Networked Radiation Sensors

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Abstract

Collecting radiation data is a difficult task as most equipment is costly and custom built. The solution is a Geiger counter that transmits data, and a server that collects it. It provides low per unit cost, and data from many locations.

1 Introduction

Cosmic ray radiation from outside our solar system are powerful gamma rays that disperse after hitting out atmosphere. As we move closer to the edge of our atmosphere, their energy increases [1]. About 90% of cosmic rays are protons, and 9% are alpha particles [1]. These very high energy particles (called primaries)Strike the upper layer of the atmosphere and transfer their energy into particles classified as secondaries. The secondary rays consist of pions (that decay to muons, neutrinos, and gamma rays) and electrons and positrons [2]. The Figure 1 shows the how the atmospheric cascade reduces the energy of the primary particle into multiple weaker secondaries, if the energy of the primary is above 500MeV, the secondaries will still reach earth's surface before dissipation [3].

The average energy of primary particles is 1GeV (corresponding to .87C) although TeV occurrences have been measured.[1]. While at sea level the radiation caused by the particles is low with an intensity of $100 \frac{particles}{m^2 s}$ [2], it can still cause memory electronic errors, and health effects to aviation [4] and space personnel.

1.1 Previous Research

The sensors currently available for radiation detection are expensive, devices made once with limited documentation to how they work, and are used. They provide a very small set of data, and at only a single location, generally inside a climate controlled lab. The devices are designed without the consideration of making more devices, and creating additional devices adds greatly to both the cost and time. Previously data has been collected and used, but in very limited amounts. The data collected has been from distant locations such as

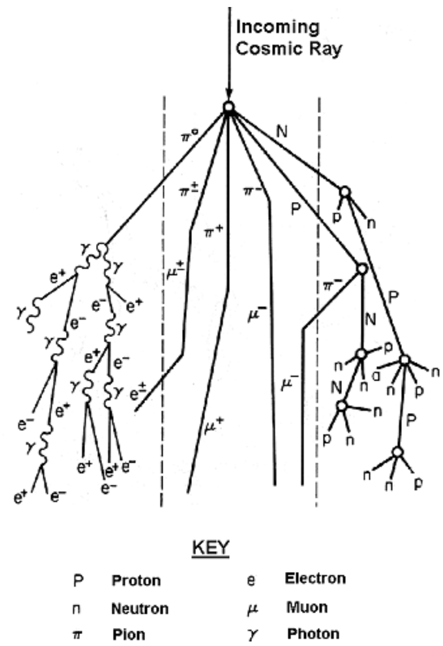


Figure 1: Atmospheric cascade.

the radiation sensor on campus, while the weather readings are measured from Peachtree City Observation Station [5], approximately thirty miles away this provides general readings but the weather variance can be so great between those locations that precise coloration is difficult to accomplish. The newer results use a weather station atop the building, but the sensors are physically too close that all the data from the detectors would not give information on the larger scale.

1.2 Infrastructure

With city infrastructure getting denser and complex, the threat of dirty bombs and danger from nuclear power facilities pose a risk in tightly packed urban areas. Detecting radiation on such a scale is difficult, expensive, and is difficult to justify the cost when the funds can be allocated to other infrastructure. Small inexpensive mountable mesh of sensors can provide real time location based radiation readings and sensors mounted on public transit and government vehicles would also provide geolocation data for trackable readings. These could give information critical to the current security for anti terrorism, public safety, and long term data that provides information on how average radiation readings fluctuate.

1.3 Workplace

In locations where retroactively hazardous materials could be handled this information can be helpful to mitigate problems caused by human error. An example scenario could be a worker dealing with radioactive materials, leaving the room without placing the sample back into storage. The system could also warn the personnel overseeing a nuclear power plant of any leaks of contamination due to the larger amount of area the sensors would cover at the same cost as currently used sensors.

