スマートイメージセンサ群を用いたネットワーク
画像センシングにおける動的レートコントロールの検討

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あらまし　多数のイメージセンサを用いた画像センシングは、広い範囲に渡っての情報収集に効果的であるものの、センサの数が増えるにつれて情報量が増加し、それに伴うデータ転送や処理の問題がネットワーク部を含むシステム全体に影響を与えることが予測される。スマートセンサは、センサレベルで情報量の削減が可能であり、ネットワークとシステムの資源を同時に節約できるため、有効な対策の1つと考えられる。本稿では、多数のイメージセンサ群を用いてネットワーク画像センシングを行うためのネットワークインタフェースを提案し、試作した。そして、空間可変サンプリングスマートイメージセンサを用い、効率的な伝送を行うための動的トラフィックコントロールのシミュレーション実験を行い、その結果を示した。

キーワード　スマートセンサ、スマートセンサネットワーク、ネットワーク画像センシング

A Study on Dynamic Rate Control for Network Image Sensing by a Group of Smart Image Sensors

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Abstract　The image sensing with a large number of image sensors is very effective for collecting global information throughout the very wide area, however, how to transfer and process vast amount of data is one of the critical issues when the number of sensors increases. Accordingly, a careful system design is required in order to avoid an unexpected congestion collapse caused by numerous image sensors. In this paper, we present several simple rate control schemes utilizing a group of smart image sensors by which random spatial sampling can be achieved at image acquisition level. An individual sensor is mounted on a TCP/IP-ready sensor node developed for communicating with other sensor nodes or a hosting machine in the system. Simulation results show that the proposed schemes are simple and effective for reducing the data volume as a source control.

key words　Smart Sensor, Sensor Network, Smart Sensor Network, Network Image Sensing
1. Introduction

A large-scale vision system with multiple image sensors is very effective to monitor wide area and obtain global information, however, high-performance processing and networking resources are typically required to perform necessary tasks. The research activities such as CMU’s “VSAM (Video Surveillance and Monitoring)”[1] or MIT’s “Forest of Sensors”[2] are targeted for the video monitoring system that enables a single operator to cover a wide and complex area using multiple cameras. “Cooperative Distributed Vision Project” [3] initiated by Kyoto University is also aimed for real-time situation analysis and interactive video generation mainly based on the image data from numerous sensor stations. Nevertheless, in all cases, the number of cameras (image sensors) is limited to a few or tens of them at most. To achieve more seamless monitoring over the extended area, more sensors should be installed, but it requires higher system performance and more network capacity. In addition, the improvement of network infrastructure costs a lot more time and money than system upgrade. Therefore, how to control the tremendous volume of data is an inevitable and one of the important issues when the number of sensors increases especially for the system with limited network resources. In general, the methods of downsizing temporal or spatial scaling [4] are generally used to reduce the data volume, however, the most effective way is to reduce the data volume at the image acquisition level. Smart sensors [5] in this sense are considered to be one of the feasible solutions to cope with this problem because they provide faster and higher throughput than conventional image processing system if the target can be narrowed down to a specific application.

In this paper, we present a large-scale image sensing system consisted of a group of smart image sensors replacing conventional image acquisition devices. To implement the system for efficient transmission by using the following dynamic rate control schemes, random accessible Spatially Variant Sampling (SVS) smart image sensors [6] are adopted.

- Closed-loop dynamic rate control: Unlike typical closed-loop source control algorithms depending on the information such as network condition, this scheme is based on the feedback information from the other sensors to obtain pre-determined total bit rate by simply adjusting the sampling rate of the sensors.
- Open-loop dynamic rate control: The data rate is dynamically controlled either by sub-sampling inactive region (the region without movement) with lower resolution or by transmitting inactive region with lower frame rate than active region (the region with movement). This is based on the principle that human visual system is more sensitive to moving objects.

2. System Overview

2.1 SVS Sensor

Smart image sensors are special image acquisition devices where processing circuits for specific operations are fabricated together with photocells on the same focal plane to provide various functionalities such as motion detection, averaging, edge enhancement, range finder, and image compression. That is why smart sensors are much smaller than conventional image processing systems. Thus, the implementation with smart image sensors can be one of the viable solutions for large-scale real-time image sensing application. For efficient transmission, we adopted a SVS sensor (Figure 1, maximum resolution 128x128, gray scale) that is geared with spatial sampling control logic for efficient transmission. As shown in Figure 2, the selected pixels can be read out by referencing control flag signal during the pixel scan. As flag signals can be provided externally, any access pattern can be loaded (write cycle) into the row and column sampling positioning line memories to be read out during the read cycle. Detailed operation is illustrated Figure 3.
2.2 Sensor Node

The network-interfacing standard for smart sensors (IEEE 1451 Family [7]) has been approved recently, however, more complex architecture and precise control are required for two-dimensional image sensors. Therefore, we developed a sensor node equipped with networking capability as depicted in Figure 4.

The system is operated on NetBSD platform and powered by SH-4 RISC CPU (167 MHz). Physical appearance is also provided in Figure 5. Figure 6 represents a simulation view from a host assuming 25 sensor nodes. Each
sensor node is given its own IP address for ubiquitous image sensing that enables the users to get access to the Internet, so this system is highly scalable and provides easy on-line maintenance such as user registration or alteration of network information.

