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Assessing The Implementation Of Data Compression Algorithms For Instrumentation And Control Systems

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ABSTRACT
This study is about the possibility of applying data compression algorithms on field instruments for instrumentation and control systems. Leveraging different algorithms and compression techniques. Also, comparing the pros and cons of the different data compression algorithms. An in-depth look at hardware compression vs software compression is provided. A conclusion was arrived at after comparing several jobs done and the outcomes of their approach.
Keywords: Implementation, Data Compression, Algorithms, Control Systems

INTRODUCTION

The essence of control in systems is to be able to put constraints on the outcome of that system, therefore forcing the system to adhere to certain criteria that define the range of the output. If the output is within a given range, we then term the system to be in a control loop. But can we truly say that the system is in control? Certain factors can be seen to be at play when considering deviations from setpoint in control systems. One of the primary culprits is delay in the transmission of the input signal, or to broaden the scope, we can say delay in communication along the loop. This delay is not only associated with communication but also with processing, but for the scope of this paper, we, will focus on communication. Setpoint is defined as the criteria we want to attain and sometimes maintain, for example setpoint of boiling water is 100 degrees Celsius, which is the point at which the water boils.

According to Bolton (2021), Instrumentation and control systems. A system can be described as a structured configuration of components enclosed within a defined limit, collaborating harmoniously to produce a particular outcome based on designated inputs. The system is demarcated from its surroundings by a distinct boundary, serving to segregate it from the environment. Interactions between the system and the environment occur through the exchange of signals that traverse the boundary, moving from the external surroundings into the system.

Instrumentation is defined as a combination of instruments which are used to control a According to Wikipedia, Instrumentation is a collective term for measuring instruments, used for indicating, measuring, and recording physical quantities. It is also a field of study about the art and science about making measurement instruments, involving the related areas of metrology, automation, and control theory. For a system to be under control certain devices referred to as instruments will be needed. These instruments include transmitters, controllers, final control elements valves and the process (the material or substance in question to be controllers, in the case of boiling water or filling a tank up with water, the process s water).

For control to be established each instrument along the loop will have to communicate which each other error free, fast and efficient. If the input is not communicated to the controller error free and timely the controller will not be able to make the right decisions and we cannot say the system is controlled. There have been several approaches to solve this problem which led to other developments of high-speed counters and protocols like canbus. These also lead to several problems which include protocol compatibility.

On the other hand, data compression has been applied in several processor powered devices for video, picture, audio compression in the information technology sphere. It has been used to better our everyday lives to the point that it is invisible. It facilitates everything we do daily with respect to multimedia consumption. According to sayood, (2018) introduction to data compression we can see data compression is more than just manipulation of numbers it involves identifying models of data structures that exist in data. So, importance is placed more on the structure rather than the data itself because it is from the structure, we can extract information.

Data compression is the art or science of representing information in compact form. With the amount of data being generated every day and the age of AI, an efficient way to store and transmit this data is very evident.

With our ever-growing industrial sector, the amount of data being produced will increase exponentially, which will bring about ways of storage of data for logs or machine learning algorithms for predictive troubleshooting or other needs. Industrial plants can have several hundred instruments used for various processes which each generates their data individually. If left unchecked in years to come, it will be cumbersome to handle and probe for information.

Statement of the problem

Before the introduction of field bus communication, the system of communication was analogue, but with the move to digital communication, which makes data transfer between devices like valve positioners, controllers, workstations and servers, the data footprint of the industrial sector has been rapidly growing. The introduction of fieldbus came partly as a result of the need for different devices to communicate together. According to Data growth worldwide 2010-2025 (Statista, 2023). We can see the rapid increase of data in 15 years an efficient and fast means of data transfer would be needed when collecting this data from field instruments and storing it. This method or technique may include processing of information on the go.

Aim and Objectives of the Study

The aim and objectives of this study were to analyze the current data processing techniques and look at possible areas of implementation in instrumentation and control systems. During this study, the objectives were:

1. Analyze digital protocols used for communication in the industrial sector about data compression
2. Examine the current hardware needed to carry out data compression in devices
3. Determine the ability to integrate data compression with current systems

Research Questions

The following Questions guided the study

1. What are the current protocols in use in the industrial sector
2. Is there a possibility to apply data compression techniques to these protocols
3. What additional hardware will be needed

Hypothesis

The study was guided by the following hypothesis:

1. Adding data compression to existing industrial setups will reduce the overall data footprint and reduce the amount of hardware needed for processing while improving data integrity and processing speeds.

Significance of the study

This study will be significant to stakeholders like industrial systems, Refineries, Pure water factories, and process control institutions. Generally, anyone who is in the industrial control systems space and is looking for continual improvement to the system to mitigate downtime and error in the system.

Conceptual Review

Instrumentation and control system:

Bolton (2004) A system can be characterized as a structured assembly of components confined within a defined boundary, collaborating harmoniously to generate specific outcomes based on designated inputs. This boundary serves to delineate the system from its surroundings, and the system engages with the environment through the exchange of signals. These signals traverse the boundary from the environment to the system, constituting inputs, while signals also traverse from the system to the environment, constituting outputs. While an instrument is a device used for specific purposes. It may be electronic or mechanical e.g. pneumatic and smart transmitters. Combining bit concepts an instrumentation system is a structured assembly of specific purpose devices to a particular field of study that are working together harmoniously.

