-wire resistance, and electrically-based temperature sensing devices (T/Cs and RTDs).

The characteristics of the multiplexer cards varied based on the type of signal they carried. This experiment used three types of cards: 350 Ω and 120 Ω strain gage cards (Wheatstone quarter-bridge circuits, 8-channel capacity) and a 16-channel voltage card (i.e., non-bridged voltage producing device). To service the different types of instruments installed on the PCCV model, 137 350 Ω cards, 26 120 Ω cards, and 23 voltage cards were used. Two types of VXI mainframes were used. One accepted seven multiplexer cards, and the other type accepted 16 cards. There were no basic differences between these mainframes other than their card capacities. In order to accommodate the cards needed, 13 mainframes were utilized.

Strain gage multiplexer cards are designed to measure the voltage produced in a bridge circuit due to resistance changes in a strain gage. Consequently, these circuits require excitation voltage, which is provided by external power supplies. The strain gage multiplexer cards provide excitation and scale the output of the strain gages. The 1326B digital multimeter measures the voltage and converts the reading to strain units. Thus, the raw data received by the data acquisition computer is in strain units.

The data are held in the VXI bus buffer until the GPIB controller-in-charge (the data acquisition computers) commands a transfer. The mainframes were located in a data analysis trailer situated near the mudmat of the PCCV model and an opening to the Tendon Gallery tunnel, as well as the small penetrations that would feed all internal instrumentation cables (180 degrees). The location, near 180 degrees, was chosen as it allowed cable lengths to be as short as reasonable, thus preserving signal integrity. The data acquisition computers were located remotely at the 9950 site. Adapting the standard GPIB cable to a fiber-optic bundle minimized digital signal loss and degradation. This cable could be extended over long distances and eventually readapted to standard GPIB format for installation into GPIB cards on the DAS computer chassis.

From the perspective of the data acquisition computers, each mainframe/multimeter pair represents a single GPIB instrument. One GPIB card is capable of controlling seven GPIB instruments. For the PCCV experiment, two GPIB interface cards and two data acquisition computers were used, as more than eight GPIB instruments were needed.

The data acquisition software used for the PCCV test was designed as a general instrumentation monitoring system, with a single GPIB card and controlled by a single data acquisition computer. This implies that any computer running the acquisition software can scan any instrumentation suite with an accurate configuration file. Thus, each data acquisition computer scanned approximately half of the instruments on the model. Each data acquisition computer operated independently of the other. The display computer read data from both computers, one at a time.

The final major piece of hardware involved in the DAS was a display computer. This computer read the experimental data from the data acquisition computers upon demand and presented it in optional formats (plot form, array form, comparison form). The display computer provided the test conductor information to help make real-time decisions during the test.

The display computer had additional monitors allowing observers (located outside the test control room) to view the display.

Additionally, the DAS included two separate data storage devices (one connected to each data acquisition computer). These stored redundant copies of the data files to ensure data protection.

4.2.1 Hardware Specifications

Manuals and hardware specifications for each DAS component were included in the DAS Plan. All of the hardware chosen for the PCCV data acquisition effort was expected to meet requirements for the overall system operation.

The total time required for the actual acquisition of data from the VXI mainframes was governed by two primary factors: the switching and settling time of the on-board multiplexer and the aperture setting for each sampled channel. This statement assumes very short times for I/O from the controller to the multimeters. By far, the largest of these components is the aperture setting for a static DAS with unfiltered data signals. (The settling time for the mechanical relays in the PCCV's VXI mainframes is on the order of µseconds.) For the PCCV tests, the aperture time was set to 16.5 ms, which ensures electrical filtering of common 60 Hz noise sources. Decreasing the aperture time allows for more rapid data acquisition, but significantly increases signal noise, particularly for unfiltered data. Signal degradation is further complicated by the moderate to long cable lengths, which are necessary in a test of this sort. Therefore, the default 16.5 ms aperture for each channel was used. This setting results in a maximum possible sampling frequency of 60 Hz. This value is decreased incrementally by the relay operation and I/O to the controller.

