USDA UV-B monitoring system: An application of centralized architecture

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Abstract

In order to monitor the spatial and temporal variations of solar ultraviolet-B (UV-B) radiation reaching the Earth surface, US Department of Agriculture (USDA) UV-B monitoring system has been developed to make ground-based measurements of UV-B radiation, photosynthetically active radiation (PAR), and temperature as well as to provide essential information to the research community, decision makers, and the public. This data collection and processing system was designed as a centralized system with a star network topology covering the domain of the United States with two sites in Canada and one in New Zealand. The system is controlled by a central data server and measurements are collected through programmed data loggers. While a centralized architecture has the single failure problem, it makes the system less complex to build, implement, and maintain. In this paper, we present the system architecture, algorithms for data collection, and data flow in the data processing procedures. Samples of our measurements and products are also shown. This work shows the principle application of centralized architecture in distributed computing and is a good reference for designers of similar systems.

Key words: UV-B radiation, distributed system, centralized architecture

1. Introduction

Ultraviolet (UV) radiation refers to a specific portion of the sun's radiative energy at shorter wavelengths. The near UV radiation at wavelengths 315-400 nm, which is close to visible light, is classified as UV-A. Solar radiation at progressive shorter wavelengths is classified as UV-B (280-315 nm) and UV-C (200-280 nm) [19]. UV radiation is recognized harmful to lives on the Earth. For human beings, excessive exposure to UV radiation (especially UV-B) can cause skin cancers, erythema, eye cataracts, or suppression of immune system [6, 19, 26]. It also brings about various damages on plants and other life forms such as reductions in plant photosynthesis and productivity [4, 8, 17, 28].

UV-C radiation is prevented from reaching the Earth's surface by the absorption of atmospheric ozone and oxygen [19]. Atmospheric gases absorb very little UV-A radiation. The intensity of UV-B radiation reaching the Earth's surface is strongly influenced by atmospheric ozone. Recent depletion of atmospheric ozone [7, 29], which is mainly caused by anthropogenic activities, raises serious concerns about the concomitant increases in UV-B radiation reaching the Earth's surface [3, 5, 9, 11, 15, 16, 18] and its detrimental effects on plants and humans [4, 6, 8, 17, 25, 28]. Initiated by the USDA in 1992, the USDA UV-B Monitoring and Research Program (UVMRP) has set up a monitoring network to provide essential information for assessing the potential impacts of increasing UV-B level on agriculture, environment, and humans [1, 2].

As an application of centralized distributed system, this network is automated by networked computers, data loggers, sensors, and probes. A central processing computer (master) is connected with data loggers (chips, slaves) that are distributed over the United States with two observation sites in Canada and one in New Zealand. This paper presents the system architecture, explains its design principle, gives the algorithms for collecting and processing data, and discusses our experiences with this system.

This work exhibits a successful example to apply a good principle and paradigm in the design of operational systems. It may serve as a good reference for designing, implementing, and developing operational distributed systems. The next section gives the domain of the network coverage. Then the system as-

Citation: Proceedings of the 2006 International Conference on Parallel & Distributed Processing Techniques and Applications & Conference on Real-Time Computing Systems & Applications (PDPTA'06), Vol I, Eds: Hamid R. Arabnia, Maria Artishchev-Zapolosky, Steve C. Chiu, Yefin Dinitz, Kazuki Joe, and Mario Nakamori, Las Vegas, Nevada, USA, June 26-29, 2006, CSREA Press,

sumptions and how they are managed in practice are explained. Algorithms for data collection and processing are presented in Section 4. Samples of products are shown in the following section. Finally we conclude this work in Section 6.

2. Network Coverage

As of 2005, thirty-two observation sites in the United States of America are operating in the network (Figure 1), with two cooperated sites in Canada and one in New Zealand. They spread over the continental United States with additional coverage of Alaska and Hawaii [2].

