DOE/FIU SCIENCE & TECHNOLOGY WORKFORCE DEVELOPMENT PROGRAM

STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

For June 02, 2008 to August 08, 2008

Modification and Instrumentation of a Siemens *In Vitro* X-ray CT Scanner for Bioenergy Sample Characterization

Principal Investigators:

Danny E. Brenner (DOE Fellow Student)
Florida International University

Dr. Justin S. Baba (Mentor)
Oak Ridge National Laboratory

Florida International University Collaborator:

Leonel E. Lagos, Ph.D., PMP®

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ABSTRACT

Currently, biofuel development is an important research area given the increase in cost of petroleum based fuels. There are a variety of sources for biofuel production. Non-corn based fuels are of significant interest due to their lessened impact on the global agricultural market, renewable crop status and environmentally friendly performance. Under this premise, information on the morphology of varying sorts of wood cores (alfalfa, aspen and switch grass) is sought. Presently, accumulation of information on the morphology of the aforementioned wood structures is considered beneficial. This shall facilitate future chemical processing of these wood structured materials in order to produce non-corn based biofuels. The primary method of investigation currently proposed to obtain material micro structural information is through the use of Computed Tomography (CT) imaging instrumentation. An in-house CT imaging machine at the Oak Ridge National Laboratory (ORNL) was not operational as it required installation of its x-ray source. Electrical troubleshooting of the device was necessary as well. The arrival of the system's circuit board permitted repairs to begin on the system. The initial stages of troubleshooting began and the x-ray source was installed. Operator interface through the control program was not achievable. Time constraints limited troubleshooting of the system. Guidelines for further troubleshooting are presented in this report. The instrumentation also requires an essential hardware component, the x-ray detector. Possible purchasing options for x-ray detectors are provided. The mention of needed calibration test and other necessities to make the system fully operable are also indicated. Once these milestones are attained, further system modification, if necessary, will be implemented to have the system operate at the desired 0.1 micrometer imaging capability. Once this has been achieved, CT scanning can commence on plant matter feedstock for bioenergy characterization.

EXECUTIVE SUMMARY

This research work has been supported by the DOE/FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2008, an FIU student spent 10 weeks interning at ORNL's Measurement Science and Systems Engineering Division under the supervision and guidance of Dr. Justin Baba. This internship was organized and directed by the Higher Education Research Experience (HERE) and the Oak Ridge Institute for Science and Education (ORISE).

The project was initiated from June 2 through August 10, 2008, with the objective of modifying a Computed Axial Tomography (CAT) Scanner. The objective was to obtain microscopic morphological volumetric data of perennial plant feedstocks for biofuel production. There were two scanners present, the *in vitro* microCAT and the microCATII. It was found to be necessary to modify one of the units in order to try and attain 0.1 micrometer (microns) system resolution. The microCATII unit functioned properly. The *in vitro* unit was inoperable, lacking a dedicated computer system, missing the main circuit board, having an uninstalled x-ray source (Kevex PXS-10-16W) and having no x-ray detector. Initially, modification of the microCATII unit was the expected course of action. The uninstalled Kevex x-ray source would be installed within the microCATII. A new mounting design along with a structural and vibrational analysis of the microCATII was expected. Discussions with the system designer alluded to the fact that the *in vitro* unit had a greater resolution of 8 microns compared to the 15 microns of the microCATII. This led to the decision of the modification of the *in vitro* unit. Circuit analysis was conducted on the system and preliminary electrical diagrams were developed. System circuit boards with an 8 week lag time were obtained from Siemens. This finally permitted repairs on the instrument to commence. Electrical connections were completed on the *in vitro* unit. The microCATII's computer system served as a surrogate to interface with the *in vitro* unit. This made it possible to bring the unit online. The Kevex x-ray source was also installed. During the testing phase, computer control could not be achieved due to software controls indicating the interlock circuit was not closed. Currently, the system is assembled lacking a dedicated x-ray detector. It was expected that the microCATII's x-ray detector would be used for testing. It is still necessary to carry out system calibration in order to quantify the *in vitro's* resolution. The desired resolution of 0.1 micrometers (microns) is questionable using the microCATII x-ray detector. The system design places the resolution limit at about 8 microns. It would be necessary to purchase a higher resolution x-detector and possibly a different x-ray source. The system is in need of a dedicated x-ray detector. The cost of a dedicated x-ray detector would be between $60,000 and $150,000. One permitting greater resolution would be in the cost range of $100,000 and $150,000. During the summer internship, many new skills were acquired by the mechanical engineering (ME) intern, most notably an exposure to the field of x-ray optics, the fundamentals of basic radiation theory/technology and a fair degree of hands-on electronics troubleshooting. All of these traits

are evidently not part of an Accreditation Board of Engineering and Technology (ABET) ME curriculum. This demonstrates the versatility that is achieved through summer internship programs such as this.

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1. INTRODUCTION

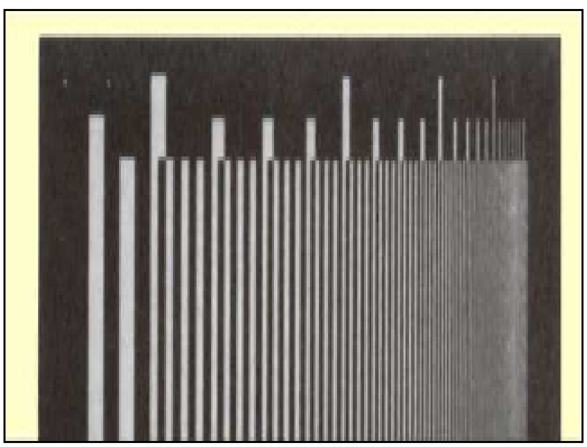
The U.S. fuel economy is in need of an alternative fuel source. Biofuels are an attractive option for fuel development. Biofuel processing and production form an important area of research to meet this need. An abundant and renewable feedstock for fuel production is necessary. Amassing data on a feasible and renewable feedstock can curb fuel consumption. To this end, herbaceous perennial species of plant matter are currently being analyzed [1]. Processing of any biofuel feedstock will require knowledge of its physicochemical properties. An understanding of the yield from the wood chemistry based on the lignin and cellulose content of the feedstock will assist in producing bioethanol. We seek to obtain the phenotype of wood core samples to assist with biofuel development. Acquiring data on the microstructure of the plant cell wall morphology will reveal physical properties of the plant matter. This can assist with wood chemistry reactions providing insight for processing feedstock. The information sought is of cellular plant matter parameters such as cell volume, density, cell wall thickness, width, length and void spacing. When analyzed, information revealed can include annular growth patterns to quantify age, content of cellulose and lignin based on mass, density along with wall thickness, fiber length and diameter. This information can lend itself to further the development of bioethanol. The method of data recollection will consist of Computed Axial Tomography (CAT).

1.1. Computed Tomography Background

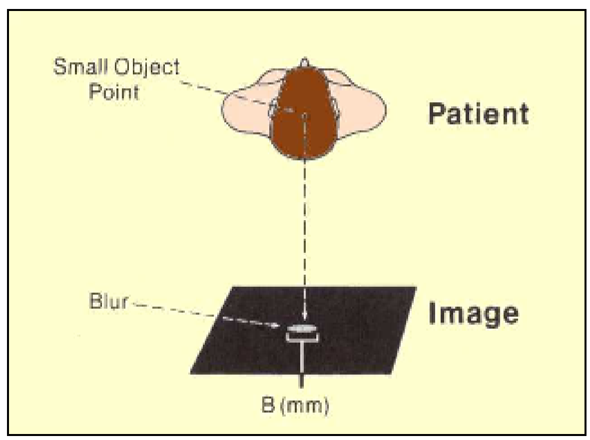
Computed Tomography (CT) is an imaging technique that employs high energy electromagnetic radiation as a means of obtaining planar images. Each planar image captures information contained within a slice plane. The sample of interest is irradiated by x-rays and the attenuation of these rays are recorded by a detector. Axial rotation of the sample or rotation of the x-ray source/detector about an axis of the sample is necessary. Rotation takes place in small angular increments until a full revolution has been completed. During each angular increment, planar images are captured and recorded. Sufficient planar images permit a volumetric image with internal features to be formed.

CT systems have the following essential components: a radiation source, a radiation detector, a mechanical assembly, an operator interface, a computer system, a graphical display system, data storage medium and a test object [2]. The primary hardware components that affect system performance are the radiation source, the radiation detector and the mechanical assembly. The mechanical assembly dictates the type of CT scan geometry along with the distances amongst the source, detector and test object. Radiation sources used in CT are of three types: x-ray tube, linear accelerator or isotope. The radiation source considered herein will be a sealed x-ray tube. Common radiation detectors for CT systems include ionization detectors and scintillator detectors. The detector for this analysis is a scintillator type consisting of a phosphor screen with a fiber optic taper coupled to a Charged Couple Device (CCD).

Some concepts for analysis and design of modern computed tomography systems fall under optics and x-ray technology. Necessary concepts in imaging systems are spatial resolution and blur. Resolution is a spatial characteristic. Resolution describes the ability of an imaging system to distinguish or separate objects that are close together [6]. This parameter indicates the minimum separation distance of two objects. An imaging system trying to resolve at a level of detail below its resolution will cause two objects to overlap. Quantification of a system's resolution is a based on a linear dimension ex micrometers (microns) or line pairs per millimeter lp/mm, as in Figure 1. Blur describes when a small point on an imaged object manifests itself with additional image information that does not conform to its small possible dimension. It is almost as if the small point on the object cast a shadow on the image plane. This additional increment from its original spatial size leads to the creation of additional image information which is not representative of the initial object. Given that, a point element on the object of interest spreads itself out and creates a certain degree of line space or surface space which results in degradation of the original image. Within a perfect imaging system, each small point within an object is represented by a small, well defined point within the image [6]. Blur is a clear indicator of the actual sharpness of an image. The amount of blur can be expressed as the dimension of the blurred image of a very small point object (mm), refer to Figure 2.



[6]Figure 1. Spatial resolution increases as line pairs increase.



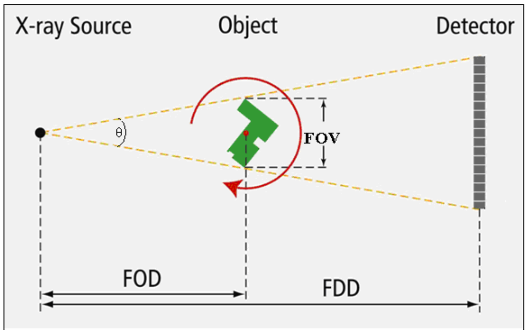
[6]Figure 2. Blur illustration

Geometrical optics plays a fundamental role in obtaining a system with a desired imaging capacity. There are 3 primary components in an x-ray imaging system geometry: x-ray source, the detector and the object imaged. The placement of these three components defines the system geometry. The distances between these objects affects system performance and relates to system parameters of interest. The focal spot-object-distance (FOD), the focal spot-detector-distance

(FDD) and the difference between FDD and FOD is equal to the object-detector-distance. Notably, the system magnification, M, is determined by a ratio of the FDD to FOD. The magnification of a system affects the field of view (FOV) and the resolution. The FOV relates to the portion of the object imaged, be it the whole object or just a segment of it. Increased magnification reduces the field of view FOV of an object while permitting a greater amount of detail to be resolved. Decreased magnification increases the field of view of an object but reduces the image detail. Magnification is limited by the spatial resolution of the system, implying that over magnification will blur the image or limit the resolution to the maximum sharpness permitted by the system. Also, another useful parameter is the scale (s) of the system, which is the ratio of the difference of the FFD and FOD to the FDD. It represents the position of the object with respect to the detector to the x-ray source focal spot. It plays a role of introducing blur into the focal spot and at the detector [6]. Finally, the field of view is indicated by the geometry of the system along with the angle of the x-ray beam, θ. It establishes the portion of the object that is irradiated by the x-ray beam.

