A Tcl/Tk Data Acquisition System for ^{11}C Nicotine Time Course Studies

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***Abstract*--It is widely believed that the addictive effects of cigarette smoking derive largely from the rapid absorption of nicotine from the pulmonary system. The immediate effects of an inhaled bolus of nicotine on brain function are thought to provide potent reinforcement for smoking behavior and maintain dependence on tobacco. A greater understanding of the initial time course of nicotine in arterial blood may be useful in achieving a greater understanding of smoking behavior.**

The Duke University Medical Center is developing a system to non-invasively measure the initial time course of ^{11}C nicotine. This apparatus observes the inhalation of ^{11}C nicotine inserted into a cigarette and the arrival of ^{11}C nicotine at four locations in the body: the throat, lungs, brain, and wrist. The counting rates in the array of detectors placed around each subject will determine the arrival times of ^{11}C nicotine with 0.5s precision.

This paper will describe the data acquisition system developed for this detector array. The system is based on a minimal Tcl extension that supports access to arbitrary VME bus addresses. Using this extension a pure Tcl/Tk data acquisition system has been written to acquire, record, and display in real-time the data from the detector array. Tcl/Tk technologies used include Tcl loadable extension modules, Tk and BLT based graphical user interfaces and snit encapuslated hardware objects. The ability of Tcl/Tk to serve as a vehicle for delivering rapid prototypical solutions and release candidates was key to the development of this system

I. Motivation and History

The Duke University Medical Center PET (Positron Emission Tomography) Facility and the Duke Center for Nicotine and Smoking Cessation Research are collaborating to investigate the effects of nicotine kinetics on smoking behavior. Previous PET studies [1] to observe the effect of nicotine on neural systems produced interesting and useful results. Limitations in the experiment method (the need to quantify nicotine in arterial blood meant continuous sampling of a subject's arterial blood which is invasive and unpleasant) reduced repeatability and limited the timing resolution to intervals of 5 seconds due to the logistics of phlebotomy techniques. Due to the rapid absorption of nicotine, increased time resolution of the initial time course of nicotine in arterial blood is desired.

Recent advances in radio-labeling techniques now allow nicotine to be labeled with ^{11}C. Radio-labeled nicotine can be observed non-invasively with timing intervals limited only by detector hardware. Thus, a new study to non-invasively observe and track the initial time-course of ^{11}C nicotine is in progress. The results of this project will lead to a greater understanding of smoking behavior and provide timing windows for future imaging studies using ^{11}C nicotine.

II. Detectors

^{11}C decays mainly via positron emission. Positrons, or anti-electrons, are short lived as they are annihilated when they encounter electrons. Electrons are plentiful which means the average range of a positron in matter is ~1 mm. When a positron and electron annihilate, a pair of photons are emitted in opposite directions with a total energy of 1.022-MeV (0.511-MeV per photon). Thus, by detecting both annihilation

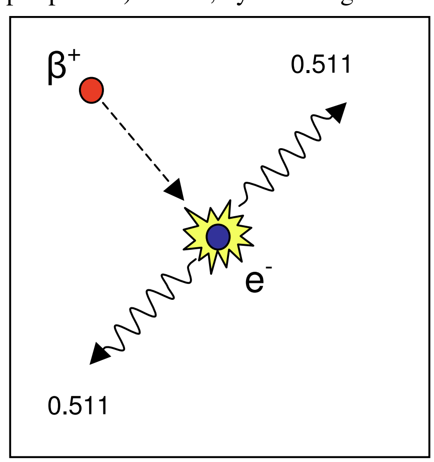

Figure 0 Schematic representation of mutual-annihilation reaction between a positron (β+) and an ordinary electron (e-). A pair of 0.511-MeV annihilation photons is emitted at 180 degrees to each other. [2]

photons coincidentally, one can infer the presence of ^{11}C along the line of response of two detectors.