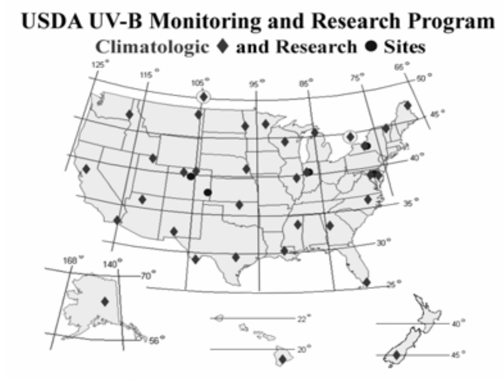

Figure 1. Network coverage as of 2005.

Figure 2. Layout of instruments at a site.

Each of the sites is equipped with instruments for measuring UV-B radiation [14, 30, 31], PAR (at wavelengths 400-700 nm) [23], air temperature, air relative humidity, and air pressure. As shown in Figure 2, all of the instruments are mounted at about the same height (about 1 m above the ground) and are connected to an onboard data logger that is operated with a processor chip. The chip is programmed to collect measurements every 15/20 seconds, to aggregate these real-time measurements to 3-min averages and store them on the chip, and to carry out primary computations. When it is polled, the chip also communicates with the UVMRP central data server to transfer the stored 3-min averaged data through either a designated phone line or the Internet. The instruments and the data logger are driven by AC power with batteries in line to act as a backup in case the AC power fluctuates/outages for a short time.

3. System Model

The monitoring network can be modeled as an asynchronous static distributed system of thirty-six processes. Let $P = \{p_0, p_1, p_2, \cdots, p_{35}\}$ denote the process set with p_0 being the UVMRP central data server and p_1, p_2, …, p_{35} representing the data loggers. We use p_i to denote a process that is uniquely identified with integer i. Process membership is static, that is, no process leaves or joins the system during the lifetime of the system. Each of the processes is programmed to run continuously. While the basic task for p_i, i = 1, …, 35, is to collect data from the attached sensors and process the raw real-time measurements primarily, process p_0 is programmed to muster data from all other processes and manipulate the data for products of different levels. In addition, we assume that all of the processes are not faulty. Although some of them may be down during a period of time, this situation will be detected and fixed by other means. In practice, this non-faulty assumption significantly simplifies the design and implementation of the system.

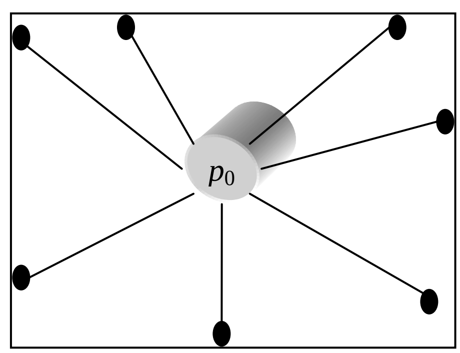

Figure 3. The system architecture.

The network topology is schematically shown in Figure 3. It can be considered as a centralized system of a star architecture with p_0 as the designated master and the others as slaves. Process p_0 is running on the UVMRP data server, which is located at Colorado State University at Fort Collins, Colorado. It is connected to each of the other processes through either a designated phone line or the Internet. For simplicity, we assume that a link exists between p_0 and each of the others through which they can communicate. This master/slave paradigm further simplifies the system design and operation. Except for local computations, the activities of slave processes are controlled by the master. Status of each slave process is monitored through the master, making it much less complex to design and operate the system. Faults either over the network or in a data logger can be detected and fixed in a short time.

The processes share neither common memory nor a global clock. They coordinate and cooperate solely through message passing over the communication network. Communications between them are reliable in the sense that each of the communicated messages is not corrupted, no spurious message is inserted into the network, messages are not duplicated, and each message is delivered to the intended destination. From a process perspective, a required communication is abstracted as a file send or a file receipt event. The file may in turn be transferred over the network in multiple data grams or packages. The underlying network delivery mechanism reconstructs the original file from its constituent data grams and delivers it to the application. A FIFO channel is not required as long as each of the transferred files is identified and assembled at the end of the server by the underlying network protocol before the file is delivered to p_0.

In operation, the membership of a process may change, especially the data loggers. Some old or damaged data loggers need to be replaced with new ones. New data loggers may be added and data loggers at old observation sites may exit the system. However, these faults are detected manually and the changes are planned in advance. The system is reconfigured when changes have been made. Consequently, the system can still be considered as being static during the period when no changes are made. Processes may also be faulty during the operation due to unpredictable reasons. For example, data loggers may be damaged or wires may be chewed by mice. Communication network may be down. And the UVMRP data server could work incorrectly or could be down. These faults are detected manually by technicians and are fixed immediately when found. For simplicity, the system is not designed to tolerate faults except necessary backups for the data on the server.