Important parameters regarding the x-ray source are the focal spot size and the energy spectrum of the source. The energy spectrum is the amount of energy imparted to each electron that is accelerated in order to produce the x-ray photons. This energy spectrum is a distribution; therefore, not all electrons have the same amount. During x-ray production, the radiation can be filtered in order to ensure a less polychromatic energy spectrum. The energy spectrum of the x-rays is of extreme importance given that materials have varying penetration characteristics. It is necessary to tailor the energy spectrum range to the material being inspected to safeguard against total x-ray attenuation. The focal spot size is the portion of the x-ray source where the x-ray photons are produced. The size of the focal spot is fundamental. It is a gauge of the x-ray imaging resolution. The smaller the x-ray spot size, the greater the detail that can be resolved.

The x-ray detector's main function is to convert x-ray photons to visible light photons and reproduce the image. The scintillator material is very important. Different materials are better suited to absorb x-ray photons and emit photons in certain energy spectrums than other. Once converted to photons, the image information can be captured and transferred for display. There is a photoactive region which captures the photons. In a CCD, this region is composed of an array of photosensitive elements called pixels. The pixel size indicates the dimensions of the region on which the photons are incident. Once captured, the image information can be digitized and then displayed.



[8]Figure 3. X-ray CT component setup

$$(1)\ M = \frac{FDD}{FOD}$$

$$(2)\ s = \frac{FDD - FOD}{FDD}$$

$$(3)\ FOV = 2 \times FOD \times \tan(\frac{\theta}{2})$$

1.2. Initial status

CT is a non-destructive testing (NDT) method based on radiographic imaging which provides planar and volumetric detail in three dimensions. CT has a strong niche in the manufacturing and medical industry for product quality control assurance and patient diagnostics. Computed Axial Tomography (CAT) scanning provides over 70% of x-ray exposure in the U.S. [2]. The level of detail a medical CAT scan can resolve lies about 0.1 mm [2]. In order to observe smaller features, microCT technology is necessary. Oak Ridge National Laboratory (ORNL) developed a microCT Small Animal Imaging (SAI) system for rodents under the microCAT series [3,4]. The microCATII high resolution system permits acquisition of 50 µm CAT scans. The research group succeeded in the entrepreneurial development of the microCT system under Imtek, Inc. The company was subsequently bought by Siemens. Siemens further developed a microCT system prototype, the *in vitro* microCAT, with better resolution than the microCATII. This prototype never reached the consumer market. This unit was acquired by ORNL but lacks an x-ray detector and a system control circuit board and has an uninstalled x-ray source.

Previous work began with the microCT systems, seeking to phenotype a wood species for bioenergy potential. MicroCT scans of a wood core sample were obtained: microCATII low resolution (50 µm) scan at ORNL and an *in vitro* microCAT very high resolution (8 µm) scan at the Siemens preclinical product facility in Knoxville, Tennessee [5]. This revealed that annular ring recognition is observed at 108 µm system resolution. The 8 µm resolution data permitted viewing of wood cells and fiber. Greater resolution is necessary to quantify cellular parameters: length, width and wall thickness [5]. It is necessary to modify the microCT systems in hope of achieving a greater system resolution. A 0.1 µm system resolution can characterize the morphology, revealing the phenotype of future wood species for biomass to bioethanol.

Initially, the microCATII was to undergo modification. The micoCATII system functioned properly with its attached x-ray source, Source-Ray SB-80-500. The Source Ray was to be removed and the Kevex PXS10-16W installed in its place. The Kevex unit was an optional x-ray source compatible with the system. Given the change in dimensions of the x-ray source, it would be necessary to swap out the current mounting bracket. Agile Engineering, Inc. previously designed the mounting bracket for the Kevex x-ray source. They were contacted and a quote was requested. Agile Engineering quoted the cost of the Kevex mounting assembly at $2,655.

Figure 4. Source Ray SB-80-500 on microCATII

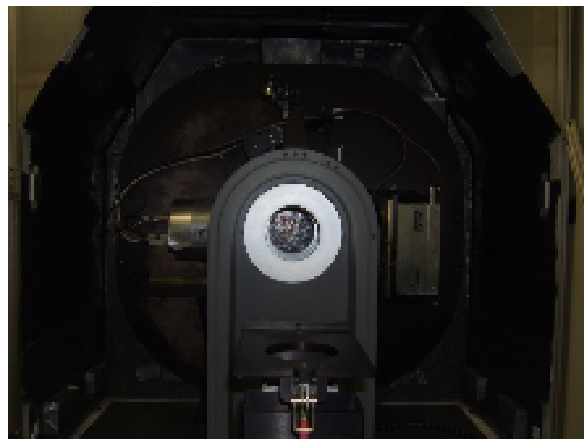


Figure 5. MicroCATII, lead shielding removed

X-ray detector on left, source on right.

Figure 6. Kevex PXS10-16W

on lab countertop

Table 1. X-ray Sources Basic Specs

	Source Ray SB-80-500	Kevex PXS10-16W
focal spot size (µm)	50	6 - 21
KVp Range	35 - 80	45 - 130

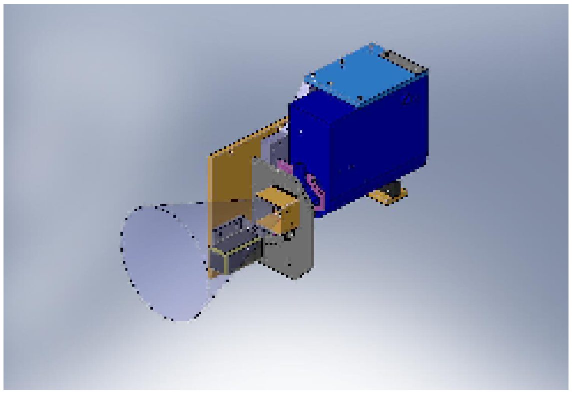


Figure 7. MicroCATII Kevex Mounting Assembly w/ existing X-ray Shutter.

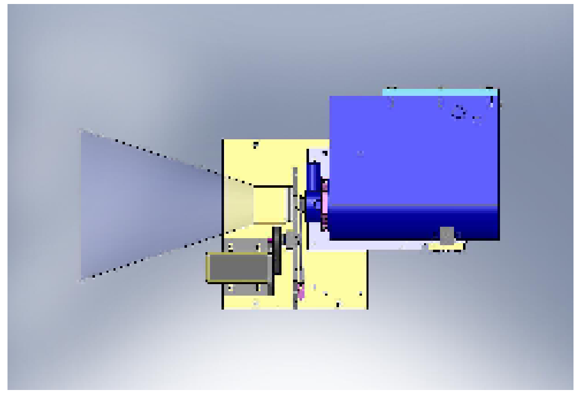


Figure 8. MicroCATII Kevex Mounting Assembly w/ Existing X-Ray Shutter (Front View).

Discussion of system modification led to the following points: (1) large lead time (1 month) for bracket manufacturing, (2) the system geometry and current x-ray detector on the microCATII made it difficult to achieve greater than 50 micron resolution, (3) microCATII is a fully functional system, and (4) the *in vitro* unit is inoperable. It was decided that the *in vitro* microCAT would be repaired and used for wood core sampling.

2. MATERIALS AND METHODS

The *in vitro* microCAT unit was inoperable when delivered to ORNL. The x-ray source of the unit, Kevex PXS10-16W required installation. Further issues with the *in vitro* unit were the system lacked a dedicated x-ray detector, it was missing the main circuit board, and it did not have a dedicated computer system and required the correct Peripheral Component Interconnect PCI cards. The system was a prototype, some of the documentation was not privy or it became lengthy and cumbersome to obtain. Likewise electronic hardware acquisition was an issue. The microCATII system served as a footprint to reverse engineer the *in vitro* unit. Both systems share the same electronic platform. The systems have very different mechanical assemblies. The microCATII unit is a 3rd generation CAT scanner. The x-ray source and detector are mounted on a rotating background called a gantry. The gantry rotates about the static subject/sample. The x-ray detector and subject/sample are in a fixed position. The x-ray detector can be manually moved. This proves to be cumbersome since the lead shielding must be removed. The microCATII is a fixed source/isocenter CAT scanner with manual low variable magnification. The *in vitro* microCAT has a mechanical assembly. The x-ray detector and source are at a fixed distance. The sample/subject rotates about its own axis of rotation. The sample holder translates between the source and detector giving it high variable magnification. The detector can translate horizontally increasing its pixel range. The sampler holder can move vertically providing a variable field of view. The *in vitro* microCAT is a fixed detector/source CAT scanner with high automatic variable magnification and variable axial/transaxial field of view.

2.1 System GUI software

The Graphical User Interface GUI is a Lab Windows CVI application. The programming language of the implementation is C. The *in vitro* GUI is a modified version of the microCATII GUI.

2.2 System Hardware

The repair of the *in vitro* unit began with dismantling the system. Lead shielding was removed and system sub components were exposed. The subcomponents were documented based on make and model number. A subcomponent documentation search was carried out in order to identify subcomponents readily and facilitate further troubleshooting of the instrument. A list was assembled of system components.

The *in vitro* unit lacked a dedicated computer system. The microCATII computer system served as a substitute computer system for testing. Computer Peripheral Component Interface PCI cards are necessary to interface with the *in vitro* unit. The microCATII PC already possessed these PCI cards. These PCI cards were purchased for a future computer system for the *in vitro* unit.

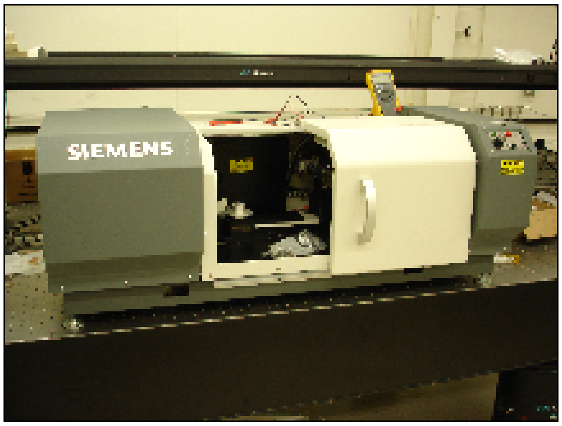


Figure 9. in vitro microCAT

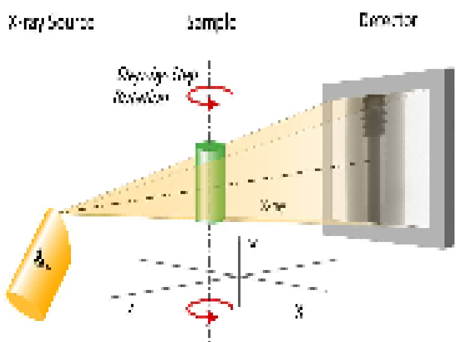


Figure 10. in vitro scanner geometry

sample rotates axially

Figure 11. microCATII

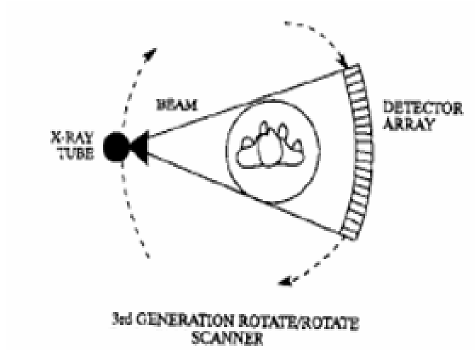


Figure 12. microCATII scanner geometry

source/detector rotates around static sample

Table 2. *In vitro* and microCATII General System Specs

	microCATII	*In vitro* microCAT
FDD (mm)	594	~421
FOD (mm)	405	~28-367
Magnification	1.46	~15-1.14
Energy spectrum (KVp)	35-80	45-130
Focal spot Size (µm)	50	6-21
X-ray Detector (type/scintillator)	CCD/phosphor screen	N/A
Pixel size (µm)	15x15	N/A

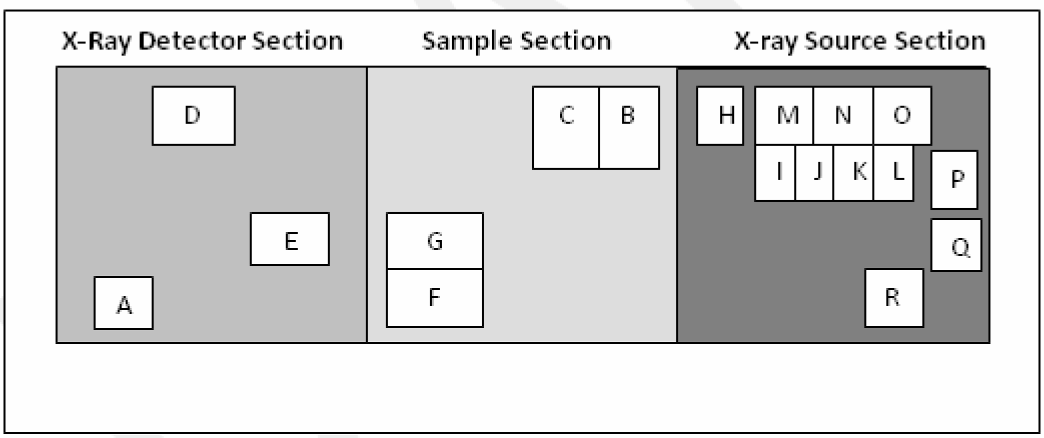


Figure 13. In vitro component layout.