3” x 3” sodium iodide (NaI) cylindrical detectors were selected to measure these annihilation photons. These detectors were chosen to maximize the geometric efficiency,

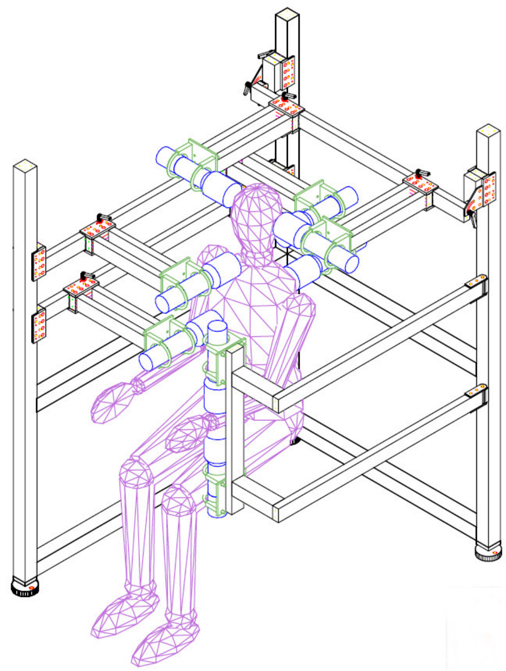

Figure 1 Position of the detectors around the subject's body.

Figure 2 Detector Frame Apparatus

provide sufficient stopping power, and minimize cost compared to other candidate scintillators. Pairs of detectors are placed around four regions of interest as shown in Figure 2. The pair around the throat tracks the ^{11}C nicotine taken into the pulmonary system. The pair monitoring the lungs determines when the nicotine arrives in the lungs and provides some information about how long it stays. The pair observing the brain measures the time it takes for the ^{11}C nicotine to reach the brain. The final pair observes the wrist to provide a secondary measurement of the ^{11}C nicotine in the arterial blood with lower scatter, attenuation, and background. Conservative calculations estimate count rates ranging from 200-1500 coincident events per second at the four regions of interest.

The cigarette monitor is a novel device to accurately determine time-zero of the initial time course of ^{11}C nicotine. The detector itself is made of heat resistant Bicron BC-448M plastic scintillator. Cigarettes are low-density; the positrons are measured directly. The scintillator is coupled to a Hamamatsu H6780 photomultiplier module by an acrylic light guide (shown in Figure 4). The entire cigarette monitor is encased in a smoke containment device to contain the radioactive smoke and to allow control of the input “puff”.

Figure 3 The cigarette monitor

Figure 5 shows a block diagram of the data acquisition electronics. Signals from the detectors are processed using a combination of VME and NIM modules. Amplification prior to processing for the NaI detectors is accomplished with a Bicron PA-14 plug-on pre-amplifier/voltage divider. The event pulse is discriminated by a Phillips Scientific Model 715 constant fraction discriminator. A suitable threshold is set to eliminate scattered photons (< 0.511-MeV) and electronic noise. 0.511-MeV photons produce pulses with a pulse height of ~350-mV depending on the bias selected for the photomultiplier tubes (typically 900 V). The discriminator, when triggered, outputs 6-ns NIM pulses. One output is sent to a Phillips Scientific Model 726 level translator to convert the signal from NIM to ECL levels. The other signal is sent to a CAEN V976 4-channel logic module. ‘And’ logic is performed between appropriate channels with the coincidence output sent to the Model 726 for level conversion. Outputs of the Model 726 are sent to a CAEN V830 32-channel latching scalar. There are 12 channels of data: the eight channels that measure the single rates from each detector and the four channels of coincident output.

The cigarette monitor detector measures positrons directly. The plastic scintillator and acrylic light guide are wrapped in aluminum to provide internal reflection of the scintillation light and then sealed with light-tight plastic to prevent light leakage. This output signal from the H6750 photomultiplier module is amplified by an Ortec Model 485 amplifier before being discriminated by an Ortec Model 406A Single Channel Analyzer. The output of the SCA is sent to the Model 726 level translator for level conversion and then to the V830 scalar module. The cigarette monitor occupies one channel in the scalar module.

