A distributed, real-time data monitoring system as ground support equipment for balloon-borne astronomy experiments

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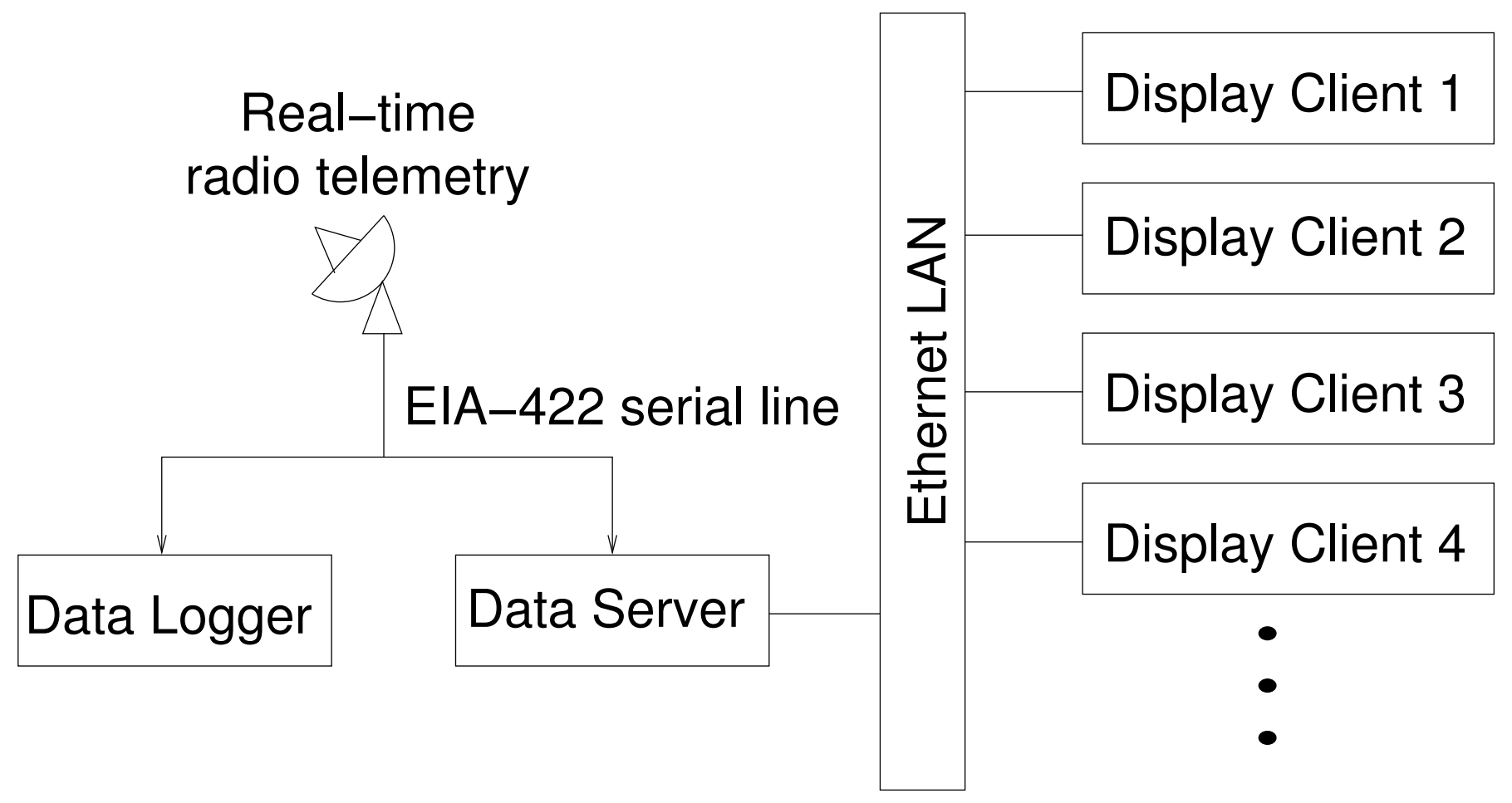
Context

We developed a real-time data-monitoring software suite for the High Energy Focusing Telescope (HEFT). HEFT, one of the first hard X-ray focusing telescopes (20–70 keV), was launched on a balloon-borne platform from southwest USA in 2005. This software suite was our ground-station equipment for monitoring the focal-plane instruments during on-site calibration, pre-launch practice drills, and an observation flight of 25 hours.

Features / Design objectives

- Distributed and scalable: servers + clients.
- Mostly platform-independent: Java (+ 1 perl client), simple UDP datagrams.
- Task-specific servers provide data redundancy.
- Allows for both real-time data input and playback of saved data.