(lead shielding enclosure removed), top view

Table 3. *In vitro* Component List and Layout Diagram

Component	Company	Model #	Description	Note
A	Animatics	PS42V6A	Power Regulator	
B	Animatics	SM2315D	Smartmotor	
C	Ultra motion	1-A. 4-NM23-2-1NO	shutter mechanism	The Bug (legacy part)
D	Dalsa	24-00001-01	Camera power source	
E	Newmark Systems	NLS4-2.5-16	linear translation stage	
F	Newmark Systems	RM-3-M17-H	rotary translation stage	
G	Newmark Systems	Assumed to be same as E	linear translation stage	Coupled to component H
H	Newmark Systems	NLS4-12-25	linear translation stage	Coupled to component G
I	Parker Hann corp	E-AC	Compumotor	Axis 4 CCD (camera)
J	Parker Hann corp	E-AC	Compumotor	Axis 3 Height
K	Parker Hann corp	E-AC	Compumotor	Axis 2 Magnification
L	Parker Hann corp	E-AC	Compumotor	Axis 1 Sample turntable
M	N/A	N/A	Power Supply	
N	Acopian	U2Y241000	Unregulated power	
O	Acopian	A5TM600	Regulated Power Supply	
P	Magnecraft & Struthers-Dunn	W25OCPX-7	Interlock circuit relay	Interlock connections
Q	N/A	N/A	Lights (interlock, x-ray)	Display panel
R	Keyence Corporation	FS-V21R	Dual Digital Display	Known as FS-V20 Series
S*	Cherry Electrical Products	E2250k; Quantity 2	Side switches of system	Covered by enclosure
T*	Cherry Electrical Products	E6940A0	switch on door	Location: Loading door
U*	Scientific Technologies Inc SRI	T2007	Latch switch top of door	Location: Loading door

*Component not shown in layout diagram

Table 4. PCI Cards Required for Computer System

Board	Manufacturer	Model	Description	PCI slot size
1	Coreco (formerly Imaging Technologies incorporated)	PC-DIG R	PCI frame grabber	32
2	National Instruments	PCI-6024E*	200 kS/s, 12-Bit, 16-Analog-Input Multifunction DAQ	32
3	National Instruments	PCI-7344	4-Axis Stepper/Servo Controller for PCI	64

3. RESULTS AND ANALYSIS

Circuit analysis, continuity testing, along with connectivity and wiring traces were conducted while the system's main circuit boards were acquired from Siemens. Repair of the Siemens *in vitro* microCAT began with circuit analysis. The interlock circuit and junction connectors to the printed circuit board were of primary interest. Continuity tests were carried out on system subcomponents for familiarity with the electrical connection layout. These tests assisted in obtaining information pertinent to the electrical component connectivity within the system. This generated preliminary control diagrams for system communication.

Arrival of the control boards permitted the system to be tested and operated. Siemens provided two control boards for the *in vitro* unit. One of the boards had a damaged integrated circuit (IC), model # 74LS04. A socket was soldered on to the faulty IC spot, for quick IC replacement if necessary during testing. System assembly was carried out and the unit was powered with no x-ray source installed. Testing of the translational stages was sought. Testing the stages by homing is a calibration step necessary for instrument use. It permits the system to find its start point. It forms part of the startup procedure to verify the system is functioning properly. The GUI application for operator interface and system control was executed. Two error messages appeared during initialization of the GUI. Operator control was not granted during the GUI initialization. The error messages included the following:

1. "Could Not Open Serial COM Port %d to Initialize Smart Motors."
2. "Please Close Loading Door."

The first error message was non-recurring; it could be bypassed. The second message was a looping prompt and did not permit access to the GUI. The source code for the GUI was examined and the Mci.h file was searched. It provided some guidance to the error messages.

The first error message can be found under "Functions to Init and End SmartMotors" in the MCi.h source file. The National Instruments (NI) Application Programmer Interface (API) OpenComConfig() function controls the conditional statement that prompts this error message under a "status" variable in the code. This communication error relates to the Animatics SM2315D smartmotor. The computer system cannot identify which COM serial port communicates with the smartmotor component. Minor troubleshooting was carried out by initially checking the COM connections, followed by inspecting serial ports connections under the device manager. These items seemed in order. The configuration file .cfg is read by the GUI and configures system resources by allocating devices names and addresses. This file was modified by assigning different values to troubleshoot the COM port issue. This did not prove successful.

The second error message can be found under "Check Interlock Status" in the MCi.h source file. The condition that triggers the error message only appears in one section of the code. The code segment appeared as a software engineering control that is based on the interlock circuit. This embedded software control has two interlock flags interlock1 and interlock2. The error message was triggered by the interlock2 flag. Based on this information, it is safe to assume the interlock circuit did not close. This led to an inspection of the interlock circuit. A preliminary diagram of the interlock circuit was created. All electrical switches seemed to have been taken into consideration. The x-ray source was connected as a means of troubleshooting the error message. It was assumed that the x-ray source might complete the interlock circuit and permit access to the GUI. X-ray source installation did not bypass the interlock GUI software control. The x-ray source did not complete the interlock circuit as hoped. Time constraints did not permit further troubleshooting of the instrument.

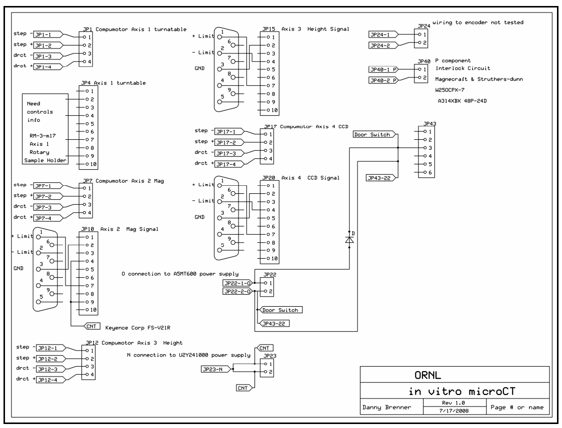


Figure 14. Junction header pin connection A

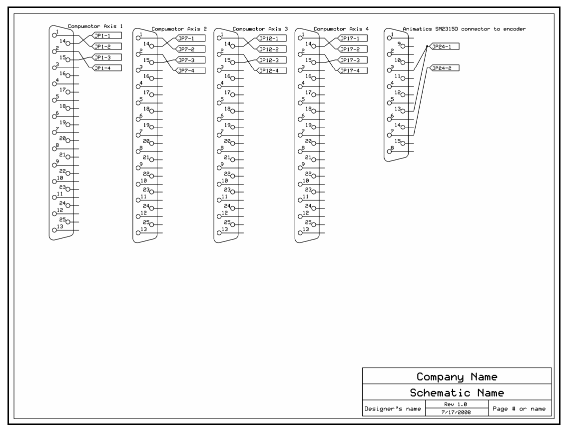


Figure 15. Junction header pin connection B

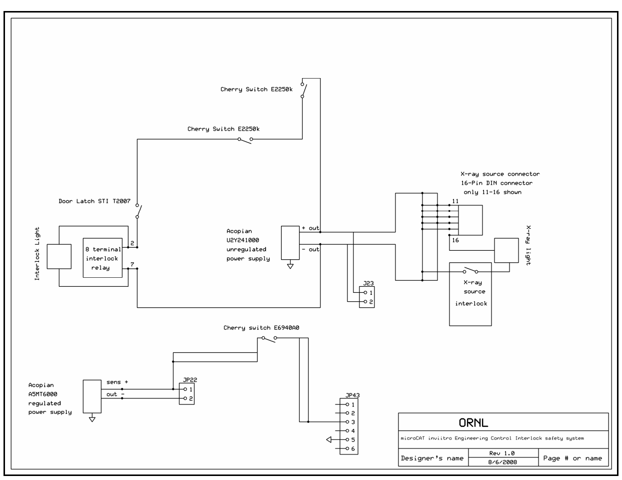
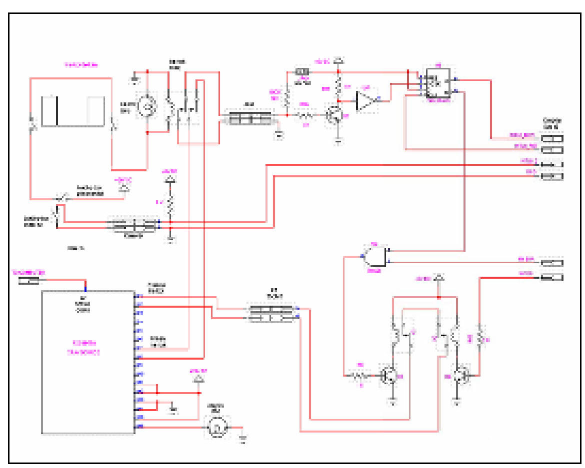
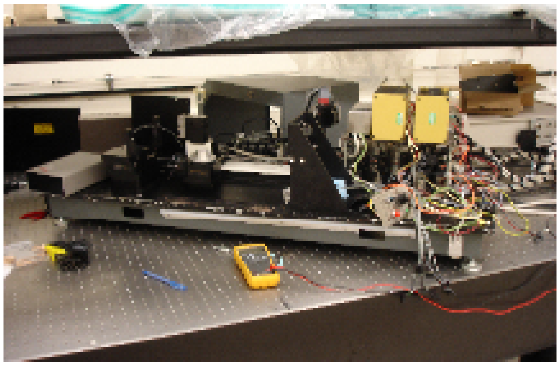
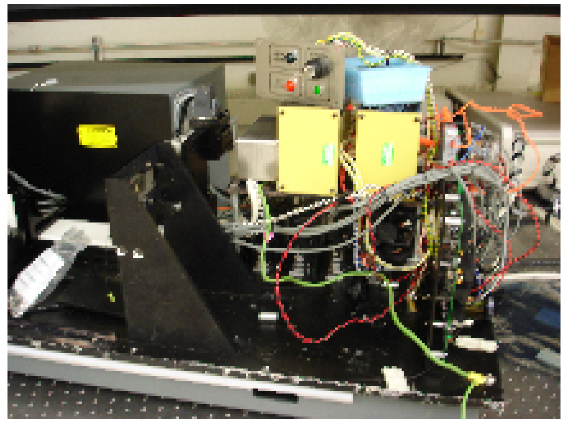
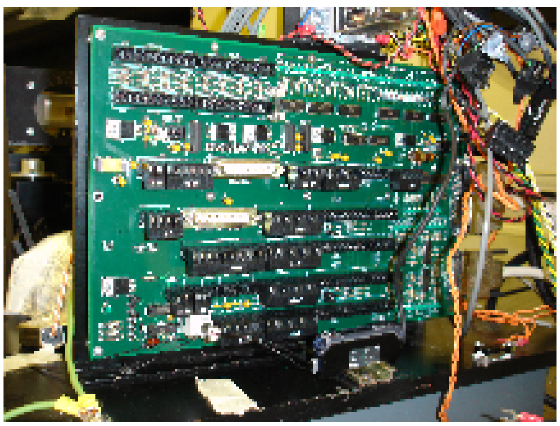
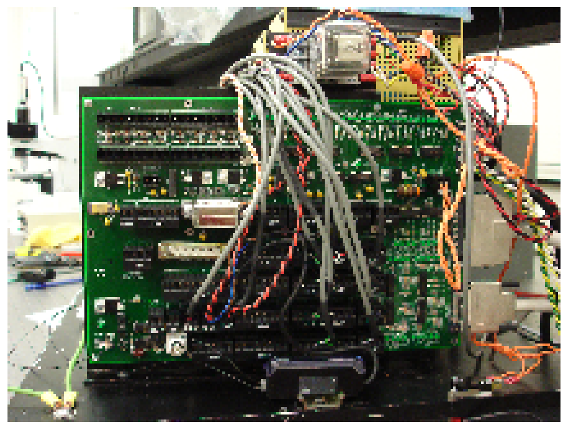
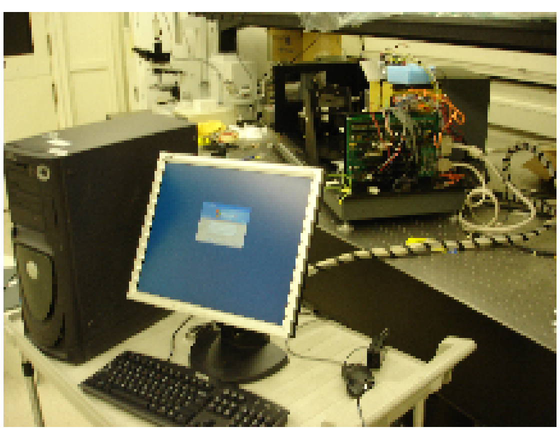


Figure 16. External interlock circuit.



