Microbolometer based infrared cameras PYROVIEW with Fast Ethernet interface

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The growing use of infrared cameras in industrial applications requires a durable and stable data connection between camera and processing unit able to transmit the measured temperatures without any loss or corruption over long distances. Fast Ethernet is currently one of the most spread network technology in the world and suited for connecting IR-cameras to almost every computer. The lecture will introduce an interface fulfilling all requirements for industrial use.

State of the art cameras as PYROVIEW come actually up with array sizes of 384 by 288 pixels and frame frequencies up to 50 Hz. The data rate generated by such a camera exceeds the transfer capacity of Fast Ethernet assuming a 16 bit wide value for each pixel. For that reason data compression must be performed under conditions different to normal TV-pictures: The compression has to be loss-free without the knowledge of the previous frame, real-time capable for each single frame and efficient enough to meet the transfer capacity of Fast Ethernet.

The first time realization for PYROVIEW cameras based on a new developed hardware solution achieves all requested qualities. The compression rate depends on the actual scene and does never drop below the critical value where Fast Ethernet comes into trouble. The camera can be connected to all computers with Fast Ethernet interface and a sufficient performance.

A co-product of the realized interface is an integrated tiny web-server: It delivers all needed information for installing and testing the camera as for service and maintenance purposes.

1 Introduction

The visualization and transmission of data gained by an IR-imager has been done with TV-equipment based on TV-standards. Since IR-cameras obtain the functionality of measurement devices with defined requirements to accuracy and resolution and the use of IR-data for industrial process control, TV based data processing is losing its importance currently. The quest for new and more suited solutions leads to PC-based data processing and visualization coupled with transmission medias as USB, IEEE1394 (FireWire), Camera-Link and Fast Ethernet.

The decision for Fast Ethernet was made because of the following advantages:

- high availability with almost each PC or Laptop
- standard maximum cable length of nearly 100 m
- the possibility to lengthen it by the use of common fiber optics components (even suited for harsh EMI-environments)
- low cost and availability for the whole equipment.

The mainly spread protocol for data transportation via Fast Ethernet is the Internet protocol (IP). The support of it by any common operating system without the need to create special device driver software is a further major advantage.

For these reasons a Fast Ethernet interface has been developed and will be described in the following chapter.

2 PYROVIEW with Fast Ethernet Interface

The main target of the development was the PYROVIEW 380, an IR-Camera with 384 × 288 pixels and a frame rate of 50 Hz. The dynamic range and the requested resolution of the detector demand a 16 bit analog to digital conversion. Based on these information a minimal data rate can be calculated:

$$382 \times 288 \times 50\ \text{Hz} \times 16\ \text{bit} = 88.5\ \text{Mbit/sec} \qquad (1)$$

The real data stream will contain some additional status and control information so the expected final data rate will touch the 90 Mbit/sec.

2.1 Transmission Properties of Fast Ethernet

The native transfer capacity of Fast Ethernet is 100 Mbit. The realized payload data rate is less than and depends on the used transmission protocol. The Ethernet itself and the IP protocol occupy more than 20 % of the transfer capacity. For controlling purposes and safety reasons additionally 10 % are reserved. The final data rate for infrared data results in less than 70 Mbit per second [1].

Other participants in the network can decrease that value further. A clear sighted planning of the network can avoid this kind of trouble. A point to point connection between IR-camera and computer is recommended and even simple to realize today.

2.2 Compression Algorithm

The raw estimation of the available data transfer capacity of Fast Ethernet and the IR camera generated data stream shows a disproportion. The only possibility to overcome it is to reduce the data rate generated by the camera. A reduction to about 2/3 of the original value would be more than enough but the higher the reduction the better the whole performance. The reduction can be done by a limitation of the frame frequency, a reduction of the number of pixel or the use of a compression procedure before pushing the data to the network.

The only way to keep the native camera properties was to develop a compression algorithm with the following main requirements:

- an average compression rate better than a factor of 1.5,
- loss free compression to keep the accuracy of the measurement
- compression without the knowledge of previous frames to keep the influence of possible Ethernet frame losses small
- generation of compressed data packets matching the Ethernet frame size and the used data structures inside the IP-protocol and
- algorithm suited to be implemented in a modern FPGA-system with integrated micro controller.