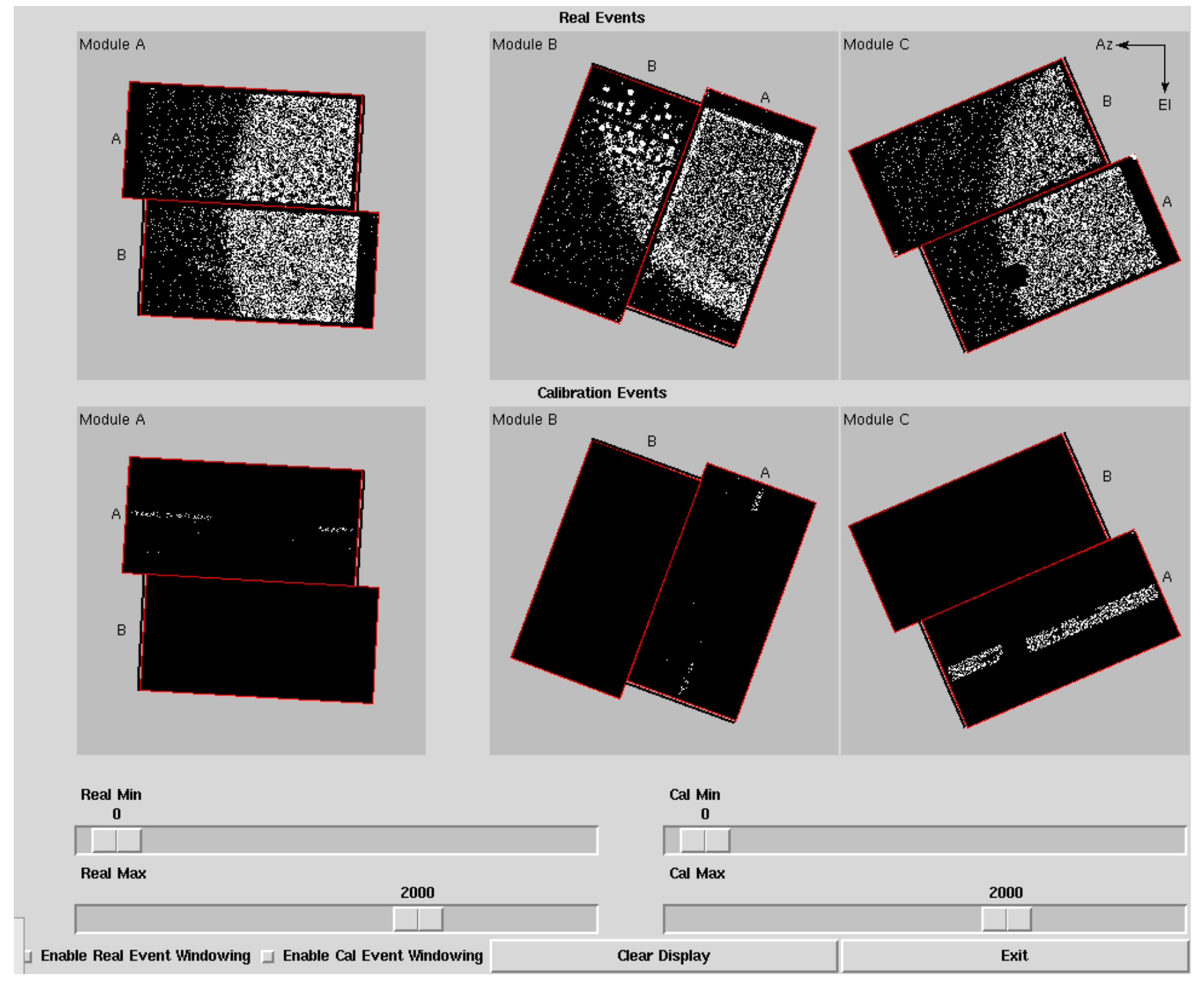
Server-client architecture



- Multiple servers performing dedicated tasks guarantee the integrity and redundancy of logged data, and reduce server load.
- UDP multicasting of photon & sensor data makes possible an unlimited number of concurrent display clients, without increasing server load.
- Separation of data processing and display makes code development modular.