Scan time is defined as including: 1) the time required for the GPIB-based READ command to reach the mainframe from the control computer; 2) the time for the command module in the appropriate mainframes to receive the request for data and set the multiplexer for operation; 3) the time for multiplexer switching and the multimeter aperture delay for each configured channel; and 4) the time required to transfer all the data from the controller buffer back to the DAS computers. Thus, the scan time was larger than the product of the sampling frequency multiplied by the number of gages scanned, because of the time required to transfer the large controller buffer contents via the GPIB. Scan times were slightly different for the two DAS computers, with PCCV1 requiring approximately 50 seconds and PCCV2 requiring approximately 70 seconds.

Cycle time includes the scan time plus the time to store the data on the requested storage devices. The plan was to immediately generate two copies of the data, one on an internal hard disk and one on a removable disk. The storage required the largest amount of time by far. To shorten this as much as possible, the DAS software was written to facilitate this operation (i.e., separation of data display and data acquisition computers, up-front creation and preparation of data files, use of binary high-speed I/O data file formats rather than ASCII, termination of all unnecessary processing during data storage, etc.) and the data storage hardware was chosen to minimize disk seek time, transfer rate, and access time. Cycle time was approximately 120 seconds during system checkout, a setting that was used for the remainder of the testing.

4.2.2 Gage Wiring

The criteria to determine from which opening each gage's wires left the model was based solely on the route requiring the shortest length of wire. Thus, in the majority of cases, each gage's wires exited the model from the opening closest to the gage itself. Once the wires exited the model, they went to one of several terminal boards. The wires leaving the terminal boards entered the DAS trailer and connected to the data acquisition mainframe cards.

As stated, lead wires were as short as reasonable while still enabling the needed connections. All gage/wire combinations were reviewed, and corrections to gage factors were made posttest, as per Appendix G.

4.3 Software Description

The software used to control the DAS and display the acquired data during the experiment was developed using National Instrument's Labview™ software package.[30] The basic building block of Labview™ is called the virtual instrument (VI). A VI is similar to a subprogram or a module of code.

The data acquisition program is made up of VI trees, each representing a code module with a specific purpose. Graphics objects (such as knobs, dials, switches, etc.) visible on the screen during the data acquisition process can adjust instrument and data acquisition control parameters. Users may manipulate these objects with mouse commands.

The PCCV/DAS software is separated into three major groups: the primary program group used to gather and store the data during the experiment, a secondary program group to display the data during the experiment, and a utility group of programs used either before or after the test. These utility routines were designed to accomplish several tasks:

1. Form the configuration file and channel set-up,
2. Run DAS diagnostics and self-testing,
3. Perform channel and instrument integrity evaluations,
4. Evaluate noise, and
5. Present posttest data and storage to customer-defined formats.

4.3.1 Software Structure

The software was separated into two main groups of programs and a group of utility routines. (The term "group" refers to a series of linked subprograms existing as separate files.)

The data acquisition software (the primary group) was used to both gather and store the data during each of the tests (e.g., pre-stressing, SIT, final). This program group required input in the form of configuration files and was primarily responsible for data scanning, immediate redundant data storage, and fault limit detection and announcement.

The data display software (the secondary group) used the data gathered by the primary group. The display software did not access the stored data files on the acquisition computer, but rather global variables that were shared by the acquisition and display computers. In Labview™, global variables are used to easily access a set of values from any active VI. This allows values to be shared between Labview™ programs without requiring any other connections between the programs. This software group was responsible for displaying the experimental data on demand in the form requested by the user. Several different display modes were developed to meet the need of the PCCV experiments. These included a stability review, strain and displacement distributions, and a primary graphical user interface.

The utility group provided the necessary input channel configuration information to the main group software. There were many other secondary tasks the utility group performed as needs arose.

[30] National Instruments Corporation, Austin, TX (http://amp.ni.com/niwc/labview/what.jsp?node=1381)

4.3.2 Software Module Specifics

The three PCCV DAS software groups were divided into seven main modules. Modules 1, 2, and 4a composed the main acquisition group. Module 4b was the main display software group. Modules 3, 5, 6, and 7 composed the Utility Group. Figure 4.2 shows a schematic of the modules and how they were grouped.