Cross referenced from microCATII manual w/ Kevex source option modified by circuit trace

Figure 17.Complete interlock circuit

 Figure 18. *In vitro* dismantled for continuity testing and circuit tracing.	 Figure 19. Circuit board attached to in vitro unit.
 Figure 20. Bare circuit board.	 Figure 21. System connections.
 Figure 22. Computer system connected for testing.	 Figure 23. X-ray source installed

The *in vitro* lacked a dedicated x-ray detector. During testing, the expected course of action was to borrow the x-ray detector, Dalsa Panthera XR 6M3 x-ray camera, from the microCATII unit. The Panthera model consists of a phosphor screen for scintillation tapered by fiber optic cables down to a Charged Couple Device CCD. The Panthera is the x-ray detector for the microCAT series. Specifications and quotes on multiple x-ray detectors were acquired. Selection of a system specific x-ray detector is still necessary. The most cost effective option is the current Dalsa model x-ray detector. This model has the added benefit of the source code not needing any modification. Another x-ray detector might require recoding the GUI.

Table 4. X-ray Detectors: Specs and Quotes

Company	Model #	Type/Scinitllator	Pixels	Pixel size (um)	Price ($)
Princeton instruments	Quad-RO 4320	CCD/ Gadox	2084x2084	24x24	94.5k
Princeton instruments	Quad-RO 4096	CCD/ none	4096x4096	15x15	97k
Dalsa	Panthera 6M3	CCD/ phosphor	3072x2048	12x12	60k
BRUKER AXS INC	APEXII	CCD/ phosphor	4096x4096	15x15	150k

An important issue to note is the type of material used for the scintillator on the x-ray detector. Operating in a certain x-ray energy spectrum range, some scintillator materials are more favorable than others for conversion of x-ray to visible photons. The expected energy spectra for analysis should reside in the 40-100 KVp range. Based on this, Gadox (Gadolinium oxysulfide) might not be a prime candidate based on its low Detective Quantum Efficiency (DQE) in the 40-100 KVP range. DQE is representative of the percent of x-rays that are converted to photons. The thickness of the scintillation material affects the QDE. Gadox seems to be the standard for some x-ray detectors. Cesium iodide scintillators might be a more useful candidate. The prices quoted above are normally for just the CCD element of the x-ray detector (refer to Appendix A: Specs and Quotes) with an additional cost for the image screen. Gadox operates well in the 5-15 KVp range as opposed to the 40-65 KVp range at 40 micron thickness as can be seen from figure 24 (info provided by Bruker). It is necessary to choose a material with the greatest QDE to maximize photon fluence at the scintillator surface thereby minimizing the loss of radiographic image information.

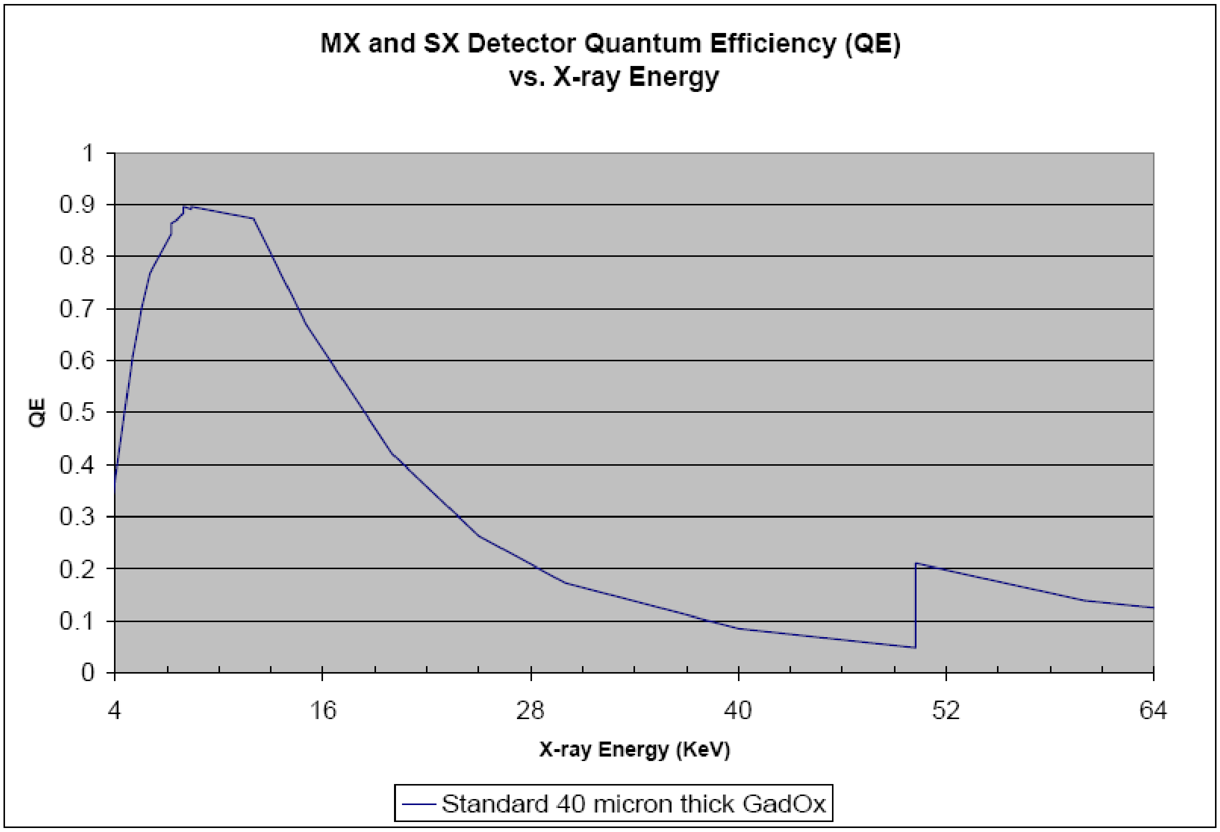


Figure 24. Graph of Gadox QDE.

4. DISCUSSION AND CONCLUSIONS

An inoperable microCT unit was repaired and brought online. Further troubleshooting of the unit is necessary in order to make it fully function in order to begin attaining experimental data on the microstructure of wood cores. Certain steps before data acquisition by wood phenotyping are still necessary. Continuation of system troubleshooting based on the aforementioned error messages is needed. Resolution for the first error message should begin with verification of the interlock circuit diagrams found under Figures 14 and 15. Revision of the interlock circuit of the unit might reveal a more detailed analysis of the interlock circuit is necessary to bypass the GUI software engineering controls. External electrical switch testing and inspection of JP 22, 23 and 43 are recommended (refer to Figures 12 and 13 and Appendix B). A resolution to the second error message might be found under National Instruments API regarding the OpenComConfig() function. It is also assumed that installation of the Dalstar Panthera x-ray detector could assist in eliminating the serial communication problem since the Animatics Smartmotor is wired in with the Dalstar hardware. GUI control will permit the unit to be tested by actuating its varying system components. It is also necessary to pass a radiation leak test to permit the radiation source to be energized by capable personnel. Once operator control has been achieved along with radiation clearance, it will be necessary to install an x-ray detector for the system. During testing and instrumentation of the unit, the microCATII's x-ray detector, Dalstar Panthera 6M3, and dedicated computer system will be used. These items are necessary in order for the system to have all its basic components necessary for operation and functionality.

Once operator control can be interfaced and an x-ray detector is in place, it will be necessary to carry out a system resolution calibration test. This is a necessary step in order to obtain the minimum resolution of the system. This procedure can be handled by imaging of a 10 micron wire standard. The imaging process of this wire resolution calibration standard will lead to the line spread function (LSP) of the system. The LSP can be derived and the point spread function (PSF) for the unit obtained. A normalized Fourier transformation of the PSF will lead to the modulation transfer function (MTF) of the system. The modulation transfer function reveals the resolution of the system. Ten percent MTF represents the minimum resolvable detail during imaging. Likewise a Contrast Transfer Function (CTF) test must be carried out.

In order to obtain the minimum resolution capability of the system, it will be necessary to purchase a dedicated computer system and, most importantly, a dedicated x-ray detector. Based on the achieved resolution, the standard x-ray detector model for the microCAT series microCT unit line, Dalstar Panther 6M3, might not achieve the desired system resolution of 0.1 microns at maximum magnification with a 3.5 cm field of view. If the standard x-ray detector does not achieve the needed resolution, it will be necessary to develop specifications for another x-ray detector for the system that can achieve the desired degree of detail, if possible. Some optical calculations must be carried out in order to see if the new specified model can achieve the needed resolution. An important issue is if it will be necessary to recode the GUI so system communication can be achieved with a non-standard x-ray detector. Financial considerations will also become a factor due to the costly nature of the x-ray detector. Creation of a user manual for the instrument would be a final step in order to have a documented and operable system.

5. REFERENCES

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2. ASTM E 1441Standard Guide for Computed Tomography (CT) Imaging.
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4. Michael J. Palulus, Shaun S. Gleason, Stephen J. Kennel, Patricia R. Hunsricker and DbaneyK. Johnson(2000). High Resolution X-ray Computed Tomography: An emerging Tool for small Animal Cancer Research. Neoplasia 2, 62-70.
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6. Sprawls, P. (1993). Physical Principles of Medical Imaging. Gaithersburg, Maryland: Aspen Publishers, Inc.
7. Phoenix X-ray website, www.phoenix-xray.com

APPENDIX A: SPECIFICATIONS AND QUOTES

Kevex PXS10-16W

Product Specifications

Kevex PXS10-16W

Operating Voltage Range:	20 to 130 kV ± 0.5%; > 45 kV to achieve full beam current and meet specifications.
Maximum Power:	16 Watts, 45 – 130 kV
Maximum Beam Current:	0.356mA ± 2% @ 45kV 0.123mA ± 2% @ 130kV
Spot Size:	≤ 6µ @ 4 watts, 60 -100 kV < 7µ @ 4 watts, 45 -130 kV < 9µ @ 8 watts, 45 -130 kV ≤ 21µ @ 16 watts, 45-130 kV
Spot to window spacing:	14 ± 1mm
Target Material:	Tungsten
Window Material and Thickness:	Be: 254 ± 50µ (.010")
Window Diameter (uncollimated):	19 ± 1mm (.760")
Cone of Illumination:	> 53°, typically 54 to 55° @ 130kV.
Ambient Temperature and Humidity:	0 to 32 °C, 0 - 95% RH, up to 5000 feet
Method of Cooling:	Internal fan. Adequate air circulation around unit must be provided.
Shielding:	X-Ray leakage behind the x-ray tube is less than 0.5mR/hour, measured one inch away. Measured with Victoreen 190
Weight:	approximately 34 lb.
Input Power:	24 VDC, 3 amps

Features

- Internal protection for the x-ray tube to prevent damage to target when changing kV or mA.
- Auto-conditioning (warm up) to ramp unit up slowly depending on how long unit has been off.
- User Interface: All control is through the RS232C port. The unit can be operated using either a Thermo supplied Windows based graphical user interface, or by utilizing the Product Interface Specification (P/N 5973-3036). Status and diagnostics available on the RS232C interface are:
  - Operating status of unit (Warm up, Interlocks, X-Ray On, etc.)
  - Warm up time remaining
  - Spot size
  - X-ray tube temperature
  - Event log for arc, anode leakage, interlock opened while x-rays on, etc.