Display clients

Detector maps, in sky coordinates



Real Min 0

Real Max 2000

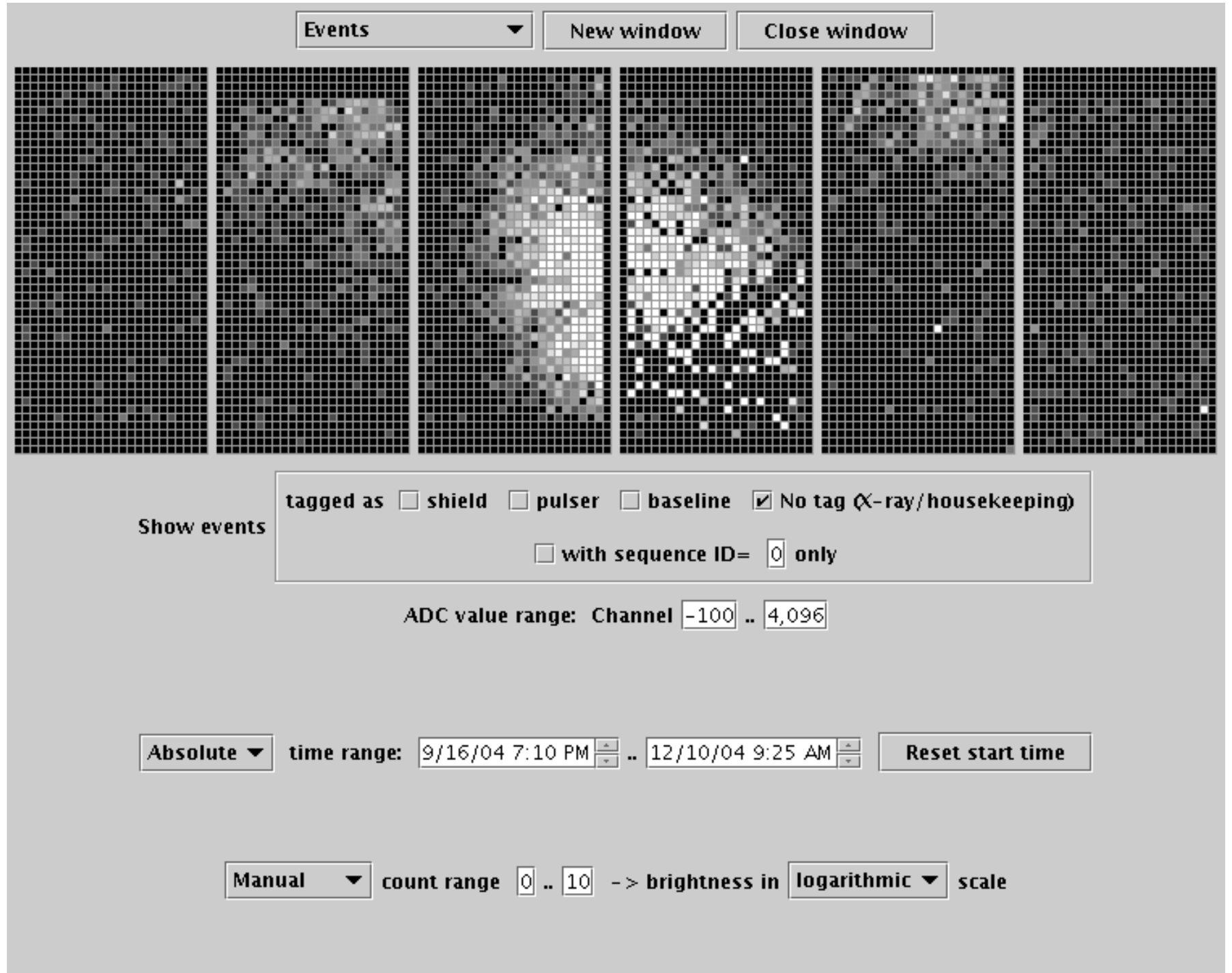
Cal Min 0

Cal Max 2000

□ Enable Real Event Windowing □ Enable Cal Event Windowing

- Rotated detector maps show X-ray images as seen from sky.
- Event selection in time and energy (wavelength) capable.

Detector maps, in detector coordinates



Show events tagged as □ shield □ pulser □ baseline ☑ No tag (X-ray/housekeeping)