A comprehensive analysis of the infrared data has shown a degree of redundancy enough to reach and exceed the requested compression rate. The next step was to select an appropriate algorithm. There are some different operations possible, a global overview is given in Figure 1:

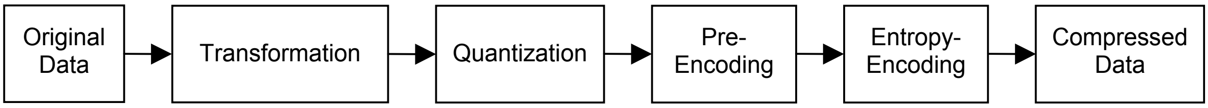

Figure 1: Compression Stages

The transformation does reorganize or concentrate the data in a way that following operations can work more efficiently. Quantization tries to replace different data symbols by a single one. That operation can not be used because of the “loss-free” demand. The next step is to reduce the inter symbol redundancy (pre-encoding). The entropy encoding tries to use statistical techniques to reduce the symbol redundancy. The last two operations replace longer symbol combinations by shorter ones.

Different transformation and encoding techniques have been tested. Finally a combination of a special difference transformation followed by variable length integer encoding has fulfilled the requirements given above. An example is given in Figure 2:

The line wise average compression rate for a detector with 320 × 240 pixels watching a test scene with various structures (lattices with high and low contrast, different kinds of noise, some plain areas) is shown there. The three lines above (*,o,• marked) show similar results based on small implementation differences. The lower line (x marked) shows the result by using a simple run length encoding only.

The main requirement, a compression rate of 1.5 is achieved. Dependent on the real data the compression rate can reach the factor 2 as well. Detailed tests have resulted in an average compression rate of 1.8 [2].

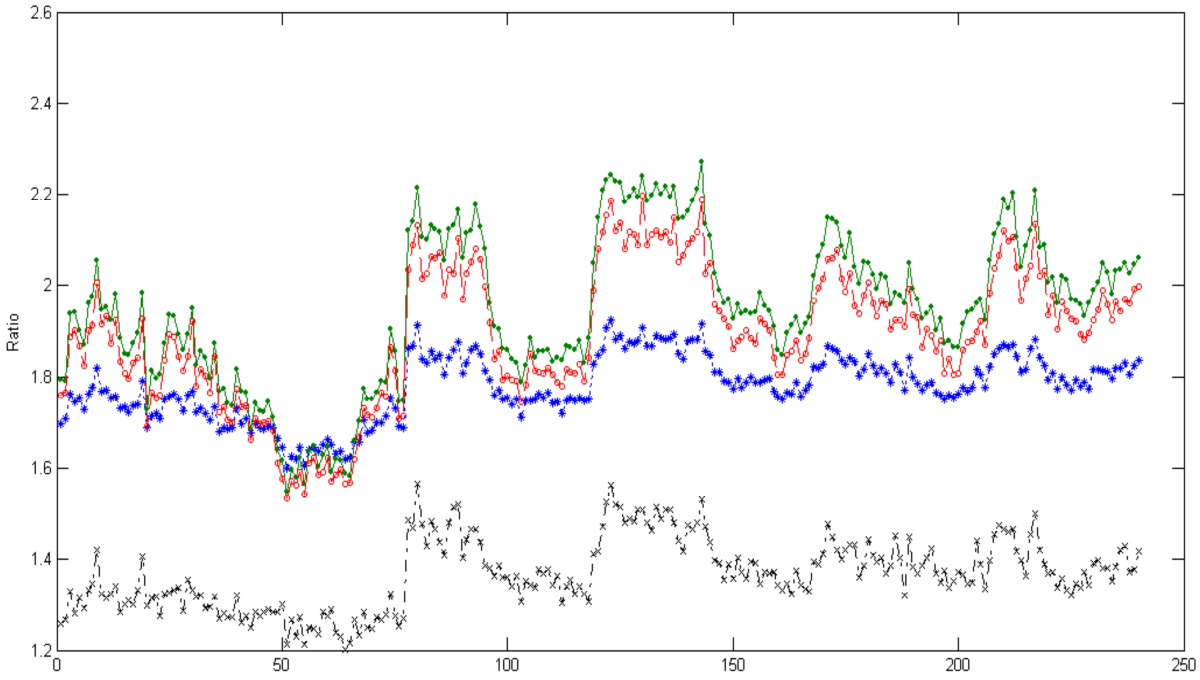

Figure 2: Trend of the real compression rate for the lines of a complete data frame

2.3 Implementation

The compression algorithm is implemented in hardware completely as part of a FPGA-circuit as the network interface too. The handling of the Ethernet network IC (physical layer) is performed by an integrated micro controller who realizes an IP/TCP-stack. The performance of the controller is not enough to process the compressed data in real time. The way to solve the discrepancy was to create a separate hardware able to wrap the data into a ready made Ethernet packet and push it direct to the network IC using a DMA-controller.