4. Algorithms

Different algorithms have been designed and implemented to operate the system. In this section, we will present protocols for data collection and processing as well as data flow in the following data processing procedures.

4.1 Data Collection

Two algorithms have been developed for data collection at different levels. One (referred to as data logger program) is implemented with the data loggers for them to scan attached sensors periodically. The other is designed for the UVMRP data server to collect measurements from the data loggers and is referred to as data polling protocol.

4.1.1 Data Logger Program

An algorithm is designed to satisfy the required functionality of a data logger (Table 1). It is essentially an infinite loop. The data logger scans attached sensors periodically for their voltages and dumps the signals into a buffer. For simplicity, this buffer is designed as a FIFO queue so that it is cleaned up automatically when new inputs are added. Since the system stores 3-min mean values only, the averages are computed periodically and the buffer is reused. These 3-min averages are stored in the chip for being polled later by the UVMRP data server that gathers the data every day. For safety, the storage is designed for an accommodation of two days' 3-min averages. In case the data are lost or corrupted during the transportation in the communication network, they can be recovered from the data logger storage. We consider it necessary to backup previous day's data for preventing permanent loss of original measurements.

Table 1. The algorithm of data logger program

```
loop:
   scan sensors for their voltages every 15/20 s;
   buffer the real time measurements;
   compute averages every 3 min and store them;
   clean up buffer for next 3 min;
```

4.1.2 Data Polling Protocol

The functionality of this protocol is essentially to collect measurements from the data loggers through the underlying network. For simplicity, it is designed in the master-slave paradigm. The UVMRP data server polls data from each data logger every day at about the same time and resets the data logger's clock to synchronize the system time. At the other end, a data logger transfers measurements in its buffer when it is demanded. Table 2 describes the protocol.

Table 2. The data polling protocol

protocol for the master (p_0):	**protocol for a slave (p_i, i = 1, 2, …, 32):**
when scheduled; for each p_i, i = 1, 2, …, 32 do request p_i for data; store the data in a buffer when arrive; send local time to p_i;	when requested for data from p_0: send previous day's data to p_0; when receives time from p_0: set local clock with the received time;

Process p_0 runs on the UVMRP data server at nights. When it is scheduled, p_0 polls the data loggers one by one for collecting data. Protocol for a data logger is straightforward. Whenever a request is received, it sends the data that were collected in the previous day. Note that the system's time is synchronized with the time from the UVMRP data server.

4.2 Data Processing

The UVMRP data server collects raw voltage measurements from the data loggers. Various data processing algorithms have been implemented to convert these voltages to irradiances and generate products of different levels. Instead of presenting the scientific algorithms, here we describe the data flow in the procedures of data processing.

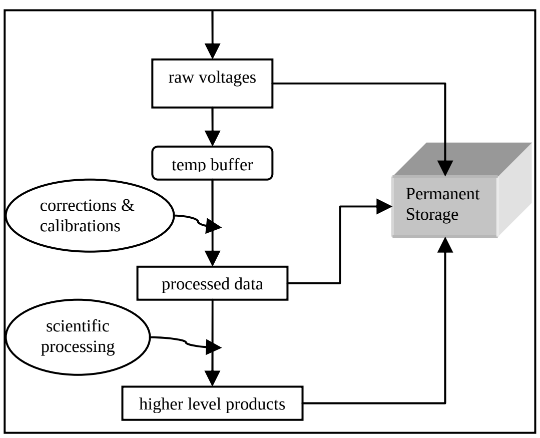

Figure 4. Data flow in the data processing procedures.