□ with sequence ID= 0 only

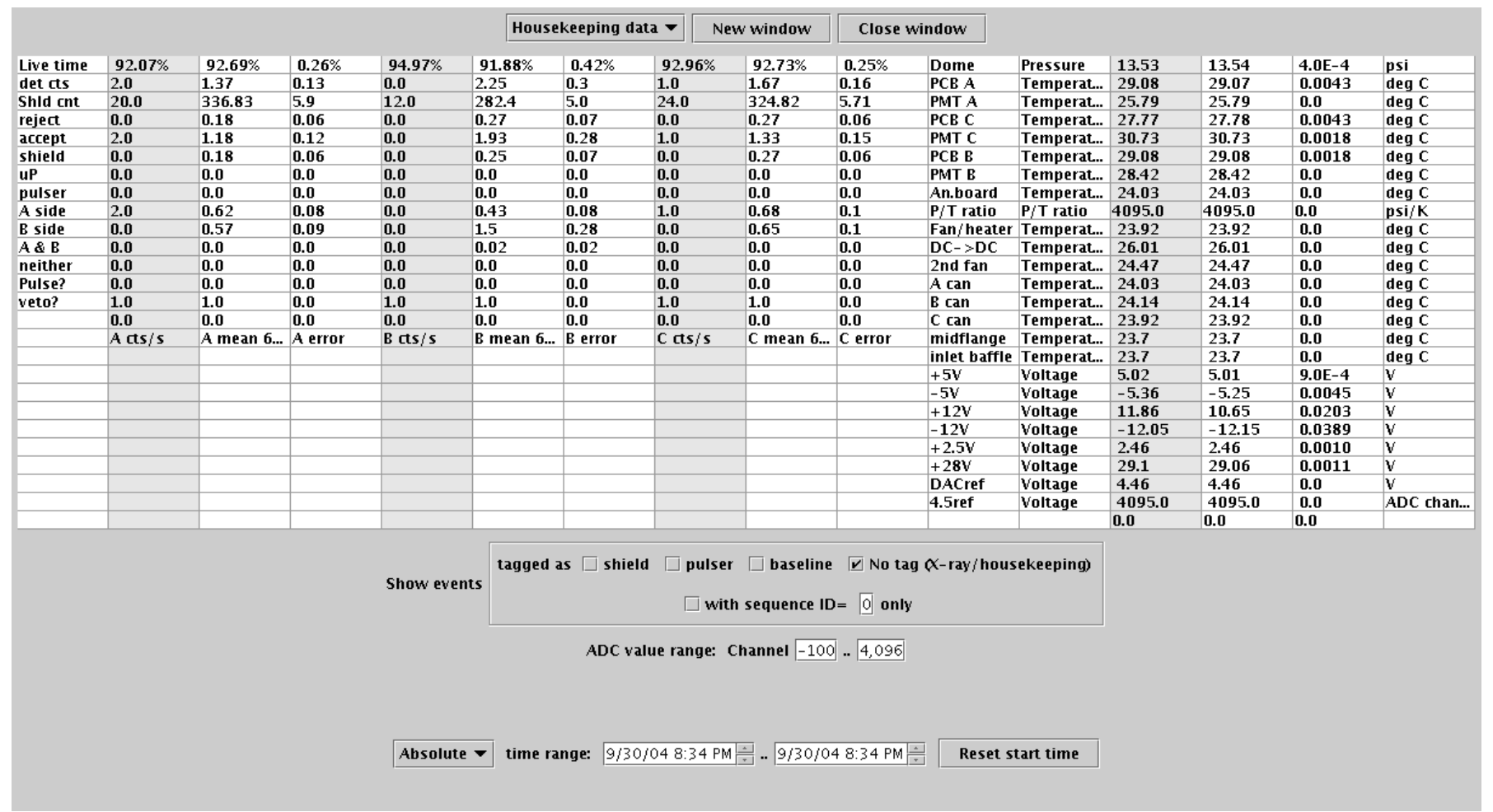
ADC value range: Channel -100 .. 4,096

Absolute ▾ time range: 9/16/04 7:10 PM .. 12/10/04 9:25 AM

Manual ▾ count range 0 .. 10 -> brightness in logarithmic ▾ scale

- Unified interface for displaying pixel-specific data: photons, test pulses, leakage current, baseline voltage, etc.
- Near-real-time update, interval adjustable.
- Event selection in time and energy (wavelength) capable.
- Resting pointer at a pixel displays pixel coordinates and value as tooltip.
- Clicking on a pixel or dragging across corners of a group of pixels displays light curve and spectrum in new window.

Housekeeping sensor readings



Live time	92.07%	92.69%	0.26%	94.97%	91.88%	0.42%	92.96%	92.73%	0.25%	Dome	Pressure	13.53	13.54	4.0E-4	psi
det cts	2.0	1.37	0.13	0.0	2.25	0.3	1.0	1.67	0.16	PCB A	Temperat...	29.08	29.07	0.0043	deg C
Shld cnt	20.0	336.83	5.9	12.0	282.4	5.0	24.0	324.82	5.71	PMT A	Temperat...	25.79	25.79	0.0	deg C
reject	0.0	0.18	0.06	0.0	0.27	0.07	0.0	0.27	0.06	PCB C	Temperat...	27.77	27.78	0.0043	deg C
accept	2.0	1.18	0.12	0.0	1.93	0.28	1.0	1.33	0.15	PMT C	Temperat...	30.73	30.73	0.0018	deg C
shield	0.0	0.18	0.06	0.0	0.25	0.07	0.0	0.27	0.06	PCB B	Temperat...	29.08	29.08	0.0018	deg C
uP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	PMT B	Temperat...	28.42	28.42	0.0	deg C
pulser	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	An.board	Temperat...	24.03	24.03	0.0	deg C
A side	2.0	0.62	0.08	0.0	0.43	0.08	1.0	0.68	0.1	P/T ratio	P/T ratio	4095.0	4095.0	0.0	psi/K
B side	0.0	0.57	0.09	0.0	1.5	0.28	0.0	0.65	0.1	Fan/heater	Temperat...	23.92	23.92	0.0	deg C
A & B	0.0	0.0	0.0	0.0	0.02	0.02	0.0	0.0	0.0	DC->DC	Temperat...	26.01	26.01	0.0	deg C
neither	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2nd fan	Temperat...	24.47	24.47	0.0	deg C
Pulse?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	A can	Temperat...	24.03	24.03	0.0	deg C
veto?	1.0	1.0	0.0	1.0	1.0	0.0	1.0	1.0	0.0	B can	Temperat...	24.14	24.14	0.0	deg C
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	C can	Temperat...	23.92	23.92	0.0	deg C
	A cts/s	A mean 6...	A error	B cts/s	B mean 6...	B error	C cts/s	C mean 6...	C error	midflange	Temperat...	23.7	23.7	0.0	deg C
										inlet baffle	Temperat...	23.7	23.7	0.0	deg C
										+5V	Voltage	5.02	5.01	9.0E-4	V
										-5V	Voltage	-5.36	-5.25	0.0045	V
										+12V	Voltage	11.86	10.65	0.0203	V
										-12V	Voltage	-12.05	-12.15	0.0389	V
										+2.5V	Voltage	2.46	2.46	0.0010	V
										+28V	Voltage	29.1	29.06	0.0011	V
										DACref	Voltage	4.46	4.46	0.0	V
										4.5ref	Voltage	4095.0	4095.0	0.0	ADC chan...
												0.0	0.0	0.0	