The integrated micro-controller is still used for two jobs relating the data transfer only: It has to deliver all the necessary data to create complete Ethernet frames inside the hardware. That task must be done only once during the connection gets established. The other duty is to coordinate its own Ethernet business with data transfer: The wrapper hardware signals the preparation of the complete Ethernet packet to the controller. It tries to finish any possible Ethernet activity and gives permission to perform sending the packet.

The administration overhead can be minimized by using the full capacity of the native Ethernet packets. The native Ethernet frame size (MTU, maximum transfer unit) can be different and depends on the actual integrated components. The wrapper is able to pack more than one compressed data packet into such a transfer unit. An integrated buffer helps to avoid any loss if a data packet does not fit into the remaining free space of the transfer unit.

3 Infrared Camera PYROVIEW 380L for industrial use

The integration of a Fast Ethernet interface into a camera for industrial use is incomplete without the right connector. Normally the Fast Ethernet hardware uses RJ45 plugs and sockets for connection. These have been made for the use in the “office” but not for the use in harsh industrial environments. A lot of companies have created their own protection gear around it with the effect of having many incompatible solutions. The recently introduced M12D connector (open standard) avoids any compatibility problems and fulfils the IP67 standard.

The availability of a micro controller not really busy and a complete Ethernet interface operated under TCP/IP gave the possibility to install a tiny web-server. The web-server delivers information about the camera, some network information and the actual status of itself. For maintenance and service there is the possibility to change some global parameters by authorized users.

The new PYROVIEW with Ethernet interface sets a mile stone for industrial applications. The use of common network techniques like Ethernet ease the integration of the camera into complex production systems without expensive costs for any special hard- and software.

The final PYROVIEW 380L has got the following technical parameters:

Spectral Range:	8 µm to 14 µm
Temperature measurement range[1]:	–20 °C to 120 °C and 0 °C to 500 °C
Sensor:	uncooled microbolometer array (384 × 288 pixels)
Lens[1]:	standard 30° × 23°, spatial resolution 1.4 mrad, optional 59° × 46°, spatial resolution 2.7 mrad, optional 15° × 12°, spatial resolution 0.7 mrad
Measurement Uncertainty[2]:	2 K (measured temperature <100 °C) or 2 % of the measured value in °C
NETD[2]:	<80 mK (30 °C, 50 Hz)
Measurement Frequency:	internal 50 Hz, selectable: 50 Hz, 25 Hz, 12.5 Hz, …,
Response Time:	internal 40 ms, selectable:2 /measurement frequency
Interfaces:	Fast Ethernet (real-time, 50 Hz max), optional fiber optic
Digital Inputs:	2 electrically isolated digital inputs (trigger)
Digital Outputs:	2 electrically isolated digital outputs (alarm or status/sync)
Power Supply:	10 V to 36 V DC, typically 5 VA
Housing:	Series industrial: Industrial housing IP65, 100 mm × 266 mm × 196 mm, optional integrated water cooling system and air purge, fixed or swivel mounting base, pan-tilt unit Series compact: housing IP54, 85 mm × 175 mm × 107 mm (without lens and connectors, optional with weatherproof housing and pan-tilt unit
Operating temperature range:	–10 °C to 50 °C (without water cooling), –25 °C to 150 °C (with water cooling, series industrial)
Storage conditions:	–20 °C to 70 °C, rel. humidity 95 % max
Software:	Control and imaging software PYROSOFT for Windows®

[1] Other available

[2] Specification for black body reference and ambient temperature 25 °C

Both PYROVIEW 380 series “industrial” and “compact” are given in figures 3 and 4.

Figure 3: PYROVIEW 380L industrial

Figure 4: PYROVIEW 380L compact

4 References

[1] T. Welz: Netzwerkanschluss von IR-Industriekameras, Diplomarbeit, HTW Dresden, 2004

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