Initiation Into Research Fondecyt Project No. 11121657 :
Optimal packetization of still images in wireless vision sensor networks

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Wireless vision sensor networks represent a technological challenge that multiplies the difficulties of traditional wireless sensor networks (WSNs). Considering the resource-constrained nature of current sensor nodes, the large amount of data needed to code a single image increases the necessity of highly efficient processing and transmission algorithms. Significant progress has been made in the design of efficient image compression and communication through WSNs, but many works put aside the problem of packet loss. Packet loss can be addressed by using ARQ or FEC-based protocols, but at the expense of additional energy consumptions and latency. Luckily, images have high loss-tolerance due to the correlation between neighboring pixels. This is exploited by lossy compression algorithms, but it can also be used to reinforce a transmission scheme. For this, one of the simplest techniques is block interleaving (BI).

The effectiveness of the application of BI methods is assumed. However, methods are generic and the choice of the correct parameters is arbitrary. Also, there is no basis for comparison, not knowing a standard optimum to reach when designing a BI method. Characteristics of the channel, batteries level and images (among others) are also not considered. In this project, we address the issue of BI techniques studying the possibility of finding optimal interleaving configurations and to numerically evaluate existing and future proposals. We will focus on five problems. (1) We will study error concealment and image quality metrics used in current image processing. (2), we will rigorous study BI methods, analyzing blocks' paths and parameters impact through extensive simulations using MPI and CUDA. (3) We will propose one (or various) objective functions, being a statistically-representative reference for evaluating the performances of a BI method, allowing researchers to evaluate and compare methods efficiency with no need for making extensive simulations (mandatory for evaluations, until now). (4) By using the proposed objective function, we will find optimal parameters for existing BI methods, to finally (5) work on an optimal (or pseudo-optimal) interleaving configuration which can serve as a comparison reference. Thus, authors working on BI methods will know if the proposals are near a reference optimal.

Context

Wireless Sensor Networks

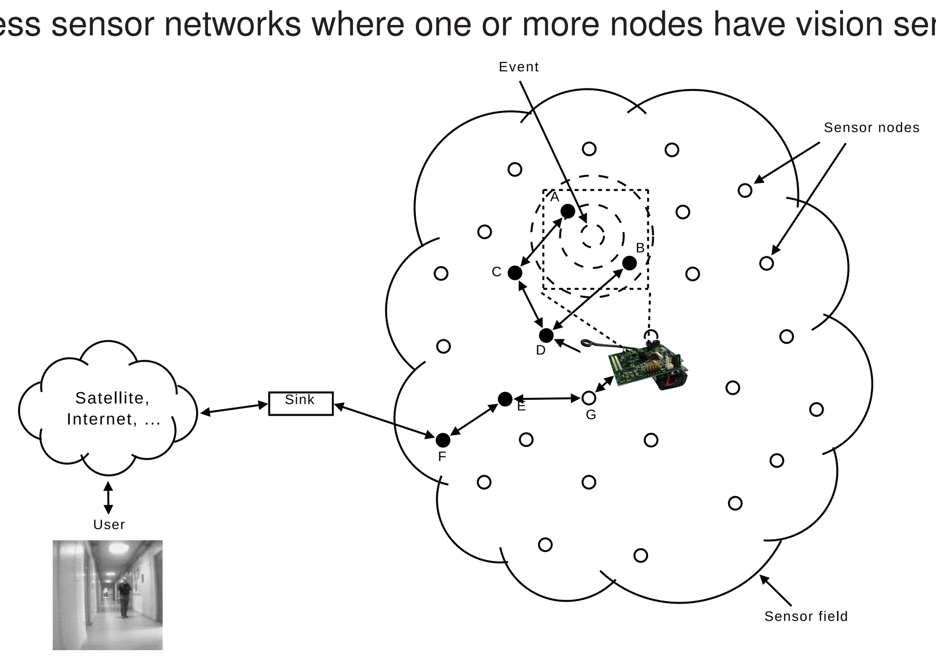
A **wireless sensor network (WSN)** [1] is a large-scale distributed system normally composed of a large number of very small electronic devices called sensor nodes. These sensor nodes are able to measure certain physical phenomena in the environment where they are deployed and to report its findings to one (or several) gateway(s) (nodes with connectivity to a standard network or computer system, generally called *sinks*).