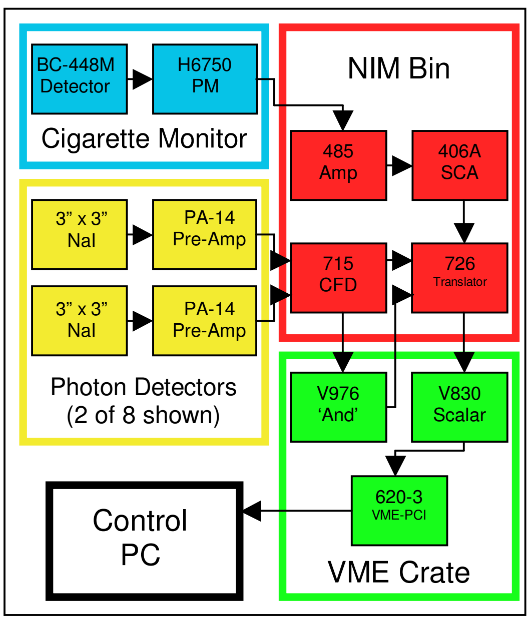

Figure 4 Electronics block diagram

III. SOFTWARE

The data acquisition software is composed of several components. A system block diagram is shown in Figure 6. The figure shows that the software loosely follows the model-view-controller pattern. The data acquisition stack at the bottom of the figure is responsible for maintaining an up-to-date description of the experiment (the model). The display block maintains both a tabular and a graphical view of this model, while the run control block allows each data taking run to be described, and initiated.

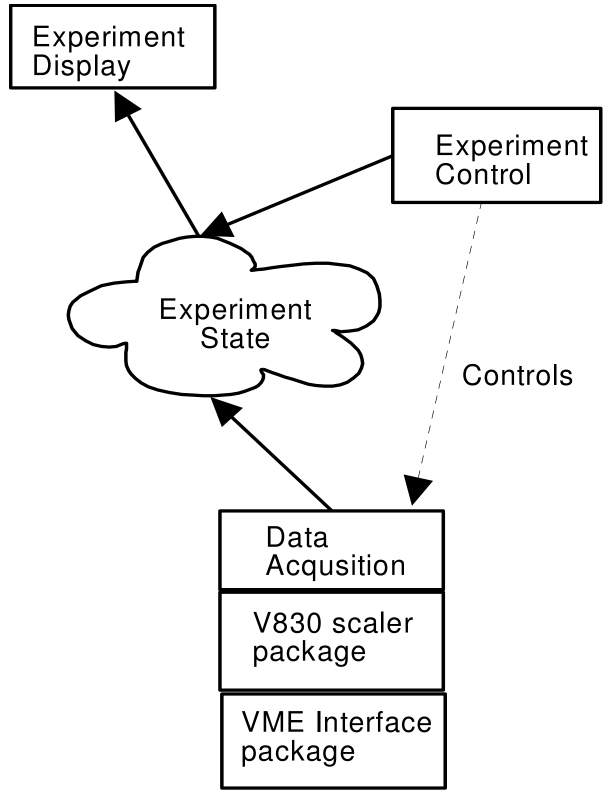

Figure 5 Software Block Diagram.

Since the timing requirements of the data acquisition blocks are relatively modest, an early decision was made to write as much of the software in Tcl/Tk as possible. This decision allowed a fast turn-around incremental development methodology to be used. Prototypes, or candidate releases were electronically delivered to the researchers who made comments, and corrections. These comments and corrections could be quickly and efficiently incorporated into later release candidates.

We describe in turn the structure of the Data acquisition stack, the experiment control and experiment display components.

A. The Data Acquisition Stack.

The Data Acquisition stack requires access to the data acquisition hardware. As far as the software is concerned, this hardware consists of VME[3] resident scaler channels (specifically a CAEN V830[4] 32 channel scaler module). The VME bus was interfaced to the data taking computer through an SBS/Bit3 PCI to VME bus bridge[5]. The Linux drivers for this bus bridge support the mapping of segments of

VME address space to segments of process virtual address space through via the mmap(2) system call.

In keeping with our “as much Tcl/Tk” as possible system philosophy, a minimal interface to the VME device driver’s mmap(2) support was written as a loadable package named *Vme*. This package, originally written to support the NSCL Data Acquisition system[6], consist of a bit more that 500 lines of heavily commented C++ code. The Vme package supports the creation of named Vme address segments. Each address segment becomes a Tcl command which can be used to peek and poke bytes, words or long words from and to the VME bus.