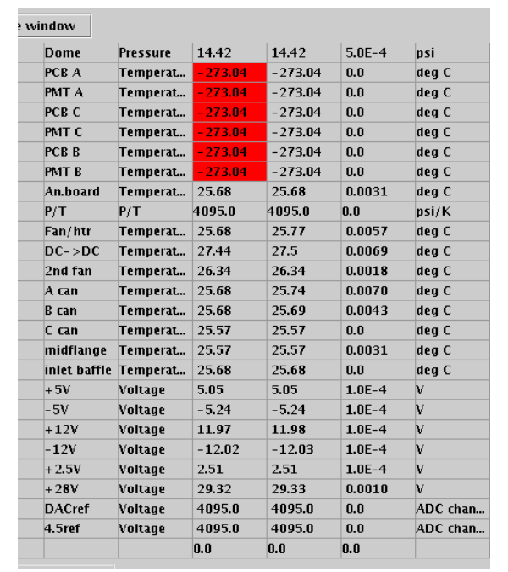
Show events tagged as □ shield □ pulser □ baseline ☑ No tag (X-ray/housekeeping)

□ with sequence ID= 0 only

ADC value range: Channel -100 .. 4,096

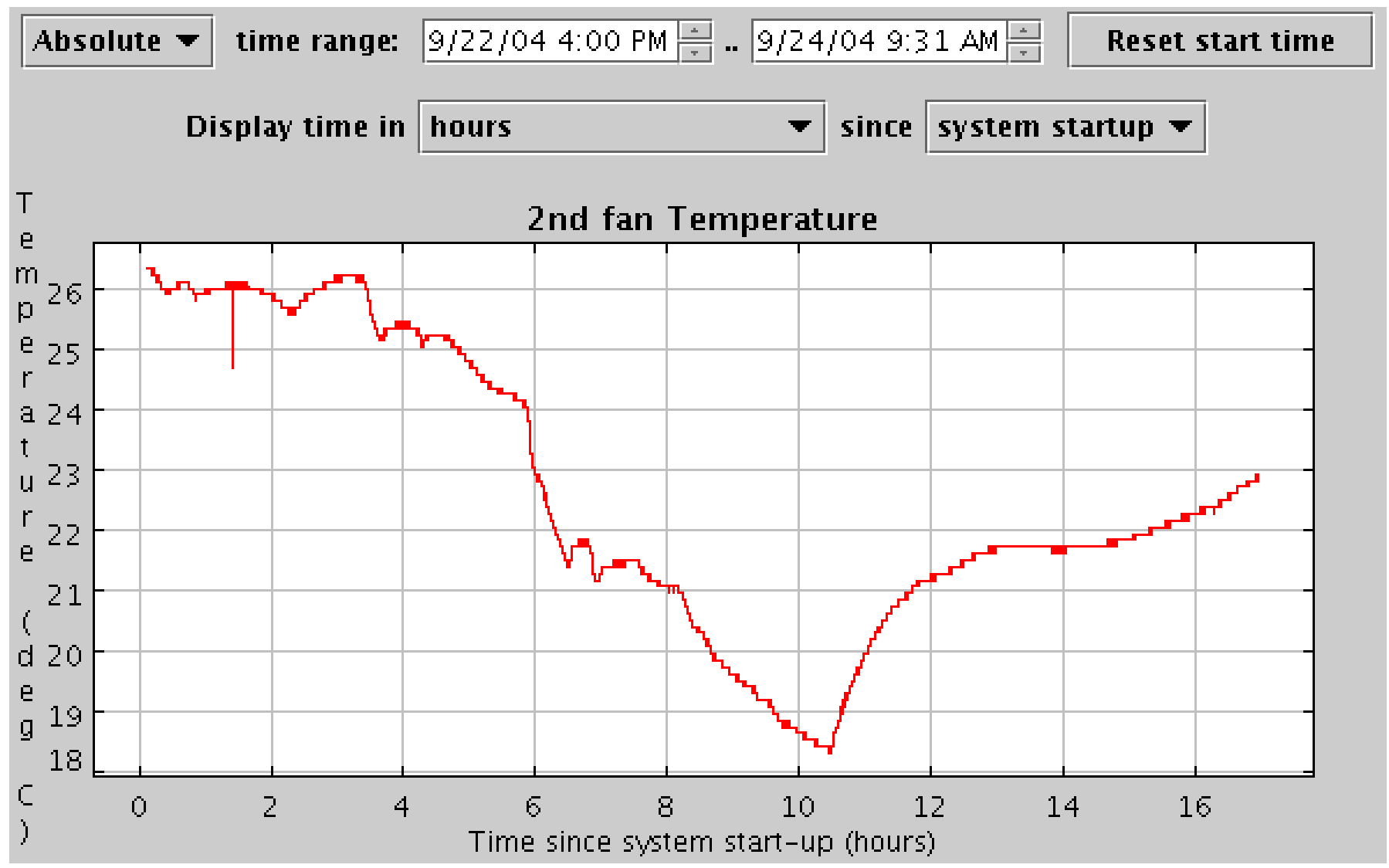
Absolute ▾ time range: 9/30/04 8:34 PM .. 9/30/04 8:34 PM