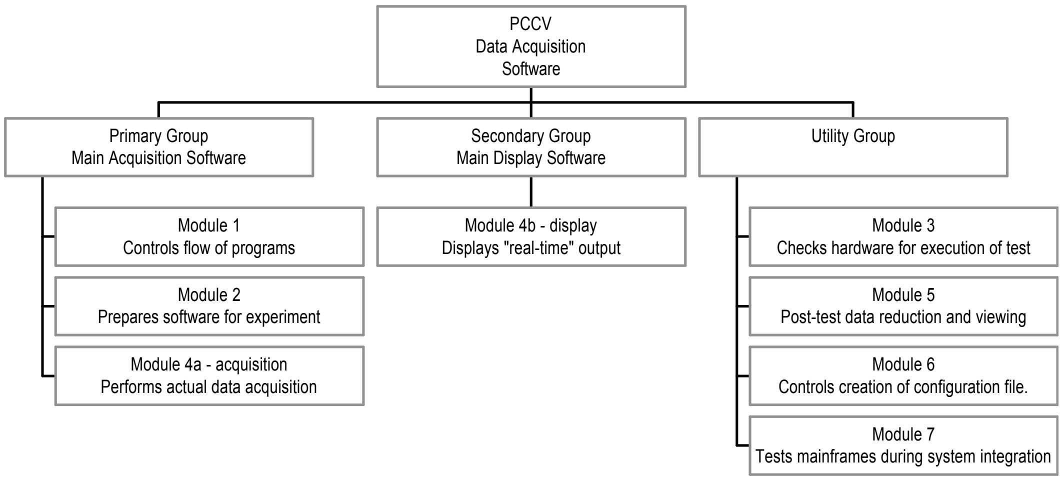

Figure 4.2. DAS Software Tree

The modules are listed below with a brief description of each.

Module 1: Controls flow of program through Modules 2, 3, and 4a.

Module 2: Prepares the software package to conduct a test including configuration information input to the acquisition software.

Module 3: Prepares the hardware for executing the test. Includes checking the GPIB bus for the configured listeners and card layouts, and diagnosing the status (electronically) of the mainframes, digital multimeters (DMMs), and any other hardware.

Module 4a: Performs the actual data acquisition, including readings during non-steady-state operation as well as the steady-state (DOR) scans. Includes writing raw data to disk as soon as possible. Provides continuous pressure information as well.

Module 4b: Allows the user to select and display the desired real-time output.

Module 5: Provides posttest data reduction and viewing.

Module 6: Simplifies creating the configuration file and putting configuration information into the configuration file to minimize errors.

Module 7: Facilitates mainframe testing during system integration. Easily configurable to rapidly indicate status of connected instruments.

4.3.3 Input/Output File Structure

4.3.3.1 File Structure Description

The two basic sets of I/O files necessary in the DAS software package were:

1. A configuration that file that provided the necessary input data to the DAS software, and
2. Data files into which the recorded data were placed.

Data File Structure

The design of the output data file structure allowed standard plotting software to select segments of data for plotting.

The output data file structure:

- Provided users with a clear map between the columns of numbers in a data file and the location and type of instrument originating the data,

- Used nomenclature for naming the files that provided the nature of the data contained and the types of instruments represented in the files,

- Generated an easily accessible set of files for archival purposes, anticipating future inquiries for analysis and presentation, and

- Facilitated rapid data correction and post-processing.

Two levels of folders below a "main" data folder were required to properly organize the data files. These levels are shown in Figure 4.3.

All data from this experiment was stored as *raw* data signals (i.e., the output of the A-D conversion step in the DAS process). Posttest data reduction converted the raw data into standard engineering units.

Table 4-1 lists the raw and reduced data units for the instruments in the PCCV experiment.

Note that the term "raw" in this table indicates the nature of the data signal after hardwired, "firmware" processing, which occurred automatically within the digital multimeter of the HP VXI Mainframe.

The data from some instruments was used to compensate or correct the raw data from other instruments. Details on this practice are found in Appendix G. Figure 4-4 illustrates the basic data flow diagram for the PCCV project.

4.4 Miscellaneous DAS Issues

4.4.1 Loss of Power

During the verification and validation testing, the results of losing electrical power to the DAS computers were determined. This determination involved actually shutting down electrical power to the computers while the DAS software was running. Several iterations of this were done, each at a different point in the acquisition process. It was necessary that data be maintained in the event of a power outage.

4.4.2 Integration of DAS with Other Systems

In general, the DAS was independent of all other systems involved in the PCCV experiments. There were two exceptions: still camera operation and the activation of redundant interior model lights. It was possible from the main data acquisition screen to operate the still cameras positioned throughout the PCCV model. Similarly, the interior model lighting was controlled from the main data acquisition screen. It was possible to turn the redundant lights on or off from the DAS computer.