The Vme package is summarized in Table 1. below

Command Syntax	**Purpose**
vme create *name* –device *space base size*	Creates a new address segment *name*. *space* selects the address space (A16, A24 or A32), and *base* and *size* specify the address range represented by this segement.
vme delete *name*	Destroys an address space created via vme create. The command is destroyed and all resources associated with the segment released.
vme list	Lists the set of Vme segments that have been created.
name get –l|-w|-b *offset*	Get a longword, word or byte from *offset* into the vme address segment.
name set –l|-w|-b *offset value*	Write *value* as a longword, word or byte to *offset* to the VME segment.

Table 1 Summary of the Vme package.

The V830 scaler is supported through a Tcl loadable package written in Snit[7], and layered on top of Vme. This package encapsulates a Vme address space mapped to a scaler module and provides methods that allow the scaler to be initialized, controlled, read and cleared, while hiding the details of the device register map and register bits fields from the users of the package. Implementing this driver as a snit type allows the system to be easily expanded should more detectors be added to the system at a later date

The code below is a fragment from the data acquisition software that initializes the scaler module:

```
proc setupScaler {} {
    global scalerBase
    global scalerModule
    global ScalerDeltaTime

    #  Create the scaler module:

    if {$scalerModule == "" } {
       set scalerModule [caenv830 v830 \
                  -base $scalerBase]
    }

   # Initialize the module.

    set dt [DwellTime $ScalerDeltaTime]
    $scalerModule setDwellTime $dt
    $scalerModule reset
    $scalerModule setEnables -1
    $scalerModule format32Bits
    $scalerModule enableHeader
    $scalerModule periodicTrigger
    $scalerModule clear

}
```

The scaler hardware allows counter values to be latched for later readout with a timing resolution 400ns. The experiment only requires a timing resolution of 0.5 seconds. The main data taking loop therefore consists simply of a rescheduled `after` proc that tests for and, if necessary, reads latched data from the scalers. Whenever the scaler has data, all latched data are read out and assigned a times that are consistent with the dwell time selected for the run. The V830 is capable of buffering several latch events for later readout. This allows the software to maintain precise timing even in the presence of potentially long scheduling latencies.

The data acquisition loop does not maintain the user interface. Instead, it simply stores incremental and total scaler counts and triggers the GUI (view component) to update itself.

B. The Experiment Display

The experiment display provides live feedback to the researcher about the rates and total counts in each detector. In addition, detectors can be paired, and ratios of total counts and rates computed between these pairs. A BLT[7] strip chart widget at the bottom of the display allows experimenter to view the time evolution of counts in any specific set of detectors.

The display layout and channels to be plotted are determined prior to a set of runs by the experimenter, via the creation of a simple configuration file which is actually a Tcl script. The script allows the user to associate a name with each scaler channel and then to layout one or more pages of tabular scaler information as well as to select channels for inclusion in the strip chart.

Figure 7 shows this display just prior to starting an experimental run.