As shown in Figure 4, the data processing procedures start with raw voltage measurements. For the purpose of safety, two copies of raw voltages are made on the UVMRP data server. One copy resides in a temporary buffer for the use in the following processing procedures, while the other is stored in a permanent storage, which may be a disk, a magnetic tape or a CD. These two copies of raw data are necessary for improving the system performance as well as preventing the original measurements from permanent loss. Before converting voltages to irradiances (the processed data), necessary corrections are made, including nighttime bias correction and cosine (angular) correction. The former is generated by electronics of the observation system, including the data logger, the amplifiers, the circuits, and the connection wires, in the absence of solar radiation since the system is operated by an AC power [20]. The latter is the correction for the deviation of the senor response from an ideal cosine regulation [12, 14, 24]. Based on our recent research results, various higher level products are produced from the processed data, such as daily column ozone and optical depths [10, 13, 27].

Note that raw voltage measurements, processed data, and higher level products are stored in a permanent storage. Technically, it might not be necessary to store processed data and the products for saving permanent storages since they can always be computed from the raw voltage measurements through the aforementioned processing procedures. However, they are used for different purposes by people in various groups. By saving the products can always enhance the system performance, especially when products are published on a Web page through the Internet.

4.3 Product Publication

Products of different levels are published through a Web page/database, which provides users with processed data and derived products. Figure 5 shows an example of the product Web page. It explains the page contents and briefly introduces the products. By clicking on the self-explainable buttons, a user can either view plots of the corresponding products or download the data that are used to generate the plots through the Internet.

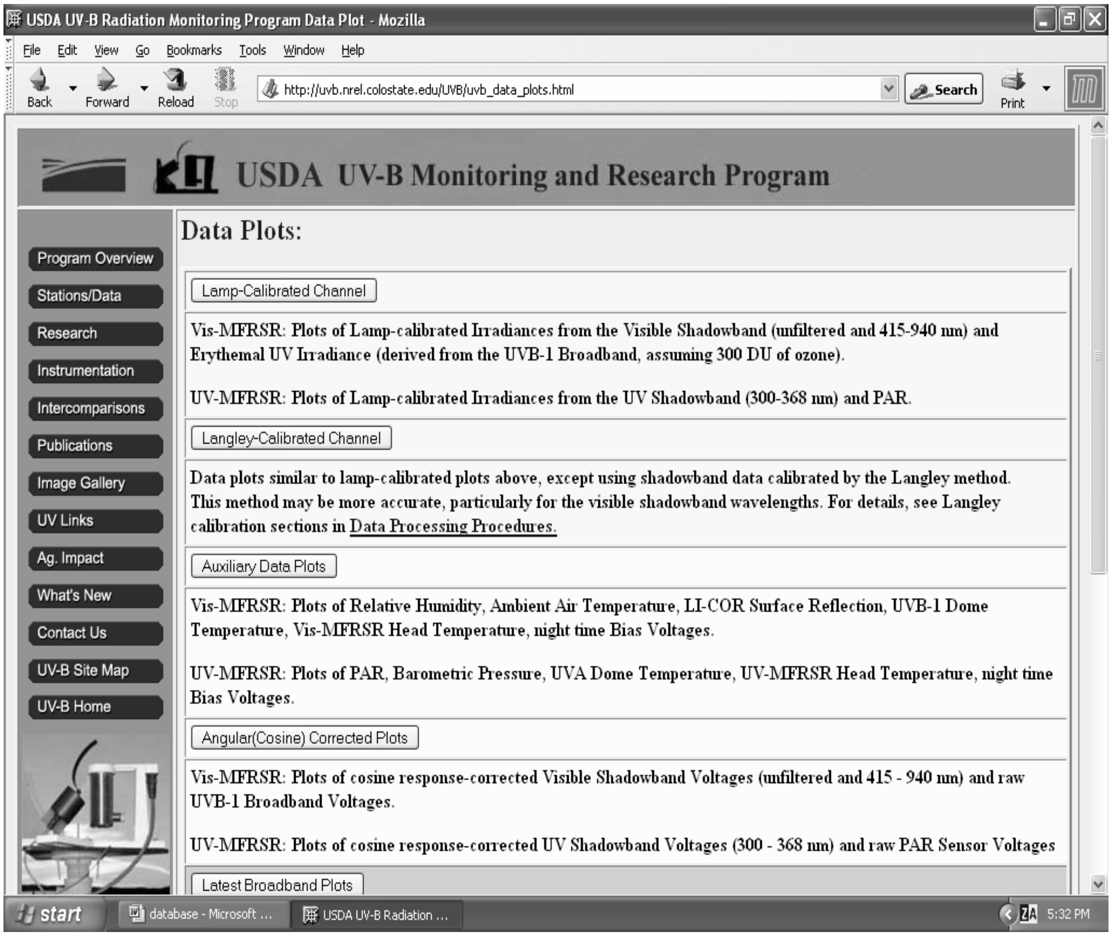

Figure 5. An example of Web-based product publisher.