The Soundprint acoustic monitoring system and the SOFO fiber-optic gages were equipped with their own independent DASs, also located in the data acquisition trailer. The only interface between these systems and the main DAS was manual synchronization of clock time. This provided the correlation between gage output and pressure subsequently used to analyze the test data.

Table 4.1. Description of Raw and Reduced Data for the PCCV Test

Instrument Type	Raw Data Units	Reduced Data Units
Strain gage (includes Tensmegs gages)	strain or microstrain (depending on gage factor format)	Strain
Cable-type displacement transducer	DC volts	Displacement (mm)
LVDT	DC volts	Displacement (mm)
Temposonic	DC volts	Displacement (mm)
Inclinometer-type displacement transducer	DC volts	Tilt angle (degrees)
Thermocouple	temperature (˚C)	Same as raw
RTD	temperature (˚C)	Same as raw
Pressure gage	DC volts	Pressure (MPa)
Load cells	DC volts	Load (Newtons)
Power supplies	DC volts	Same as raw (data used to reduce instrument voltages to CPOT distances)

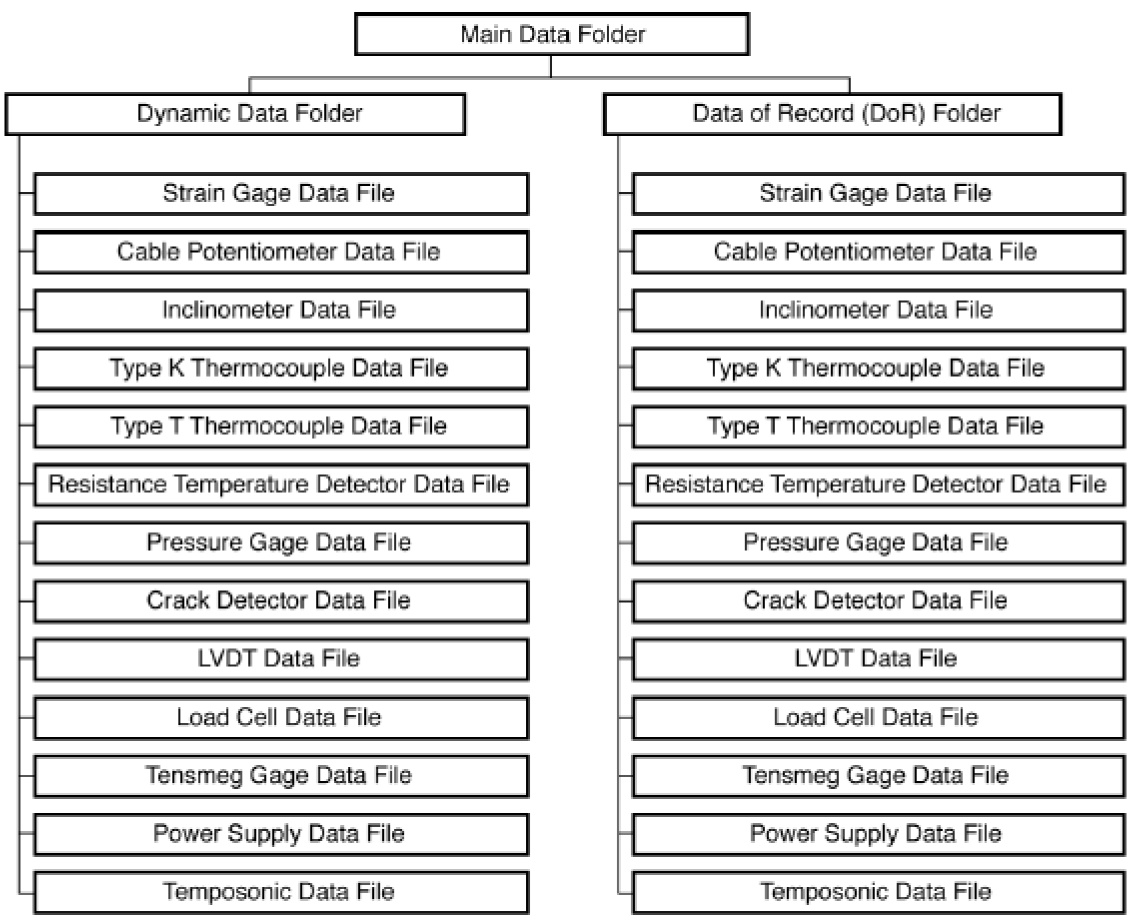

Figure 4.3 Top-Down Data File Folder Structure

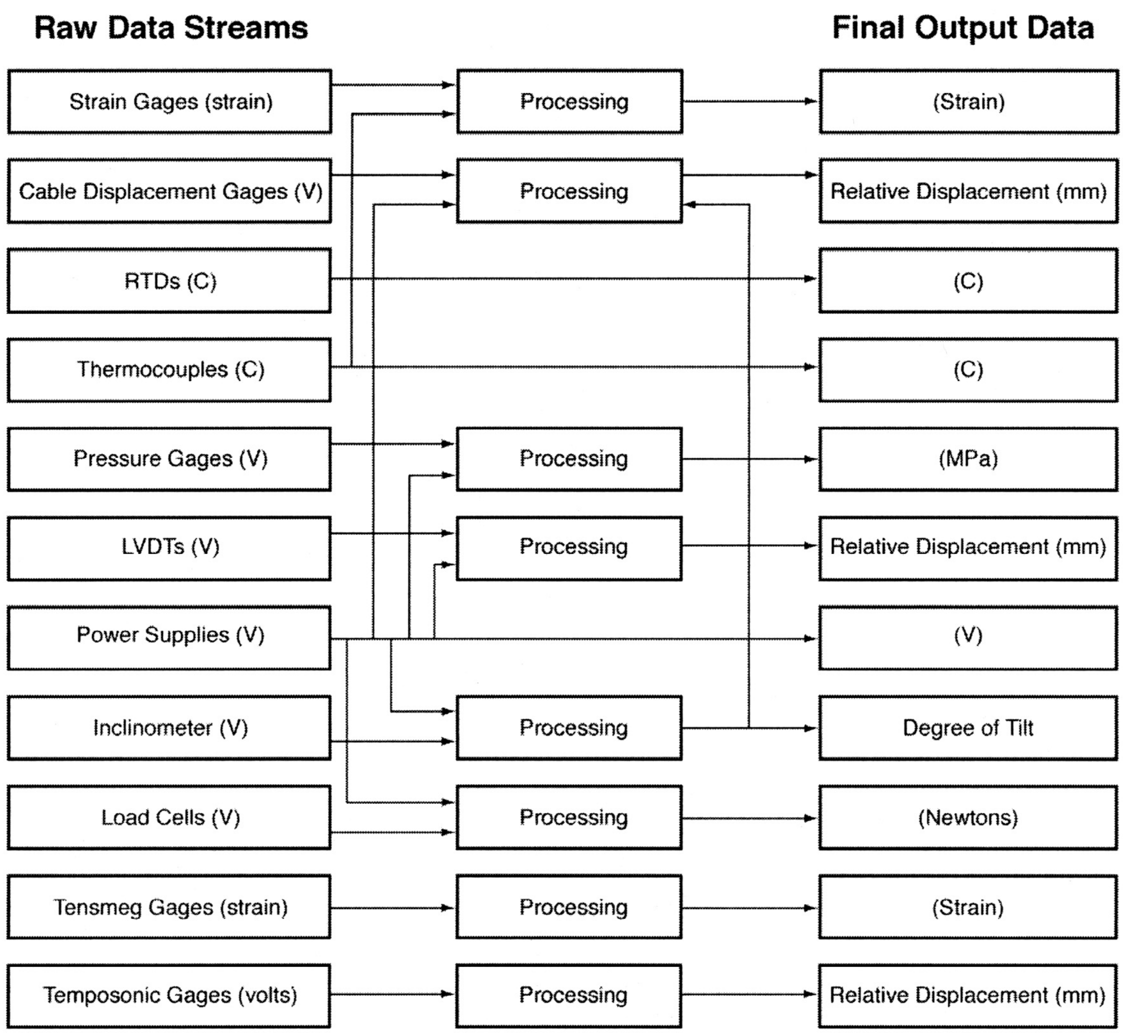

Figure 4.4 Basic PCCV Data Flow Diagram