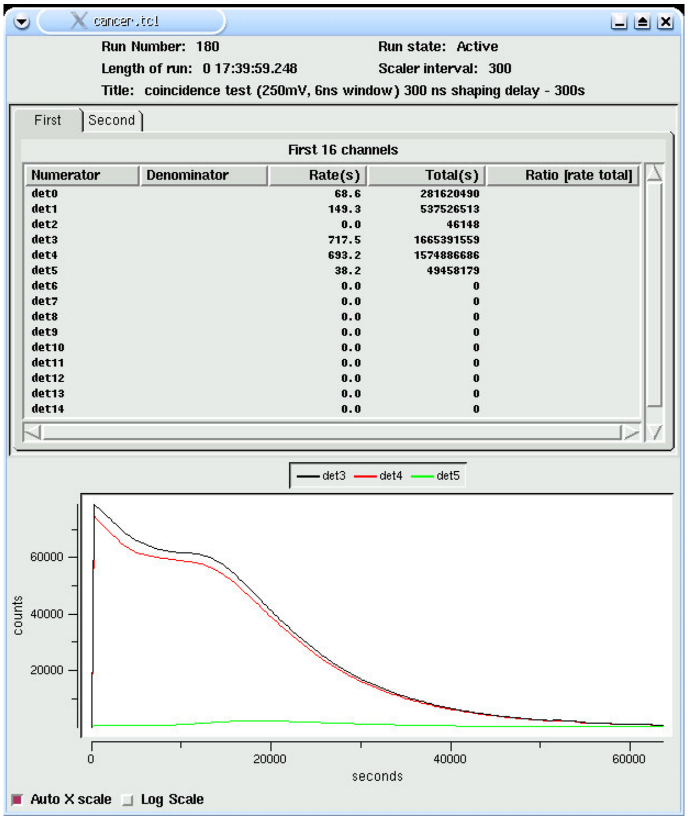

Figure 6 The experiment monitor display.

The top portion of the window displays general information such as the run number, the run title, the run state, duration, and dwell time. Scaler tables are organized as pages in a BLT tabbed notebook widget located in the middle section of the GUI. Each line of the table can contain a single scaler or a numerator/denominator pair. Rates are computed by the display from the scaler increments maintained by the data acquisition component, as are ratios, if required. The display software also updates data sets that are used to maintain the strip chart located in the bottom section of the window.

The strip chart can by dynamically switched between linear and log Y axis scales. The X axis can either show the most recent set of points in high resolution or be compressed to show the entire run.

The GUI also maintains a log file of the increments for each run. The log is written in CSV format. CSV format allows log data files to be easily imported into data analysis packages such as Origin or Excel for offline analysis. The Tcllib csv package was used to produce these files.

C. The Experiment Control Panel

The Experiment control panel is a simple Tk window. The panel is shown in Figure 8 below:

Figure 7 The experiment control panel

The control panel allows the parameters of each run to be defined. These include a run title describing the run, a run number which auto increments for each run, and the desired scaler dwell time which determines the time between scaler latch events. The Begin button when clicked, starts data taking and turns into an End button, allowing the user to start and stop runs once the run parameters have been set.

IV. Initial Results and Conclusions

This apparatus has been in the testing and development stage for several months. The system is performing as designed for the initial tests. The cigarette monitor has been assembled and positrons have been successfully detected . A sensitivity test of the cigarette monitor is shown in Figure 9. The photon detectors and acquisition hardware also work. They have been tested extensively. Coincidence performance still needs to be characterized. Computer performance was initially a concern. However, tests indicate that the system can run with 0.1 s timing intervals without any negative effect if desired.

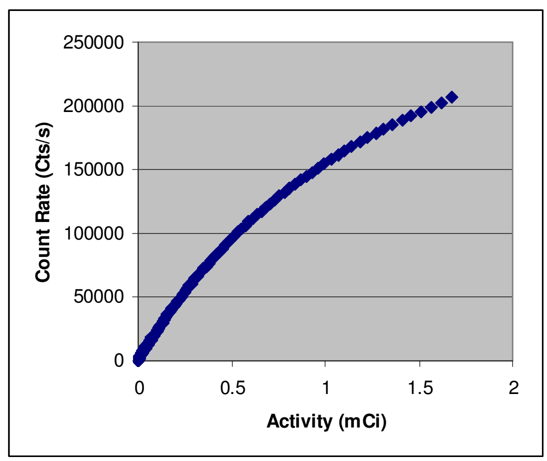

Figure 8 Count rate vs. activity measurement for the cigarette monitor using 13NH3 contained in a plastic syringe. Nonlinearity of the plot shows the effects of hardware dead-times at high count rates.

The ^{11}C nicotine data acquisition system described in this paper should allow improved accuracy in studies of the time evolution of the concentration of nicotine in the bodies of smokers. The entire data acquisition system was written in less than 1000 lines of source code split between a minimal, pre-existing C++ Tcl loadable package to support access to the instrumentation, and Tcl, Tk, Snit and BLT scripts.

Implementing the majority of the functionality in a high level scripting language, and using existing library packages wherever possible allowed the entire system to be written in less than 1 week of programmer time. This time included several rapid prototyping and iterative development steps.

At this time, the system is in final testing. The experimental protocol requires three repeatable sessions for ten subjects. Future work will investigate the initial time-course of ^{11}C nicotine using alternative nicotine delivery systems. Hopefully measurements on human subjects will begin in late October 2005.

V. References

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