Input/Output Connectors

J1 is a 16 pin Amp #206036-8 low voltage connector for DC power, interlocks, and internal relays.

J2 is a 9 pin Amphenol 841-17-DEFR-A9S female "D" connector for the RS232C port. RS232C interface specifications:

Baud rate	38400
Data bits	8
Stop bits	1
Parity	none
Xon/off	none

Worldwide Sales
320 El Pueblo Road, Scotts Valley, CA, USA 95066
Phone: 831-439-5940, Fax: 831-439-5292

www.thermo.com

Thermo ELECTRON CORPORATION

Source Ray SB-80-500

source-ray, inc.

Specifications

Model Number	SB-50-1K	**SB-80-250	**SB-80-500	SB-80-500-EW	SB-80-1K	SB-100-3K	SB-120-400
Modality Served	Industrial & Medical	Industrial & Medical	Industrial & Medical	Industrial & Medical	Industrial & Medical	Industrial & Medical	Industrial
Applications	BMD, Fluoroscopy	Inspection, Micro-CT	Inspection, Micro-CT	Inspection, Micro-CT	Inspection, Micro-CT	Inspection, Fluoroscopy	Inspection
Power Supply	Integrated HF Inverter	Integrated HF Inverter	Integrated HF Inverter	Integrated HF Inverter	Integrated HF Inverter	External H.F. Inverter	Integrated HF Inverter
X-Ray Tube	Glass	Glass	Glass	Glass	Glass	Glass	Glass
Min. Focal Spot	50 microns	50 microns	50 microns	50 microns	50 microns	1mm	75 microns
Port Material	Ultem	Carbon Fiber	Carbon Fiber	Ultem	Ultem	AL	Berylium
Input Power	26 VDC, 3.5A †	24 VDC, 2A †	24 VDC, 3A †	24 VDC, 3A †	26 VDC, 5A †	115 VAC, 5A	24 VDC, 4A †
Duty Cycle	CW, Pulsed	CW, Pulsed	CW, Pulsed	CW, Pulsed	CW, Pulsed	Pulsed	CW, Pulsed
Cooling	Forced Air	Convection	Forced Air	Forced Air	Forced Air	Convection	Forced Air
KVp Range	25 – 60	35 – 80	35 – 80	35 – 80	35 – 80	40 – 100	60 – 120
MA Range	0.1 – 1.0 mA	20 – 250 uA	20 – 500 uA	20 – 500 uA	0.020 – 1.0 mA	0.05 – 3mA	20 – 400 uA
Line Reg. (kVp)	0.10%	0.10%	0.10%	0.10%	0.10%	0.1%	0.10%
Load Reg. (kVp)	0.10%	0.10%	0.10%	0.10%	0.10%	0.1%	0.10%
Line Reg. (mA)	0.50%	0.50%	0.50%	0.50%	0.50%	0.5%	0.50%
Load Reg. (mA)	0.50%	0.60%	0.60%	0.60%	0.60%	0.5%	0.60%
Ripple	< 1%	< 1%	< 1%	< 1%	< 1%	<1%	< 1%
Rise Time (kVp)	< 200 mS	< 200 mS	< 200 mS	< 200 mS	< 200 mS	<200 mS	< 500 mS
Setability	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
Temp. Stability	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%	0.01%
Operating Temp.	10 - 35° C	10 - 35° C	10 - 35° C	10 - 35° C	10 - 35° C	10 - 35° C	10 - 35° C
Storage Temp.	0 - 45° C	0 - 45° C	0 - 45° C	0 - 45° C	0 - 45° C	0 - 45° C	0 - 45° C
Size (approx. ")	8.5 x 3.5 x 5.0	8.5 x 4.0 x 5.25	8.5 x 4.0 x 5.25	5 x 7.25 x 5	11 x 5.5 x 5.25	7.5 x 8.0 x 7.0	9.5 x 5.5 x 5.5
Weight (approx.)	11 Lbs.	17 Lbs.	17 Lbs.	12 Lbs.	14 Lbs.	21 Lbs.	22 Lbs.
Optional Equip.	See below	See below	See below	See below	See below	See below	See below
Warranty	1 Year, Prorated X-Ray Tube	1 Year, Prorated X-Ray Tube	1 Year, Prorated X-Ray Tube	1 Year, Prorated X-Ray Tube	1 Year, Prorated X-Ray Tube	1 Year, Prorated X-Ray Tube	1 Year, Prorated X-Ray Tube

Specifications Subject To Change Without Notice

Optional Control Units: Reference Individual Brochures for Specifications

Digital Interface: Model DI-RS232

Human Machine Interface: Model PI 8.3A

Analog Interface: Model XRC-600

UL 60601-1 on models ** SB-60-50, SB-80-250, SB-80-500, SB-80-500-DI

† Recommended Power Supply, VOLGEN SPN150-24S (+/-10% Adjustable)

Princeton Instruments Quad-RO 4320

Princeton Instruments ACTON

3660 Quakerbridge Rd., Trenton, NJ 08619
Phone: (609) 587 9797 Fax: (609) 587 8914

Danny Brenner
Oak Ridge National Lab
P.O. Box 2008; M/S: 6006
Oak Ridge, TN 37831-6006

Phone : +1 (865) 241-2984
Fax :
Email : brennerde@ornl.gov

55416

Issue Date: June 30, 2008
Valid Until: August 29, 2008
Application: X-Ray Diffraction

Item	Qty	Part Number and Description		Unit Price	Total Price
1	1	Quad-RO: 4320/1-75	7541-0001 - SPR-2955	$94,500.00	$94,500.00
		Princeton Instruments Quad-RO: 4320/1-75 Digital CCD Camera System thermoelectrically cooled camera head • Kodak KAF 4320, grade 1, front-illuminated MPP CCD, 2084 x 2084 pixels • 24 µm pixel (50 x 50 mm CCD image area) • with 75 mm fiber optic (1:1 taper ratio) • water cooled only			
2	1	WinView/32	4412-0046	$1,500.00	$1,500.00
		Real time acquisition, display, and data processing software for Microsoft Windows 2000/XP			
3	1	GdOS-17/90	2520-0017	$1,250.00	$1,250.00
		GdOS phosphor optimized for 17 keV 90 mm dia.			

Discount (Class): $9,725.00

Total Price **$87,525.00**

Princeton Instruments Quad-RO 4096 (Grade 1 and 2)

Princeton Instruments ACTON

3660 Quakerbridge Rd., Trenton, NJ 08619
Phone: (609) 587 9797 Fax: (609) 587 8914

Danny Brenner
Oak Ridge National Lab
P.O. Box 2008; M/S: 6006
Oak Ridge, TN 37831-6006

Phone : +1 (865) 241-2984
Fax :
Email : brennerde@ornl.gov

55415

Issue Date: June 30, 2008
Valid Until: August 29, 2008
Application: X-Ray Diffraction

Item	Qty	Part Number and Description		Unit Price	Total Price
1	1	**Quad-RO: 4096-4/2/90**	**7484-0001**	$99,750.00	$99,750.00
		Princeton Instruments Quad-RO: 4096-4/2/90 Digital CCD camera System Thermoelectrically cooled camera head • 4096 x 4096 pixels, grade 2, front-illuminated MPP CCD • 15 µm pixel (61.44 x 61.44 mm CCD image area) • with 90 mm fiber optic (1:1 taper ratio) • water cooled only			
2	1	**WinView/32**	**4412-0046**	$1,500.00	$1,500.00
		Real-time acquisition, display, and data processing software for Microsoft Windows 2000/XP			
3	1	**GdOS-17/90**	**2520-0017**	$1,250.00	$1,250.00
		GdOS phosphor optimized for 17 keV 90 mm dia.			

Discount (Class:): $10,250.00

Total Price $92,250.00

Princeton Instruments ACTON

3660 Quakerbridge Rd., Trenton, NJ 08619
Phone: (609) 587-9797 Fax: (609) 587-8914

Quotation

Danny Brenner
Oak Ridge National Lab
P.O. Box 2008; M/S: 6006
Oak Ridge, TN 37831-6006

Phone : +1 (865) 241-2984
Fax :
Email : brennerde@ornl.gov

55414

Issue Date: June 30, 2008
Valid Until: August 29, 2008
Application: X-Ray Diffraction

Item	Qty	Part Number and Description		Unit Price	Total Price
1	1	**Quad-RO: 4096-4/1/90**	**7484-0004**	$107,500.00	$107,500.00
		Princeton Instruments Quad-RO: 4096-4/1/90 Digital CCD camera System thermoelectrically cooled camera head • 4096 x 4096 pixels, grade 1, front-illuminated MPP CCD • 15 µm pixel (61.44 x 61.44 mm CCD image area) • with 90 mm fiber optic (1:1 taper ratio) • water cooled only			
2	1	**WinView/32**	**4412-0046**	$1,500.00	$1,500.00
		Real-time acquisition, display, and data processing software for Microsoft Windows 2000/XP			
3	1	**GdOS-17/90**	**2520-0017**	$1,250.00	$1,250.00
		GdOS phosphor optimized for 17 keV 90 mm dia.			

Discount (Class:): -$11,025.00

Total Price $99,225.00

Dalsa Panthera 6M3

Pantera XR 6M3

X-Ray Camera

Key Features

- 105 mm x 70 mm entrance aperture with 100 μm Lanex Fine phosphor, 3:1 taper
- TrueFrame ™ CCD sensor
- 10-100 keV energy range
- 6 megapixels, 3 fps with true 12 bit digitization
- High sensitivity, low noise without cooling
- 100% fill factor

Programmability

- Selectable pixel binning up to 4 x 4
- 1x or 4x adjustable gain
- Selectable trigger mode

Typical Applications

- Industrial non-destructive testing with ionizing radiation
- Security imaging
- Industrial and medical small field computed tomography
- Materials science and nanotechnology
- Agricultural inspection
- Container inspection

Overview

High resolution, high dynamic range, high speed, and scientific image fidelity.

The Pantera XR 6M3 X-ray camera is a high resolution, high sensitivity CCD camera for digital X-ray applications. The Pantera XR 6M3 brings a rare suite of capabilities to performance driven small field X-ray imaging applications.

Built on a proven camera platform with a full frame progressive scan CCD, the Pantera XR 6M3 simultaneously achieves outstanding resolution and gray scale characteristics in 12 bit images with 3k x 2k spatial resolution at up to 2.75 frames per second. Its very low noise and high dynamic range provide quantifiably superior image quality.

The Pantera XR 6M3 uses a 105 mm x 70 mm entrance aperture with a fiber taper (3:1) bonded directly to the sensor using a hard epoxy for maximum transmission efficiency and robustness.

The Pantera XR 6M3's true 12 bit performance (without cooling) provides up to 4096 distinct gray levels – perfect for capturing the best possible images in challenging, low-contrast situations.

Specifications

Resolution	3072 x 2048
Data Rate	20 MHz
Pixel Size	12 μm
Detector Area	105 mm x 70 mm
Spatial Resolution	6 lp/mm
Output	12 Bit LVDS @ 20 MHz
Responsivity	2 DN/mR @18 KeV
Dynamic Range	70 dB
Nominal Gain Range	1x or 4x
Size	238 mm x 168 mm x168 mm
Mass	12 kg
Operating Temp	10 °C to 45 °C
Power Supply	+5 V, -5 V, +15 V
Power Dissipation	< 17 W
Regulatory Compliance	
Example Part Number	99-78-0000-00

Pyramid Imaging LLC

615 Bannockburn Ave.
Tampa, FL 33617
phone 813-984-0125
fax 813-984-1231
FEIN 59-3760253

Quote

Date	Quote #
6/23/2008	7643

Name / Address
Oak Ridge National Laboratory Danny Brenner

Terms	FOB	Lead Time
see notes	Origin	20 weeks

Item	Description	Qty	Cost	Total
Cougar 6M03 X-Ray	3k x 3k resolution 12bit, RS-422 or LVDS output X-ray camera	1	59,500.00	59,500.00T
Cougar PS	Cougar 6M03 power supply	1	835.00	835.00T
Cougar PS cable	Cougar power supply cable	1	289.00	289.00T
Cougar AC cable	Cougar AC cable	1	22.00	22.00T
	These items are non-returnable/non-refundable custom order			
	E-mail orders to dlee@pyramidimaging.com, fax 813.984.1231,or mail. Quote is valid 30 days. It is customers responsibility to verify performance of components within 30 days.			
	Prepayment of 50% due with purchase order. Balance due net 30 from invoice date.			