Main problems:

- **At the node level:**
  - Limited energy (batteries)
  - Reduced processing/storage capacities
  - Low transmission data rates
  - ...
- **At the network level:**
  - Huge scale (large number of nodes)
  - High deployment density
  - Dynamic topology (nodes activation/deactivation, etc.)
  - **High packet loss rates**
  - ...

Wireless Vision Sensor Networks

Wireless sensor networks where one or more nodes have vision sensors (cameras).



Main problems:

Same problems of traditional WSNs
+
A more complex/expensive sensor
+
A much larger amount of data to process/transmit

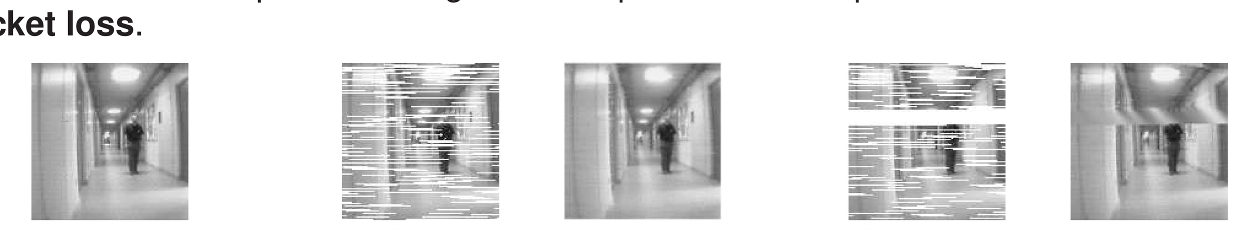
Figure 1. General scheme of a wireless vision sensor network.

- As one of the most important problems of WSNs is **energy consumption**, image compression seems an obvious solution. Problem: **data packets loss**

(a) Original (128 × 128) image (b) 1% packet loss (c) 5% packet loss

Figure 2. Impact of packet loss on the quality of JPEG compressed/transmitted images.

- Packet loss can be important in WSNs (40% and more)
- **Note:** transmission of non-compressed images or compressed in independent blocks is more error resilient. Problem: **burst packet loss**.



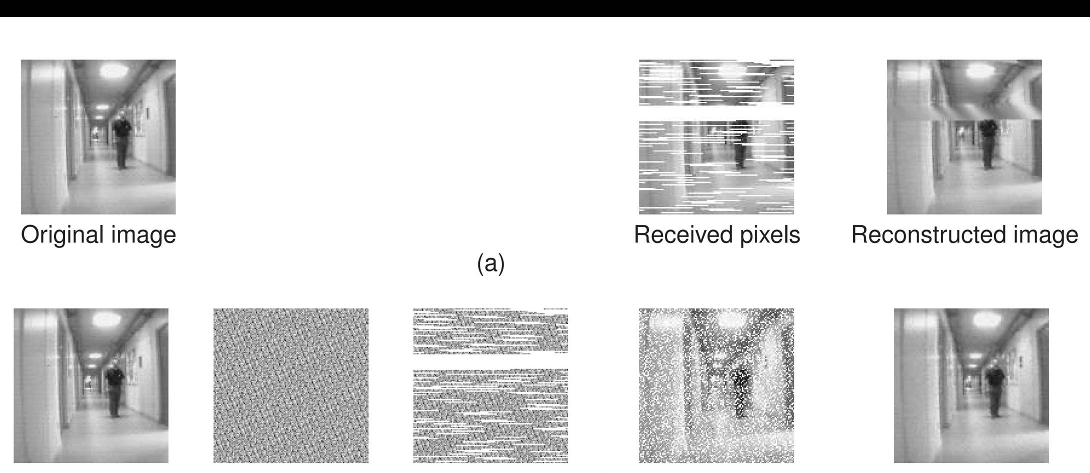
(a) Original (128 × 128) image (b) Example of simple packet loss (c) Example with burst packet loss

Figure 3. Effects of packet loss on image quality.