1.4 Current Options

The options for the collection of current data has been very sparse. Small hand held sensors can provide data that would either have to be manually logged, along with the location and hence is highly impractical. Other options include addons to weather stations, and computers with many sensors connected via USB, and modular sensor systems. But the major problem with all these options is the physical size and high power consumption that limits the locations and areas the devices can be placed. Most devices have a volume of ten to one hundred times the volume of the sensing apparatus, and a power consumption on the order of ten to hundreds of milliamps, that is too high for long term data logging.

1.5 Requirements

An ideal sensor setup would consist of a physically small sensor with very low power consumption. Multiple transmitters with little computing all sending to a single internet connected receiver with error checking. It should be physically strong, easily mountable, and weather proof. Finally the unit should be designed for manufacturing to make the cost per unit as low as possible. The device should have good code and hardware documentation for further research and for others to use it as a platform for making other sensors.

2 Methods

The construction of this sensor will follow a hardware driven methodology as cost is the major factor in determination of components and functionality. Everything will be built in a modular fashion to make expansions and future development simple. The components will be designed in sections talking in power and signals, or outputting data.

2.1 Hardware

The general build of the hardware will consist of a microcontroller, the acting processor, executing code based on inputs and outputs attached. There will be sensor attached to multiple pins including temperature, humidity, light, and location sensors. The high voltage power supply tuned to hold the a Geiger tube at its operating voltage. A sector for collecting and storing power, and finally a wireless transmitter.

Microcontroller The selection of the microcontroller is the factor the rest of the project will be constructed around. The prototypes were initially made from the ATtiny13A made by Atmel. It is a eight pin device in package sizes down to $3mm \times 3mm$. It was chosen for its low cost, and personal experience with the Atmel's offerings. As pins ran out and additional functionality was needed, an upgrade to ATtiny24 was in order, it provided six additional sensor and communication pins. The programming is done though C and/or Avr assembly, a lower level interface for faster operations.

The receiver is mainly being designed for testing, and will be made in the Arduino (a popular prototyping platform based on Atmel microcontrolers) and programmed in C++ for quicker prototyping.

Wireless The wireless system will consist of a transmitter on the sensing device communicating at either 433 MHz or 915 MHz as those are the legal ISM (Industrial, Scientific, Manufacturing) frequencies in most of the world. Another option would be the 2.4GHz band, but with a lower penetration and a more congested frequency it is a worse option, the lower frequencies have enough bandwidth. These bands are FCC compliant to keep certification simple, and the transmitter will be using a trace antenna, one that resides only on the circuit board, to keep costs low.

Sensors The main requirement of the device is to sense radioactive particles, so a Geiger Müller tube will be used, the SBM-20 shown in Figure 2, a Russian tube designed for detecting Hard Beta, and Gama rays. With a manageable recommended voltage of 400 V, pulse life of 2×10^{10}, and ease of availability, makes it a great choice [6]. Other sensors such as a temperature, humidity, and light will be added to provide ambient information. GPS sensors will be designed as an expansion module for devices that are expected to have changed position after installation, such as those on rail.

Figure 2: SBM-20 Geiger Muller Tubes [6]

Power Power to the unit will be provided through a lithium ion 3.7V (nominal) battery such as those common in consumer electronics. Its safety will be manged by a charging and protection chip which will be able to monitor current draw, and provide recharging power through a solar panel attached outside the enclosure. The high voltage supply will be a simple boost converter (a circuit that uses the voltage rise in inductors to generate higher voltages) tuned to the 400V required for the Geiger tube.

Casing Enclosure design will be based around PVC pipe for lower volume and injection molded ABS for higher volumes. The pipe is conducive to the long components that take the majority of the volume of the design. The Tube, and the battery will stack vertically with PCB (printed circuit board layers) in the middle very similar to Cordwood construction ,exampled in Figure 3, previously used in missile and telemetry systems where space was at a premium. These layers will be connected with long strips of PCB material connecting them top provide rigidity and structure and act as power lines. The ABS design will be based on ease of mounting and identification of the modules.