Thank you for the opportunity to provide you with this quotation.

Subtotal	$60,646.00
Sales Tax (0.0%)	$0.00
Total	$60,646.00

BRUKER AXS INC APEXII

BRUKER AXS INC.
5465 E. Cheryl Pkwy, Madison, WI 53711-5373

OAK RIDGE NATIONAL LABORATORY
DANNY L. BRENNER
PO Box 2008
OAK RIDGE TN 37831

Quote Number Q30-5962-0

Number/Date
Q30-5962-0 / 06/30/2008
Customer no.
8274
Your reference no./Date

Contact person
Sales group: Gary Bauer
Phone: (608)847-6015
Fax: (608)276-3006
EMail: Gary.Bauer@bruker-axs.com
Assistant: Dave Molina
Phone: (608)276-3083
Fax: (608)276-3006
EMail: dave.molina@bruker-axs.com

Item	Material/Description	Qty	Total Price USD
0010	Part#: SC9000	1	

EB# 842-001569 APEXII 16 megapixel CCD Area Detector

Charge Coupled Device area detector for X-ray diffraction frame data collection and imaging.
System includes:

APEXII CCD Area Detector with high counting efficiency.
Single module 62 mm 4k CCD area detector with high counting efficiency, low noise and large capacity.
- 90 mm diameter (62 mm x 62 mm) active detection area
- no demagnification (ratio 1:1)
- 15 µm on-chip pixel-to-pixel resolution
- highly effective, high resolution phosphor optimized for Molybdenum or Copper wavelengths (or other, on request)
- gain (nominal) of 170 electrons per Mo x-ray photon, 85 electrons per Cu x-ray photon
- user selectable 512 x 512 or 1024 x 1024 pixel frame readout mode four-port readout

Frame read time in seconds dependent on binning and selected readout speed, selectable from 1000 KHz per port to 250 KHz per port, resulting in minimum times 0.2 seconds (8x8 bin), 0.5 seconds (4x4 bin), 1.7 seconds (2x2 bin), 4.1 seconds (unbinned)

Linear Full well capacity, typical 750,000 electrons (4x4, 8x8 binning), 300,000 electrons (2x2 binning in 2048 x 2048 frames)
Superior dynamic range up to 60,000 due to highest full well and low noise

Low maintenance Joule-Thomson cooling to -60 degrees C
Dark current less than 0.01 electrons per pixel-second, resulting in the ability to expose for many hours on a single image before the dark noise approaches the signal from a single x-ray photon.

Bruker Frame Buffer Computer
For instrument control. Pentium 4 computer, 512 Mbytes RAM, 80G hard drive, DVD-RW, DVD, floppy, NIC, modem, 17" LCD monitor, keyboard, MS Intellimouse. Windows XP and Acrobat Reader software. Allows backup of 4.7GB to DVD-R or DVD-RW media and 700 MB to CD-R or CD-RW media.

Software for detector control, including collection and imaging of frame data.

NOTE: depending on level of integration with user-supplied source, optics, shutter and motor control, can be run off-line to display and evaluate images.

TOTAL PACKAGE PRICE ITEM 0010 - 0010 150,000.00

Agile Engineering

AGILE ENGINEERING
10337 Yellow Pine Lane
Knoxville, TN 37932
Tel. (865) 693-6544 Fax (865) 693-6545

Proposal
Fixed Price

Proposal Number: PP-1637-R00

Proposal to: ORNL

Date: 6/19/08

Description: Kevex Mount for ORNL MicroCAT 2

Deliverables: Agile Engineering will provide a mounting assembly that will mount a Kevex PSX-10 x-ray source to the ORNL MicroCAT 2 scanner. The mounting assembly will replace the current Source-Ray mounting assembly and will mount to the same holes. It will be designed to position the beam of the Kevex source concentric to the existing shutter aperture on the ORNL scanner. A graphic showing the mounting assembly integrated into the existing shutter can be seen in Figures 1 and 2.

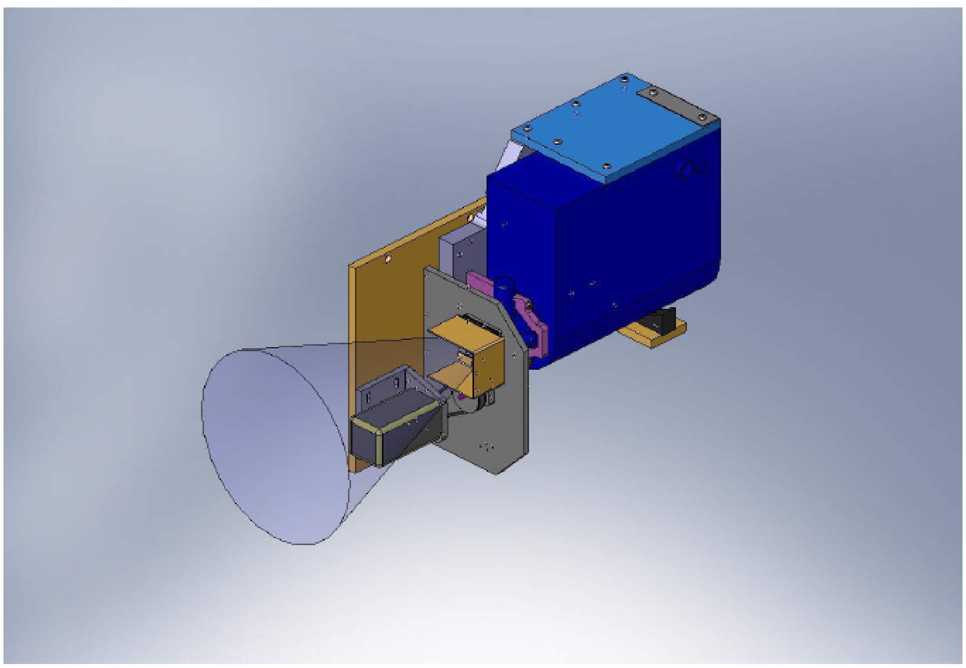


Figure 1. Kevex Mounting Assembly w/ Existing ORNL X-Ray Shutter

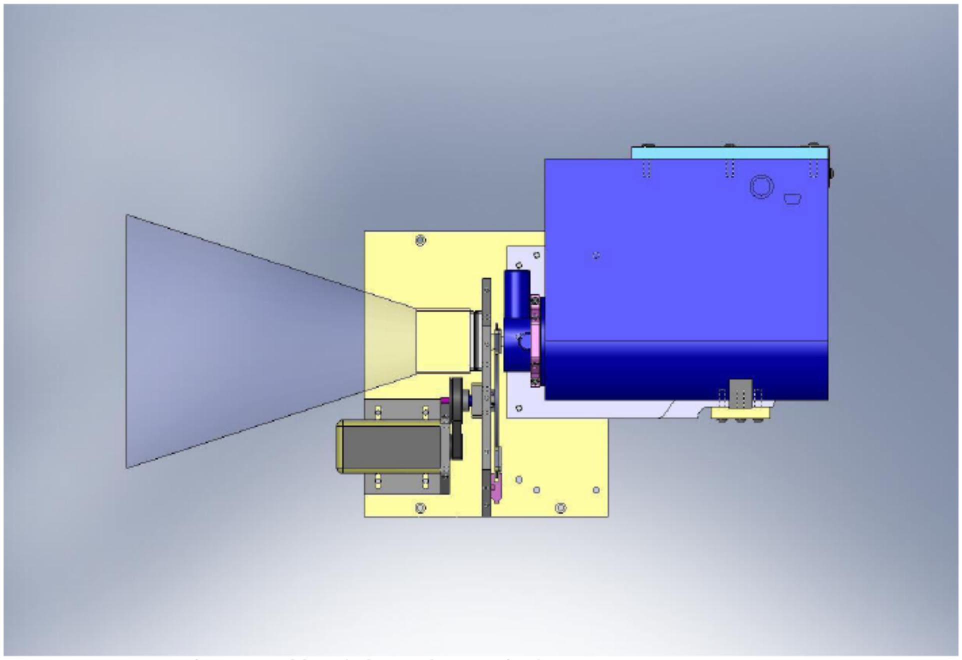


Figure 2. Kevex Mounting Assembly w/ Shutter (Front View)

Schedule: 4 weeks ARO

Pricing and Terms: The total cost for one Kevex Mounting Assembly is $2,655.00

Terms are net-30 upon delivery (FOB Knoxville, TN).

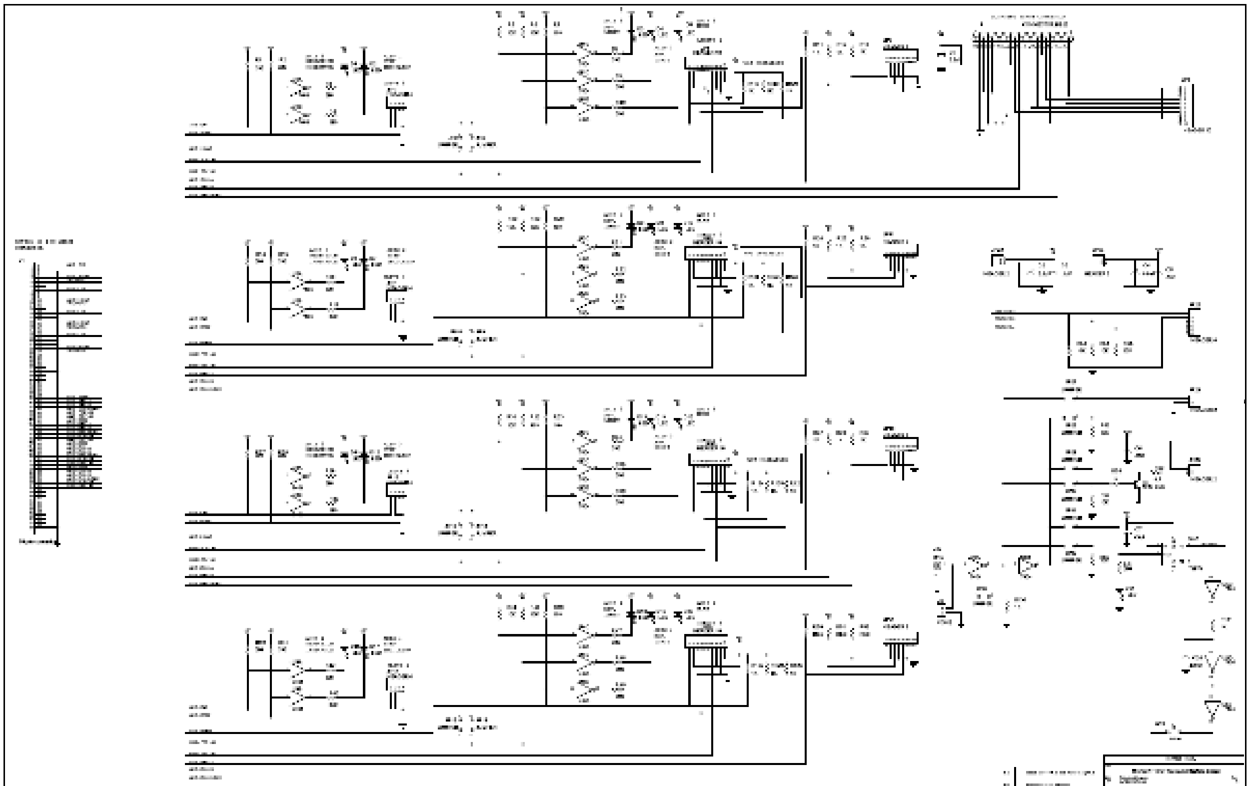
This is a fixed price proposal, and as such the pricing is based on the scope of work described above. If a scope of work change is required during the course of the design effort, then the new scope will be documented by a change notice and the total cost of the project will be reassessed. At that point the customer can decide whether to proceed with the original scope, amend the contract to the new project cost, or cancel the project and pay costs for actual time and materials to that point in time.
Price proposed is valid for 30 days from date of proposal.