Block interleaving

Summarizing, we can define:

- Packetization in blocks and communication
  - An image is a $I(H \times W) = \{I_{r,c}\}$ matrix, each $I_{r,c}$ containing b bpp
  - Packetization of I in $q = \lceil \frac{H \times W \times b}{m} \rceil$ packets, m = number of image data bits per packet
  - P packets communication of scheme $\overleftrightarrow{\Gamma}$, each packet with a probability p_l of being lost
  - Error concealment at the receiver side (various methods)
- Block interleaving
  - Bijection $\vartheta : I \to I'$, where I' is a new map, with each block $B_{i,j} \to B'_{i',j'}$
  - An adapted interleaving considers $B'_{i,j} \leftarrow B_{i',j'}$ [2]



Original image / Received pixels / Reconstructed image
(a)
Original image / Interleaved image / Received pixels / Reallocated rec. pixels / Reconstructed image
(b)

Figure 4. (a) Sequential communication vs. (b) Comm. with interleaving.

Examples of block interleaving methods

- [DeBrunner *et al*] methods [3] (*Horizontal, Vertical, Horizontal-Vertical, Dynamic*)
- Linear pixel shuffling [4]
- [El Bendary *et al*] interleaving [5]
- Torus Automorphisms [6, 2]

Optimal Interleaving

Comparison and evaluation of interleaving methods require extensive simulations, because their performance depend on the image and on the loss pattern characteristics. Current simulators used in WVSNs bibliography are mostly oriented to network protocols and not to quality image assessments. For this, we developed a simple simulator for image quality assessment [7], but event when parallel computing is performed, extensive evaluations are too expensive in computing time.

This project will focus in the following problems:

- **Problem 1** *Study of error concealment and image quality evaluation methods.* To search the methods for error concealment and the image quality metrics the more used in current image processing.
- **Problem 2** *Simulation of interleaving methods.* The rigorous study of block interleaving methods, analyzing blocks' paths and parameters impact through extensive simulations using MPI and CUDA. Simulations must consider multiple image sets and loss patterns. Comparisons, including image quality of reconstructed images and computing cost, will be provided.
- **Problem 3** *Objective evaluation functions.* To establish evaluation parameters and to propose an objective function (or various) $F(\vartheta)$. This function must be a representative reference for evaluating the performances of an interleaving method ϑ. Thus, researchers will be able to estimate and compare the efficiency of interleaving methods without the necessity of making extensive simulations (what is mandatory for evaluations, until now). The idea is to count on a statistically-representative objective function to maximize (or minimize), whose validity will be supported with comparisons with our extensive simulations.
- **Problem 4** *Optimal parametrization of interleaving methods.* By using the proposed objective function $F(\vartheta)$, to find optimal parameters for methods
- **Problem 5** *Optimal reference interleaving.* Considering the proposed function $F(\vartheta)$, to find optimal (or pseudo-optimal) configurations which can serve as a comparison reference for more traditional interleaving methods. In this way, authors working on interleaving methods will know if their proposals are near a reference optimal.

Project's Hypotheses and Goals

Hypotheses

1. The main hypothesis is that it is possible to find objective functions to evaluate the effectiveness of interleaving methods. This function should have a high mean correlation with extensive simulations over large sets of images and loss patterns.
2. With an objective function, it is possible to find optimal bitmap configurations such that, any applied interleaving method throws equal or lower evaluation results. This optimal bitmaps should be reached with metaheuristics such as generic algorithms, simulated annealing, or any other.
3. It is possible, with aid of programs using MPI and CUDA, to calculate extensive simulations in reasonable times, with sets of images and loss patterns big enough to generate results considered as statistically representative.

Goals

- **General goals:** The general goals of this research project are to propose a correct optimization function for the evaluation of block interleaving techniques and to find optimal configurations of coded/non-coded bitmaps, using the optimization function, to serve as a basis of reference for further proposals on the matter.
- **Specific goals**:
  1. To analyze interleaving methods by performing extensive simulations using parallel programming with MPI and CUDA.
  2. To establish an objective function allowing the evaluation of interleaving methods without the necessity of perform extensive simulations and to prove that this objective function is statistically representative.
  3. To study, with the proposed objective function, interleaving methods in the bibliography, finding optimal parameters to each of them.
  4. To find optimal bitmap configurations, in order to count on a comparison reference on the design of interleaving methods.

Acknowledgments

Project financially supported by CONICYT (Comisión Nacional de Investigación Científica y Tecnológica), Chile. Fondo Nacional de Desarrollo Científico y Tecnológico (FONDECYT), Initiation into research Fondecyt project.

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