This Web page/database is designed under the client-server paradigm. All data reside on the UVMRP data server and a Web service demon is running continuously to provide various services for any client requests. Requirements can also be directed to UVMRP staff for special services.

5. Sample Results

Our measurements include, among others, UV-B irradiances at different wavelengths, erythemal weighted UV-B index, and PAR. Three-minute averages of these measurements fabricate our database of processed data and provide essential data sets and information to interested researchers. As an example, Figure 6 shows the erythemal weighted irradiances observed in August 2005 at the Pawnee site in Colorado, USA.

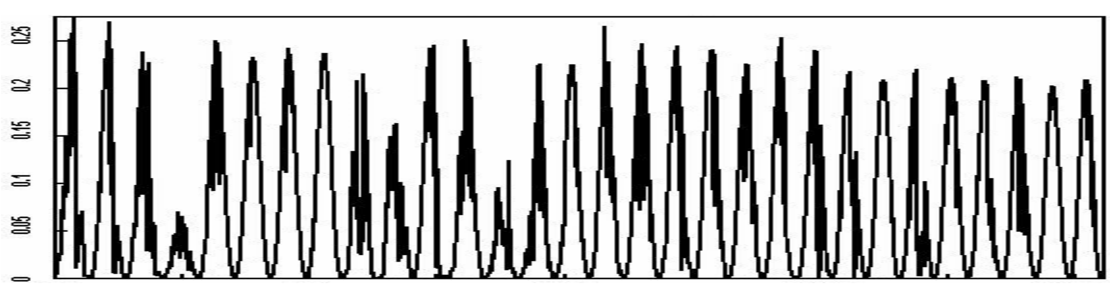

Figure 6. Erythema weighted UV-B irradiance (W/m^2) in August, 2005, Pawnee, Colorado, USA.

Erythema (reddening spots on skins) is a sort of skin damage caused by exposure in UV radiation (especially UV-B). A weighted integration of radiation spectrum in these wavelengths is called erythemal index [21, 22]. From Figure 6 we can see clear diurnal variations of erythemal weighted irradiance with peaks around solar noon. Exposure in the sunlight around noon is more risky than other times in a day.

6. Conclusion and Discussion

We have presented the architecture of USDA UV-B monitoring system and the algorithms for data collection. This system is a subsystem of USDA UV-B Monitoring and Research Program for data collection and processing as well as product publication through the Internet. This system covers the continental United States with the additional coverage of Alaska and Hawaii. Two sites are located in Canada and one in New Zealand. Thirty-five observation sites equipped with UV-B instruments, among others, are operating in this domain. Each site is operated with a programmed data logger (a processor chip). The system is controlled by the central UVMRP data server. With a star network topology, a master-slave paradigm, and a client-server design, this system is a typical application of a centralized architecture. While the centralized system possesses the inherent drawback of single failure problem, this architecture makes the system less complex to build and operate. Since it was initiated in 1994, our system has been providing high quality data to the research community, decision makers, and the public [1, 2].

Based on our research results, techniques have been developed for retrieving useful information from our measurements, including optical depths and daily column ozone [10, 13, 27], among others. As examples, we presented samples of our data and produced results. Internet access to all of our data and products is available for users through the Web site "http://uvb.nrel.colostate.edu/UVB".

Although this system has been operating for more than a decade, there is still room for improvements. Data are transferred through the Internet connection or designated phone lines. Security vulnerability may exist and will be more important when the system is accessed by more and more people, especially to our Web-based database. With the growth of user community, faster measures and algorithms will be necessary for product publication. Algorithms for fault tolerance may be helpful to reduce manual workload.

Acknowledgement

This work is funded by USDA UV-B Monitoring and Research Program under a grant from USDA CSREES 2005-34263-14270.

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