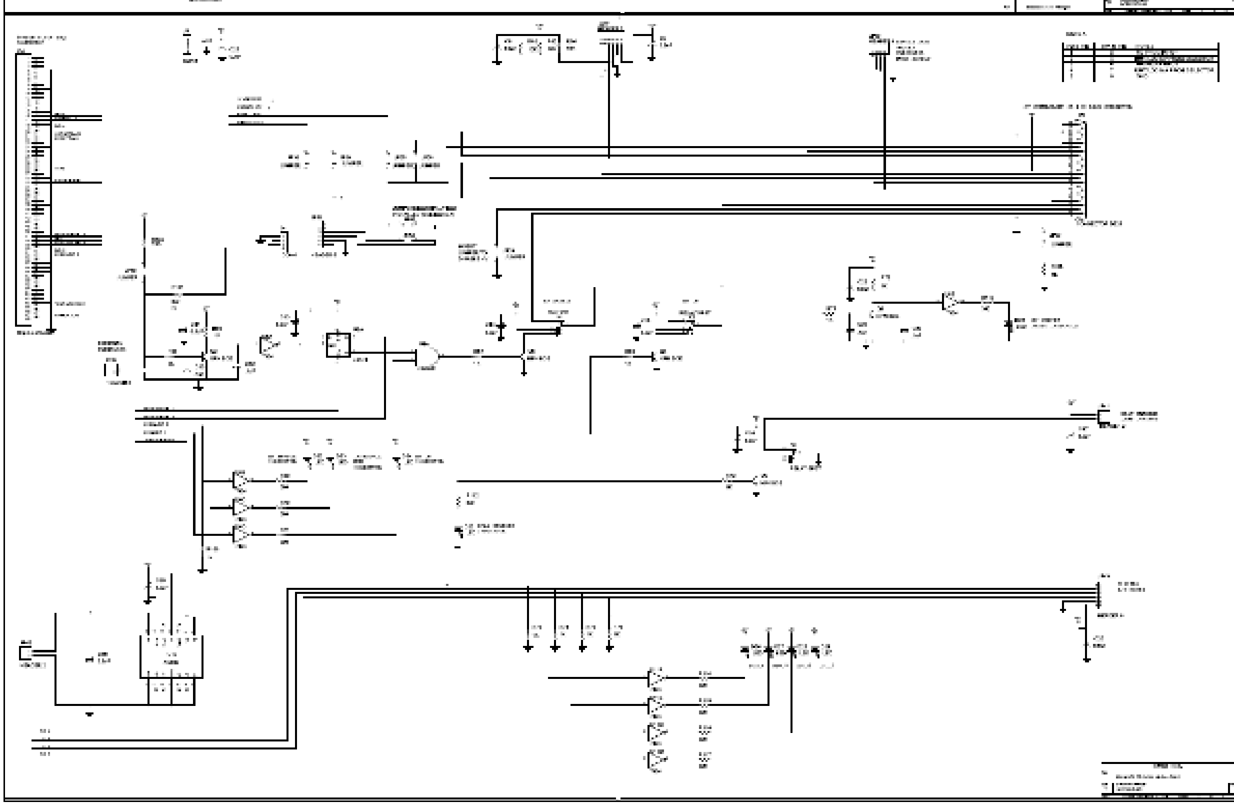
Proposal Submitted by:

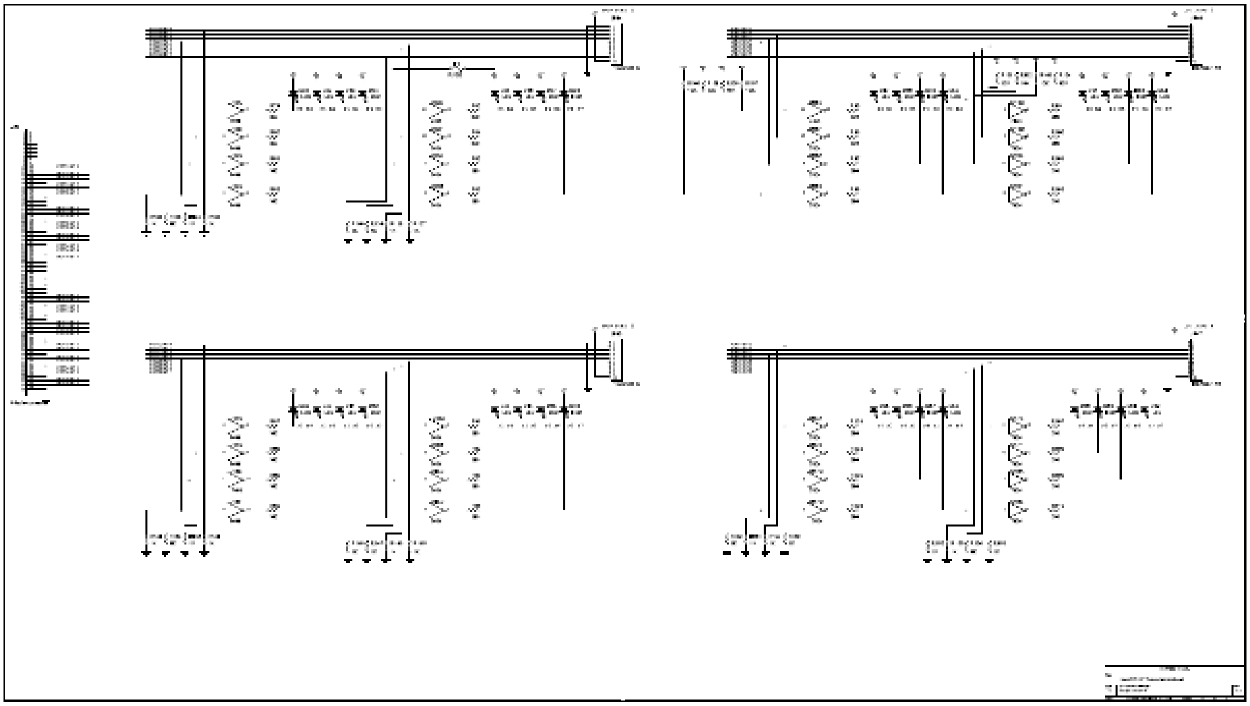
David Willis
Engineering Group Manager
Agile Engineering, Inc.
10337 Yellow Pine Lane
Knoxville, TN 37932
dwillis@agile-engineering.com

