SVD-based Hierarchical Data Gathering for Environmental Monitoring

Abstract
We introduce a new data compression method for efficient data gathering in hierarchical sensor networks. Our proposed method compresses sensor data sequences by decomposing them into local patterns and weight variables using Singular Value Decomposition (SVD). Our proposed method can achieve efficient data gathering for environmental monitoring.

Author Keywords
Sensor networks; SVD; Environmental monitoring

ACM Classification Keywords
C.2.1 Sensor networks

Introduction
Sensor network systems capable of aggregating data monitored by thousands of sensors would enable us to achieve numerous ubiquitous computing applications, including environmental monitoring. A base station aggregates sensor data (e.g., light, temperature, humidity, sunshine, gas, wind) from numerous sensor nodes and analyzes them for the various applications.

Environmental monitoring has large potential to promote efficient agriculture. Eustoma is a cut flower commonly used for ceremonial functions. Although
Eustoma is very profitable, it is difficult to grow long and its price depends on its length. Farmers need knowledge about optimum cultivation environments. Fig. 1 shows a eustoma greenhouse that cooperated with our experiments.

Wireless sensor networks can gather such environmental data. However, since the battery power of each sensor node and the wireless bandwidth are limited, we focus on effective data compression for environmental monitoring. Most environmental data, such as temperature and humidity, periodically repeat similar patterns everyday. We expect to identify the correlated data patterns in the greenhouses because farmers water all their plants or set sunshades for them at the same time.

We propose a data gathering method by exploiting two characteristics of environmental sensor data: the periodicity of sensor data sequences and data correlation among sensor nodes. Although there are many works on sensor data gathering algorithms (e.g. [1] and [5]), our proposed method exploits both of the characteristics and it is enough simple to perform with the limited computational resources of small sensor nodes.

**Proposed method**

We compress sensor data sequences using Singular Value Decomposition (SVD). Sensor data sequences are decomposed to typical data sequences (called local patterns) and the weight variables for local patterns. We can approximate sensor data sequences using a small number of local patterns if the sequences periodically repeat similar movements.

The SVD-based data aggregation can be repeated hierarchically. Fig. 2 is an example of hierarchical data gathering. In the middle of the tree topology, a sensor node aggregates data sequences from neighboring sensor nodes. The base station receives common local patterns from the entire sensor network and weight variables to reconstruct the original data sequences.

Fig. 3 shows the data compression details. First, the sensor node normalizes the sensor data sequences and stores them to matrix $A$. Next, it decomposes matrix $A$ to weight variable ($W$) and local pattern ($V$) by SVD. It just sends several local patterns ($V'$) whose contribution ratio is high. When the base station receives the data, it restores the data sequences by multiplication of received $W'$ and $V'$. 
When the sensor node sends a new data sequence, it calculates new $W$ and only sends $W$ as compressed data if the error ($e$) is smaller than threshold $\epsilon$. If the $e$ exceeds $\epsilon$, the local pattern is updated.

In hierarchical data gathering, the process of each sensor node is almost the same. The updated local patterns are transferred to a parent sensor node who processes the received local patterns from its child nodes in the same manner as its own sequences, and forwards them to its parent (Fig. 2). Finally, the base station receives all the sensor data and restores the data sequence by recursive multiplication of $W'$ and $V'$.

The idea of hierarchical SVD was inspired by previous work [3].

**Demonstration**

In our demonstration, we show actual data gathering by the proposed method using small sensor nodes (Fig. 4). Table 1 shows their detailed specifications. We used our proposed CIL virtual machine CILIX [2], and implemented an incremental SVD [4] because of its limited computational power. The actual data gathering program was written by Visual C#. The length of one data sequence is 24, and the number of columns of matrix $A$ is 12 based on the memory size and...
computational power of the sensor nodes. Fig. 5 shows a screenshot of the brightness visualization from eight sensor nodes. Each sensor detects brightness at 500-msec intervals. Brightness data arrive at 12-second intervals. When the brightness pattern is changed, the local patterns are updated.

Conclusions
We introduced our proposed hierarchical data gathering method using SVD. We will adopt it and demonstrate sensor nodes for actual greenhouses and environmental data analysis.

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References