Figure 3: A circuit built with stacked PCB [7]

2.2 Software

Software will be programed in AVR C for the transmitter and C++ and Java for the receiver for quicker prototyping. Code flow with be dependent on incoming pulses form the radiation detector. Upon receiving the microcontroller will cycle through it's duties shown in Figure 4 before returning to sleep(the low power mode).

Encoding The receivers auto gain control adjusts to ambient noise level. This means the gain must be reduced before the first byte can be transmitted. There is a pulse train of square waves one unit width in timing that are transmitted before any messages to reduce gain and therefore interference. Then a synchronization pulse is sent so the receiver knows where to begin timing. The data is sent in a Manchester encoding style as recommended in RF Monolithic guide [8]. This forces the output pin to not remain in one state for too long causing the gain to not fluctuate as much as it might otherwise by sending the inverse of the previous bit for one unit, see Figure 5 as reference. The encoded

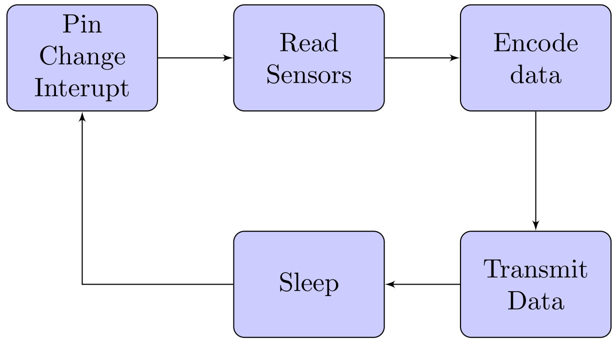


Figure 4: Software Structure

data to send will include ID of the unit (set at install), the readings from the sensors, and calculated parity bits to verify data on the receiving end.

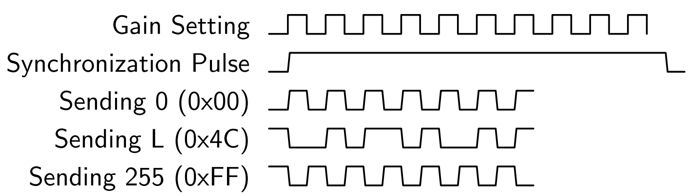


Figure 5: Timing Tables of transmitting pulses

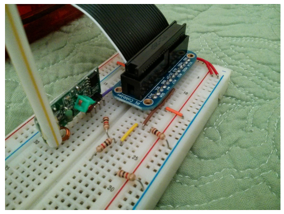
2.3 Testing

The devices will be range tested at distances of up to 100m for both data integrity, and verification that the majority of pulses that occur are received. With the solar panel, discharge rate and recharging time will be addressed to verify that device will remain operable over its lifespan.

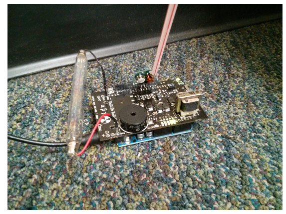
2.4 Production

Designing for production requires more forethought than when building a one off system.

Scaling The quantity is the major determinate in at what cost you can build your devices. Component selection is important as slight cost increases trickle to larger costs. The cost assembly and shipping become major expenditures as with smaller runs, the designer does assembly and shipping is consider to be nominal as it only occurs once. Another important aspect during scaling is to consider time required between each step, different fabrication facilities have varying fulfillment times.



(a) Raspberry Pi RX



(b) Arduino Transmitter

Figure 6: Prototype devices

Documentation Documenting work for future development will be done though a document that explains the use and modifications required for it to fit the purpose. The hardware will have 3D models created for it during development and those will provide diagrams and animations for documentation.

3 Results

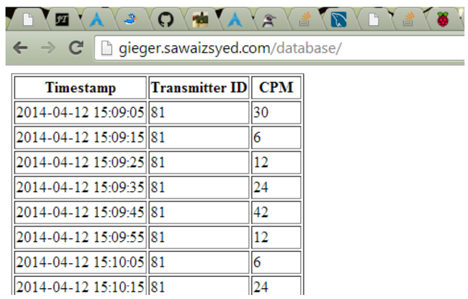
The device, although still under development, has reached a late prototype stage. Many of the design goals set out were reached. Circuits and schematics still need to be finalized therefore testing was completed with the prototypes, Figure 6.