- Unified display of housekeeping sensor readings (of pressure, temperature and voltages), showing latest readings, 5-minute averages and standard deviations.
- Near-real-time update, interval adjustable.
- Clicking on a cell displays time-series in new window.
- Colour and (optional) audio alarms when a value goes out of expected range.



Dome	Pressure	14.42	14.42	5.0E-4	psi
PCB A	Temperat...	-273.04	-273.04	0.0	deg C
PMT A	Temperat...	-273.04	-273.04	0.0	deg C
PCB C	Temperat...	-273.04	-273.04	0.0	deg C
PMT C	Temperat...	-273.04	-273.04	0.0	deg C
PCB B	Temperat...	-273.04	-273.04	0.0	deg C
PMT B	Temperat...	-273.04	-273.04	0.0	deg C
An.board	Temperat...	25.68	25.68	0.0031	deg C
P/T	P/T	4095.0	4095.0	0.0	psi/K
Fan/htr	Temperat...	25.68	25.77	0.0057	deg C
DC->DC	Temperat...	27.44	27.5	0.0069	deg C
2nd fan	Temperat...	26.34	26.34	0.0018	deg C
A can	Temperat...	25.68	25.74	0.0070	deg C
B can	Temperat...	25.68	25.69	0.0043	deg C
C can	Temperat...	25.57	25.57	0.0	deg C
midflange	Temperat...	25.57	25.57	0.0031	deg C
inlet baffle	Temperat...	25.68	25.68	0.0	deg C
+5V	Voltage	5.05	5.05	1.0E-4	V
-5V	Voltage	-5.24	-5.24	1.0E-4	V
+12V	Voltage	11.97	11.98	1.0E-4	V
-12V	Voltage	-12.02	-12.03	1.0E-4	V
+2.5V	Voltage	2.51	2.51	1.0E-4	V
+28V	Voltage	29.32	29.33	0.0010	V
DACref	Voltage	4095.0	4095.0	0.0	ADC chan...
4.5ref	Voltage	4095.0	4095.0	0.0	ADC chan...
		0.0	0.0	0.0	