APPENDIX B: CIRCUIT SCHEMATICS

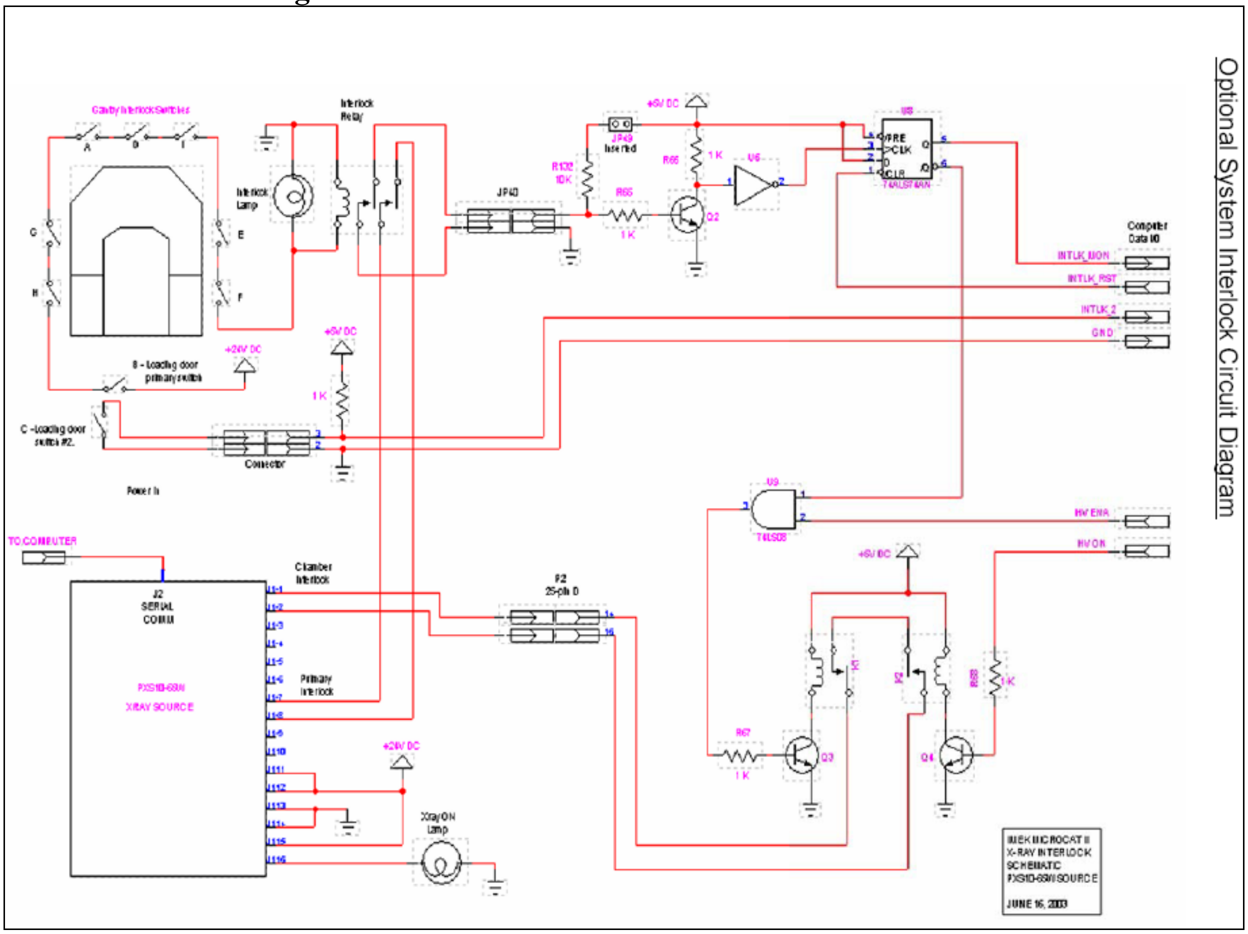
Printed Circuit Board Schematics



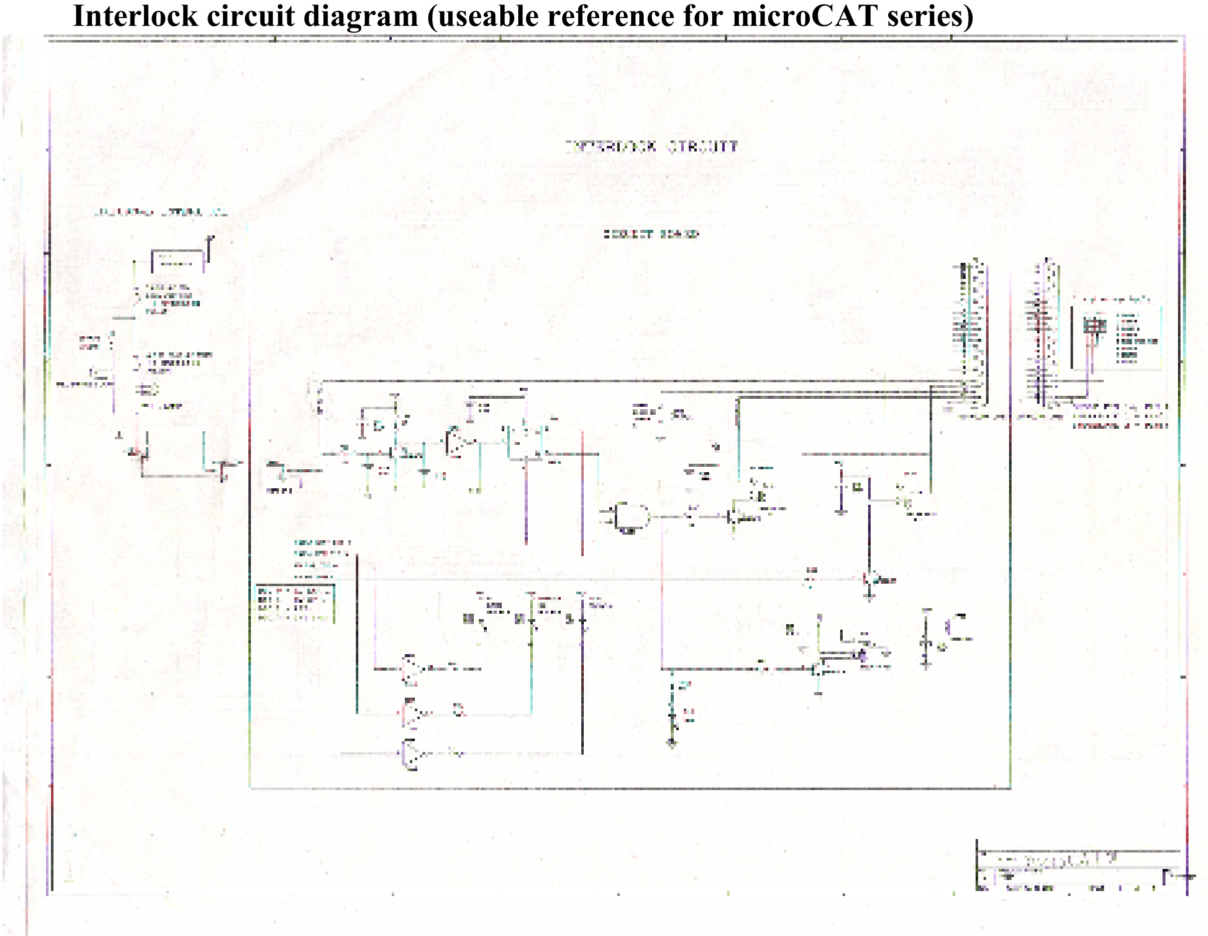




Interlock Circuit diagram w/ Kevex Source from microCATII manual



Interlock circuit diagram (useable reference for microCAT series)



APPENDIX C: GUI CODE

in vitro microCAT code segments containing error messages

```
/***************************************************************************
 *
 *           Functions to Init and End SmartMotors
 *
 **************************************************************************/


//Initialize Smart Motors

int initSmartMotors (void)
{
      char writeBuffer[80];
      char readBuffer[80] = {0};
      char eMsg[80];
      int length;
      int i;
      int shutteropen;
      int shutterhomed = 0;

      status = OpenComConfig (intSMComm, SMComm, 9600, 0, 8, 1, 0, 0);
      //Initialize com port

                              //SMComm = "Com1" or "Com2"
      if (status < 0)
      {
            sprintf(eMsg, "Could Not Open Serial COM Port %d to Initialize
Smart Motors.", intSMComm);
            MessagePopup("Smart Motor Error", eMsg);
            return -1;
      }

      status = SetWaitCursor (1);                                      //set
mouse to hour glass

      status = SetComTime (intSMComm, 0.1);                      //set comm
port time out
      status = ComRd(intSMComm, readBuffer, 40);                 //clear
read buffer
      status = SetComTime (intSMComm, 4.0);                      //set comm
port time out for shutter below

      //Send WAKE to wake up all smartmotors
      writeBuffer[0] = 0x80;                                           //ext
ascii 0 required for all smartmotors
      writeBuffer[1] = NULL;
      strcat(writeBuffer, "WAKE ");                              //wake all
smartmotors
      length = strlen(writeBuffer);
      status = ComWrt(intSMComm, writeBuffer, length);
```

```
	status = ComRd(intSMComm, readBuffer, length);		//read echo

	//Allow 3 attempts to home shutter smartmotor
	i = 0;
	while (i<3 && shutterhomed==0)
		{
		i++;
		//Send RUN to start shutter smartmotor
		writeBuffer[0] = ShutterAddr;
	//shutter address
		writeBuffer[1] = NULL;
		strcat(writeBuffer, "RUN ");
	//start program
		length = strlen(writeBuffer);
		status = ComWrt(intSMComm, writeBuffer, length);
		status = ComRd(intSMComm, readBuffer, length);		//read echo

		//Send GOSUB20 to home shutter
		writeBuffer[0] = ShutterAddr;
	//shutter address
		writeBuffer[1] = NULL;
		strcat(writeBuffer, "GOSUB20 ");
	//start program
		length = strlen(writeBuffer);
		status = ComWrt(intSMComm, writeBuffer, length);
		status = ComRd(intSMComm, readBuffer, length);		//read echo
		readBuffer[0] = '1';
	//make sure first char is not '0'

		//iv1.0
		Delay(1.0);
	//allow shutter some time to home
		status = ComRd(intSMComm, readBuffer, 2);		//check
status of homing routine

		//Check for homing error
		if (readBuffer[0] == '0') shutterhomed = 1;
	//homed if readbuffer == '0'
		else
		{
			status = CloseCom(intSMComm);
			Delay(0.05);
			status = OpenComConfig (intSMComm, SMComm, 9600, 0, 8, 1,
0, 0);		//Initialize com port
			Delay(0.05);
			status = SetComTime (intSMComm, 0.1);
	//set comm port time out
			status = ComRd(intSMComm, readBuffer, 40);
	//clear read buffer

			//Send WAKE to all motors again
			writeBuffer[0] = 0x80;
	//all motors
			writeBuffer[1] = NULL;
			strcat(writeBuffer, "WAKE ");
	//wake up motors
			length = strlen(writeBuffer);
```

```
                    status = ComWrt(intSMComm, writeBuffer, length);
                    status = ComRd(intSMComm, readBuffer, length);
      //read echo

                    //Send END to shutter to stop its program if running
                    writeBuffer[0] = ShutterAddr;
      //shutter address
                    writeBuffer[1] = NULL;
                    strcat(writeBuffer, "END ");
      //end program
                    length = strlen(writeBuffer);
                    status = ComWrt(intSMComm, writeBuffer, length);
                    status = ComRd(intSMComm, readBuffer, length);
      //read echo
                    status = SetComTime (intSMComm, 4.0);
             }
      }

      status = SetWaitCursor (0);                                 //turn off
hour glass
      status = SetComTime (intSMComm, 0.1);                 //smartmotor
ComTime = 100 ms from here on

      if (!shutterhomed)
      {
             status=GenericMessagePopup("Smart Motor Error","X-ray Shutter
Failed to Find Home Position.\n\nPlease cycle power if problem
persists.","Continue","Abort",0,0,1,0,VAL_GENERIC_POPUP_BTN2,2,2);
             if (status==2)
             {
                    endSmartMotors();
                    return -1;                    //will abort microcat program
initialization in main()
             }
      }

      return 0;
}



//End Smart Motors

void endSmartMotors (void)
{
      char writeBuffer[80];
      char readBuffer[80];
      int length;

      status = SetComTime (intSMComm, 0.1);                             //set
comm port time out

      //Send x-ray shutter back toward home position
      writeBuffer[0] = ShutterAddr;
      writeBuffer[1] = NULL;
      strcat(writeBuffer, "P=-200 ");
      length = strlen(writeBuffer);
```

```
      status = ComWrt(intSMComm, writeBuffer, length);            //send
command
      status = ComRd(intSMComm, readBuffer, length);              //read echo

      writeBuffer[0] = ShutterAddr;
      writeBuffer[1] = NULL;
      strcat(writeBuffer, "G ");
      length = strlen(writeBuffer);
      status = ComWrt(intSMComm, writeBuffer, length);            //send
command
      status = ComRd(intSMComm, readBuffer, length);              //read echo
      Delay(1.0);

      //Send X to stop all smartmotors
      writeBuffer[0] = 0x80;
      //ext ascii 0 required for all smartmotors
      writeBuffer[1] = NULL;
      strcat(writeBuffer, "X ");
      length = strlen(writeBuffer);
      status = ComWrt(intSMComm, writeBuffer, length);            //send
command
      status = ComRd(intSMComm, readBuffer, length);              //read echo

      //Send END to all smart motors
      writeBuffer[0] = 0x80;
      //ext ascii 0 required for all smartmotors
      writeBuffer[1] = NULL;
      strcat(writeBuffer, "END ");
      length = strlen(writeBuffer);
      status = ComWrt(intSMComm, writeBuffer, length);            //send
command
      status = ComRd(intSMComm, readBuffer, length);              //read echo

      //Send SLEEP to all smart motors
      writeBuffer[0] = 0x80;
      //ext ascii 0 required for all smartmotors
      writeBuffer[1] = NULL;
      strcat(writeBuffer, "SLEEP ");
      length = strlen(writeBuffer);
      status = ComWrt(intSMComm, writeBuffer, length);            //send
command
      status = ComRd(intSMComm, readBuffer, length);              //read echo

      status = CloseCom (intSMComm);
      return;
}


/************************************************************************
 *
 *          Check Interlock Status
 *      Resume Scan when doors are closed
 *
 ***********************************************************************/
```

```
int check_doors(int readprimary)
{
	//if readprimary==0, just check 2ndary interlock, used by MoveStages()

	unsigned short flipflop = 2;
	unsigned short interlock = 2;
	unsigned short interlock2 = 0;
	int xray_was_on = 0;


	//toggle interlock reset to prevent unnecessary popup message
	status = DIG_Out_Line (DAQBoardID, 0, INTLK_RST, 0);
	// Low to Reset
	status = DIG_Out_Line (DAQBoardID, 0, INTLK_RST, 1);
	// Leave line high


	//read primary interlock
	if (readprimary)
	{
		status = DIG_In_Line (DAQBoardID, 0, INTLK_MON1, &flipflop);
	// read flip flop
		status = DIG_In_Line (DAQBoardID, 0, INTLK_MON2, &interlock);
	// read interlock
	}

	//read secondary interlock
	status = DIG_In_Line (DAQBoardID, 0, INTLK_2NDARY, &interlock2);  //
read secondary interlock

	door_open = 0;
				  // reset flag

	/***  shut down if door is opened   ***/
	if(flipflop==1 || interlock==1 || interlock2==0)
	// if doors are open
	{
	    door_open=1;
	    xray_was_on = xray_on;
			// set flag high
		if (xray_on) stopxray();
			// shut down since door is opened
	}

	else return 0;		//doors are closed

	/***  wait for user to close doors or quit  ***/
	while(flipflop==1 || interlock==1 || interlock2==0)
	{

		if (interlock2==0)
			status=GenericMessagePopup("X-Ray Warning","Please Close
Loading Door.","OK","Abort",0,0,1,0,VAL_GENERIC_POPUP_BTN1,1,2);
		else if (xray_was_on && CTscan_in_progress)
			status=GenericMessagePopup("X-Ray Warning","Please Close
Door.","Resume","Abort",0,0,1,0,VAL_GENERIC_POPUP_BTN1,1,2);
		else
```

```
                  status=GenericMessagePopup("X-Ray Warning","Please Verify
Door is Closed.","OK","Abort",0,0,1,0,VAL_GENERIC_POPUP_BTN1,1,2);

            if (status==2 || Conditioning==1)
            {
                  quit = 1;
                  return 1;
            }

            status = DIG_Out_Line (DAQBoardID, 0, INTLK_RST, 0);
      // Low to Reset
            status = DIG_Out_Line (DAQBoardID, 0, INTLK_RST, 1);
      // Leave line high

            if (readprimary)
            {
                  status = DIG_In_Line (DAQBoardID, 0, INTLK_MON1,
&flipflop); // Read Flip Flop
                  status = DIG_In_Line (DAQBoardID, 0, INTLK_MON2,
&interlock);      // Read Interlock Line
            }

            //read secondary interlock
            status = DIG_In_Line (DAQBoardID, 0, INTLK_2NDARY, &interlock2);
      // read secondary interlock
      }

      /***  resume scan if user closed doors and hit "OK"  ***/
      if(door_open==1 && flipflop==0 && interlock==0 && interlock2==1)
      {
            quit=0;
                                    // re-enable scans, etc.
            if(xray_was_on && CTscan_in_progress)
            {
                  startxray();
                              // restart x-ray source
                  if(xray_on && !quit)
                  {
                        ResetTextBox(MicroCAT_p, MicroCAT_TEXTBOX,
"Resuming...\n"); // message box
                        xray_was_paused = 1;
                              // set flag for GetFrame()
                  }
            }
      }

      return 0;

}
```