Power The device design has not reached the phase to focus on power consumption. The power regulators on the board consume the majority of power and therefore even an estimation of the final designs power consumption would not be possible. The unit is not able to run for elongated periods of time on batteries, although because the average current consumption is less than 100mA and is dependent on the amount of radiation it could be run from a solar panel.

Cost Although the price per module was not reduced to the expected final product's cost, the device's cost per sensor is lower than commercially available sensors. The cost per module was reduced to about $130 per transmitter mostly representing the cost of the Arduino Geiger Shield, with the Microcontroller unit and radio transmitter as the rest of the cost.

Testing Range Range tests were conducted of the 433 MHz modules with a 173mm quarter wave whip antenna, with an indoor range of approximately 10m, it can be used in close range, but would fare much better outdoors. With a longer range due to less obstruction, approximately 30m is enough to mount receivers on lamp posts in urban areas, and attach the sensing transmitters to nearby buildings. Testing of multiple devices was also done, the receiver successfully took data from two sensors and differentiated counts based on their address. Through testing, of the 13588 rows transmitted, only 14 were not received properly.

Server The server was built on two platforms based on usage scenarios. The Raspberry Pi (a small, inexpensive ARM based computer), and a Arduio. The Raspberry Pi also has the advantage of not needing anything but a 700mA power connector and an Ethernet port. This server is able to provide live data through a web page and internally through a SQL query-able database shown in Figure 7. The Arduino based implementation (Figure 8) is great for debugging and testing transmitter technologies before they need to be ported.



Timestamp	Transmitter ID	CPM
2014-04-12 15:09:05	81	30
2014-04-12 15:09:15	81	6
2014-04-12 15:09:25	81	12
2014-04-12 15:09:35	81	24
2014-04-12 15:09:45	81	42
2014-04-12 15:09:55	81	12
2014-04-12 15:10:05	81	6
2014-04-12 15:10:15	81	24

Figure 7: Web Page hosted on Raspberry Pi

Documentation All the hardware and software specifications to this point are hosted on-line under open source licenses. There is also documentation of hardware setups and code hosted on an internal Wiki for parallel testing. This documentation allows upkeep of the code-base and devices by others.

Future Prospects

The device still has a lot to be completed before it reaches the production quality needed. The prototype has shown significant promise and therefore steps to the final product should be few.

Production Preparing the device for production, with custom made circuit boards, and reducing connectors, and part counts is the best way to reduce cost. For this to take place, components need to be ordered an assembled in prototypes of circuit boards and casing.

Radio Transmitter For longer range modules using the NRF24L01+ chip based modules, are available and suggest a more concrete hardware link, and with their engineered antennas, provide longer range.

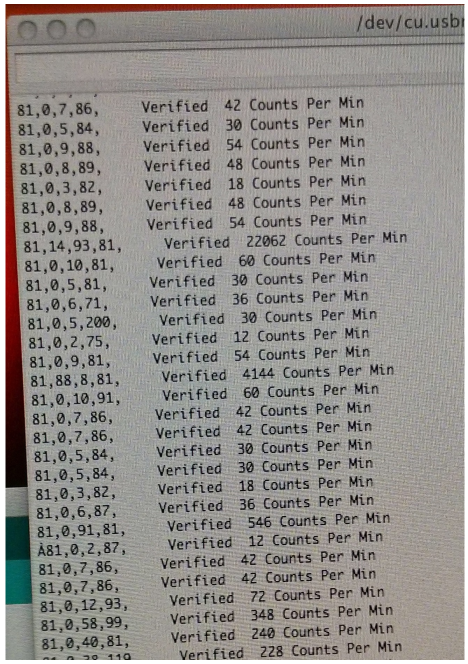


Figure 8: Arduino Receiving Data

4 Conclusion

The design has taken many strides from the idea, as this is the initial prototype, the amount of progress is substantial. This lays a working model for future development.

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