Time series, light curves and spectra



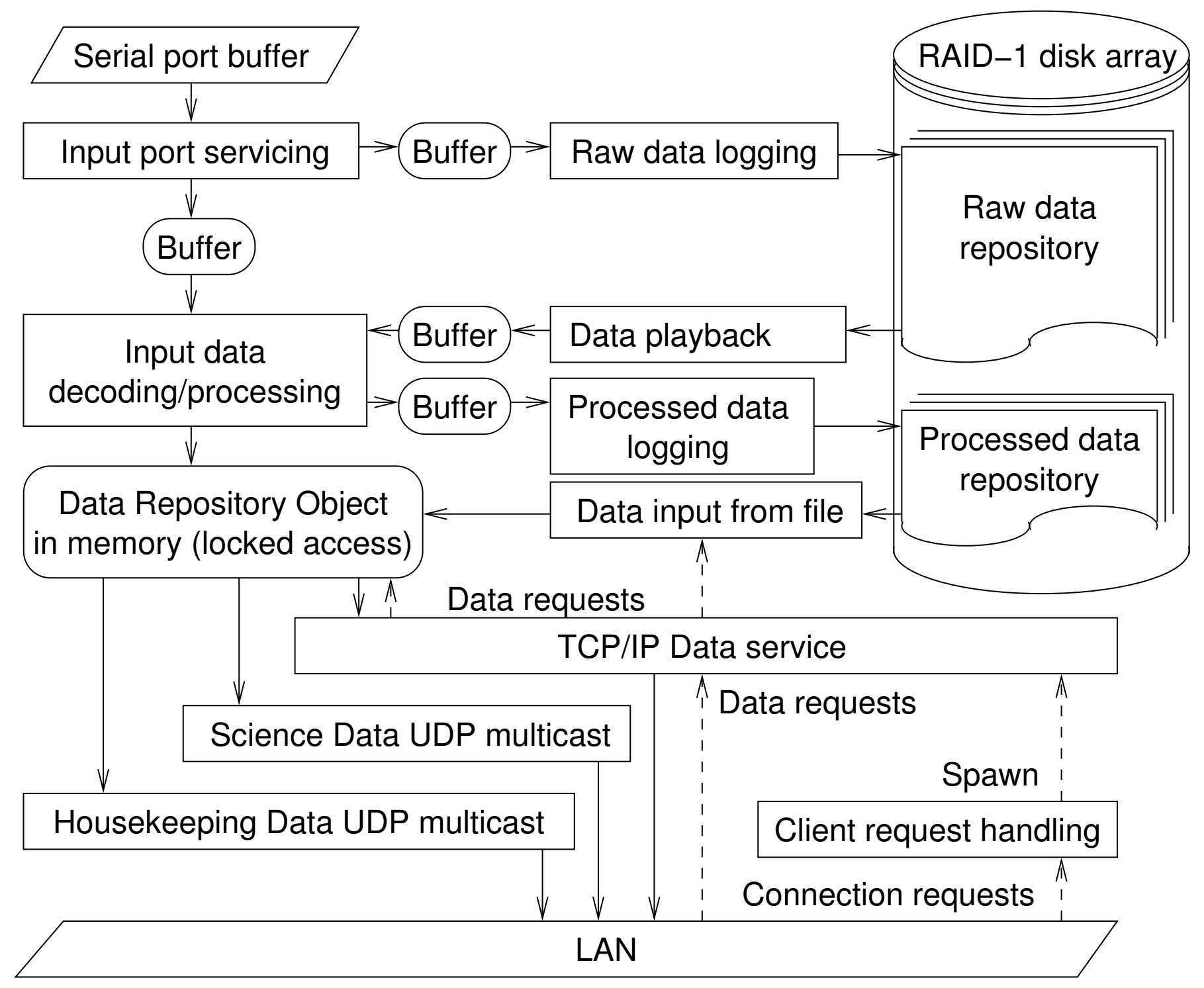
Absolute ▾ time range: 9/22/04 4:00 PM .. 9/24/04 9:31 AM

Display time in hours ▾ since system startup ▾

- Unified display of time series, light curves and spectra.
- Near-real-time update, interval adjustable.
- Event selection in time and energy (wavelength) capable.
- Zoom in by dragging pointer from top-left corner of zoom window to bottom-right; zoom out by the reverse.