3. Simulation : Dynamic Rate Control Schemes

The data volume increases in proportional to the number of sensor nodes. Therefore, in case of large-scale image sensing with numerous image sensors, how to deal with the tremendous volume of data will be a very important issue. We attempted the following dynamic rate control schemes as a new approach making use of the SVS sensors to reduce the data volume.

3.1 Closed-Loop Dynamic Rate Control

The data rate can be controlled dynamically by referencing information among the sensors. In other words, the sub-sampling rate is automatically adjusted by the feedback information from the other sensors. An example how to coordinate the sampling rate for each sensor is simulated by assuming 25 sensor nodes (128x128, gray-scale). Each sensor node computes the absolute value of frame difference by the following equation and sends the result to a host only when the frame difference is above the pre-determined threshold level.

\[ Diff = \sum |f(x,y) - f_n(x,y)| \geq Th \]  

On the other hand, a hosting machine collects the information from all sensor nodes within designated time frame and decide necessary sampling rate for each sensor based on the sampling mode conversion table (some part of it is listed in Table 1).

Table 1. Example of Sampling Mode Conversion Table

<table>
<thead>
<tr>
<th>No. of Activated Sensors</th>
<th>128x128</th>
<th>64x64</th>
<th>32x32</th>
<th>TBR (bps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>655,360</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>8</td>
<td>0</td>
<td>1,966,080</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>2</td>
<td>22</td>
<td>1,884,160</td>
</tr>
</tbody>
</table>

Three sub-sampling modes (128x128, 64x64, 32x32) are regarded in this simulation and the network capacity limitation is 2M b/s. As shown in Table 1, even though all 25 sensors are above the threshold level and need to transmit the images at the same time, the total bit rate can be adjusted automatically by sub-sampling of each sensor node based on the sampling mode conversion table. If there is more activity in the scene, the higher
sampling rate is provided and the conversion table can be replaced in necessity considering network capacity. Figure 7 shows the simulation results in regard to the number of activated sensors for 25 test image sets (100 consecutive frames each) simulating 25 sensor nodes. Figure 8 provides the result for total bit rate in the system showing that it is controlled under the pre-determined total bit rate (TBR).

3.2 Open-Loop Dynamic Rate Control

The data rate can be controlled by adjusting inactive region (the region without or little movement) as follows.

- **Spatial Resolution Control**: The active region (AR) with movement is sampled at maximum resolution while the inactive region (IR) without or little movement is sparsely sampled for low resolution. In most cases, AR takes up much less area than IR. As a result, the data will be greatly decreased.
- **Temporal Resolution Control**: AR is transmitted with normal temporal rate while IR is refreshed by pre-determined rate (e.g., 1/10 of normal rate). In this case, the data rate will be controlled by the rate of IR.

These schemes are simulated with 90 consecutive images (*Rain*, 256x256, gray scale). The result of spatial resolution control by selective resolution reduction is presented in Figure 9.

![Figure 7. Number of Activated Sensors](image1)

![Figure 8. Total Bit Rate Controlled Under 2Mb/s](image2)

![Figure 9. Simulation Result: Spatial Resolution Control](image3)

(a) Original Image, (b) Frame Difference, (c) Result

![Figure 10. Traffic Change for Spatial Resolution Control](image4)

![Figure 11. Simulation Result: Spatial Resolution Control](image5)

(a) Original Image, (b) Frame Difference, (c) Result
The result image shows that the main object (train) maintains the maximum resolution while the IR (background) resolution is lowered to 32x32. The total traffic volume for 90 frames is decreased approximately by 1/3.4, 1/8.6, 1/13.8 when the IR is transmitted with the resolutions of 128x128, 64x64 and 32x32, respectively. Figure 11 shows the result of temporal resolution control by reducing the rate of IR by 1/3 of AR (train). It should be noted here that small changes in IR are almost unrecognizable as IR is cached in the result image. In this case, the total traffic volume for 90 frames is decreased approximately by 1/2.6, 1/4.6 and 1/6.1, if the IR is transmitted with the frame rate of 1/3, 1/6 and 1/9 of AR, respectively. The traffic change is shown in Figure 10 and 12 for each case.

![Traffic Change for Temporal Resolution Control](image)

**Figure 12. Traffic Change for Temporal Resolution Control**

4. Summary and Future Work

The effective real-time rate control for video sequence in the Internet environment is one of the challenging research themes today. However, it is very difficult as well because video is characterized by rapid changing with time due to the effects of scene complexity and motion. In this paper, we presented a large-scale image sensing system using a group of SVS smart image sensors to reduce the data at image acquisition level. Obtained overall information can be used for the real-time applications such as global motion tracking and analysis throughout the very wide area. The proposed schemes are very simple but considered to be an effective approach as an open-loop or closed-loop source control. Nevertheless, the proposed schemes should be reinforced by more efficient active region search algorithm instead of frame difference for practical application because this system is highly dependent on precise segmentation of active regions.

References