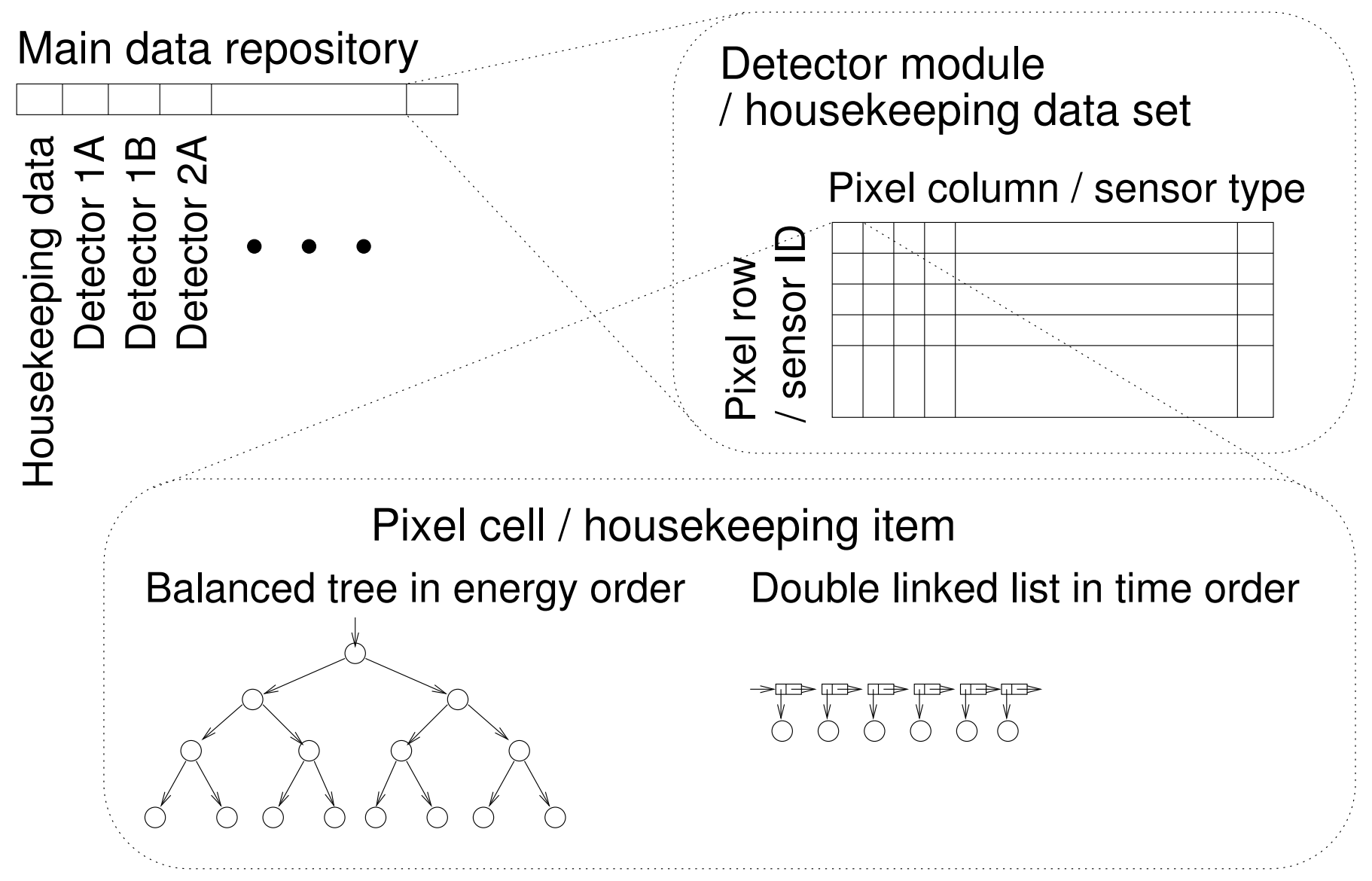
Implementation detail

Data server: Data flow



- Multi-threading provides modularity, enables incremental development.
- Task-specific servers (logging, playback) reuse the same code, running only relevant threads.
- Events from input serial port drives execution, minimizes risk of data loss.

Data server: Data structures


Main data repository
Housekeeping data
Detector 1A
Detector 1B
Detector 2A
• • •
Detector module / housekeeping data set
Pixel column / sensor type
Pixel row / sensor ID
Pixel cell / housekeeping item
Balanced tree in energy order
Double linked list in time order

- Data structures in both time and energy order allow efficient insertion, retrival and selection.
- Data from housekeeping sensors share the same data structure as pixel-specific data from detectors, reducing code complexity.

Display clients

- Multi-threading separates timed data request/input, graphical rendering, and user interface.
- Shared, common code for TCP/IP communication with data server for all Java clients, while graphical front ends vary.

Network interface

UDP multicast

- Latest science and housekeeping data require immediate mass distribution; occasional data loss is unimportant.
- Data server transmits data as UDP datagrams to designated IP multicast group address (and port) at 1 Hz; display clients 'tune' into the same group.
- Platform- and languange-independent protocols make possible separate code development for server and client, and modular upgrade/rewrite.

Byte	Content	
0– 3	Datagram ID: "HEFT" in ASCII (0x48, 0x45, 0x46, 0x54)	
4	Bits 0–4: Detector ID (0x2–0x7)	/ Housekeeping (0x0)
	Bits 5–7: Data type (photon/test pulse/vetoed/baseline)	
5	Pixel column ID (0–47)	/ sensor type (P/T/V)
6	Pixel row ID (0–23)	/ sensor ID
7–14	Time tag	
15–18	Pulse height	/ sensor reading

TCP/IP unicast

- User-selected time series, light curves and spectra requires dedicated communication line.
- Display client sends data requests (data type, $[x_{\min}, x_{\max}]$, $[y_{\min}, y_{\max}]$, $[E_{\min}, E_{\max}]$, $[t_{\min}, t_{\max}]$) to listening port on data server.
- Data server transmits requested data as serialization of Java objects (as all unicast clients are currently implemented in Java).

Performance and testing

We ran the system daily over two months-long flight campaigns, including a 110 hr-long continuous calibration run (wired input directly from the focal plane) and a 25 hr-long balloon flight (input from radio telemetry with data dropouts). Changes were made iteratively over the campaigns until a final code freeze in view of the balloon launch. The software has since been functioning, meeting specifications.

Invitation to adopt

This system, and individual ideas of its implementation, can be adapted for use in future experiments requiring sophisticated real-time monitoring and data display. We welcome discussions of prospects for collaboration and code reuse.

Acknowledgements: This work is funded by the NASA Space Science "Supporting Research and Technology" (SR&T) programme under award number NAG5-5398.