Sensors:

A sensor is a device that generates an output signal to detect a physical phenomenon. In the broadest definition, a sensor is a device, module, machine, or subsystem that identifies events or changes in its environment and transmits the information to other electronics, often a computer processor. Sensors find application in everyday objects, such as touch-sensitive elevator buttons (tactile sensors) and lamps that adjust their brightness based on touch. They are utilized in numerous applications, many of which people may not be aware of. With advancements in micromachinery and user-friendly microcontroller platforms, the applications of sensors have expanded beyond the traditional fields of temperature, pressure, and flow measurement.

Algorithms

According to Wikipedia in mathematics and computer science, an algorithm is a finite sequence of precise instructions, commonly employed to address a specific set of problems or carry out a computation. Algorithms serve as specifications for executing calculations and processing data.

Protocols:

According to Wikipedia a communication protocol, on the other hand, denotes a defined set of rules and regulations governing how data is transmitted within the realms of telecommunications and computer networking.

Communication/Transmission

Communication is often described as the conveyance of information, although its exact definition is a matter of debate. Disagreements arise regarding the inclusion of unintentional or unsuccessful transmissions and whether communication solely conveys meaning or also engenders it. Communication models offer simplified representations of the primary elements and their interconnections. Numerous models incorporate the concept that a sender employs a coding system to articulate information into a message. This message traverses a channel to reach a recipient who must decipher it for comprehension. The primary area of study dedicated to exploring communication is referred to as communication studies.

Transmitters

According to Wikipedia A transmitter is an electronic apparatus that generates radio waves using an antenna. The transmitter produces a radio frequency alternating current, which is then transmitted to the antenna. When the antenna is energized by this alternating current, it emits radio waves. But within the constraints of instrumentation and control a transmitter is a component or a device which is a foundational member of the process control loop. They interface with sensors to convey physical signals as electrical or pneumatic signals using a reference table for a calibrated range. There is various manufacturer which include Rosemount, Yokogawa, Foxboro etc. They convey data/information as electric or Pnuematic signals to the
controller or remote terminal unit.

Controllers

Controllers are the brain of the process loop they take decisions based on input from the sensors most times through transmitters, they are several implementations of controllers these include remote terminal unit (RTU), programmable logical controller (PLC), Supervisory control and data acquisition (SCADA)

etc but for the context of this work they will also be referred to generically as controllers.

Mackay and Park (2003) go into detail about more concepts of instrumentation and control systems focusing on filed instruments from transducers/ sensors to the pc) which is deployed as at the supervisory level of industrial control systems. They also talk about plug and play systems directly interfacing sensors to the computer system which has become widely adopted due to its scalability and off-the-shelf performance. Several terms like linearization are discussed in this book, and these terms will help an instrument man to progress along this path rather quickly.

Data compression

Data compression can be defined as coding according to Lelewer and Hirschberg (1987). It is defined as representing information in special forms. It encompasses transmitting data fast, efficiently and error-free. Many data processing systems need large data storage and processing features. The use of computing devices increases with time. There are two types of compression, which include lossy compression and lossless compression. (Pu,2006) defines data compression and gives some insight explain data compression, both a science and an art involving condensing information into a more concise form. Initially confined to a limited group of engineers and scientists, it has now become pervasive. This field has played a crucial role in the ongoing digital multimedia revolution, without which the expansive developments in the Internet, digital TV, mobile communication, and video communication wouldn't have been feasible. In the realm of computer science, data compression remains an active area of research, focusing on developing efficient algorithms to represent data with less redundancy, eliminate redundancy, and implement coding, encompassing both encoding and decoding. The fundamental approaches to data compression revolve around modeling and coding, where modeling constructs a knowledge system for compression, and coding involves designing codes to produce compact data forms.

Lossless Compression:

Lossless compression ensures that the original data can be reconstructed from the compressed version, preserving all information without any loss. This applies to symbolic data like character text, numeric data, computer source code, and executable graphics and icons. Lossless techniques are crucial for scenarios where maintaining every detail is essential, such as medical images, legal documents, and certain computer executable files.

Lossy Compression:

In contrast, lossy compression sacrifices some details during the compression process, making it impossible to reconstruct the original data exactly. While achieving a high compression ratio, there is a trade-off between visual quality and computation complexity. This method is commonly applied to multimedia data like images, video, and audio, where some loss of quality is acceptable for the sake of reduced file sizes.

Software compression

Software compression is data compression implemented through the use of algorithms implemented through software to compress data. It is relatively lower but doesn't need specific hardware. Hardware data compression involves using dedicated hardware, for example, a dedicated data compression chip or module with the primary job of carrying out data compression. There have been several models that are based on hardware compression

Theoretical Review

Data compression is grounded in the concept of eliminating redundancy from data to enhance its representation efficiency. It primarily addresses spatial and temporal redundancies within data.

Spatial Redundancy: This pertains to repetitive patterns within individual data elements. Compression algorithms exploit these patterns by representing them more succinctly. For example, in an image, neighboring pixels may exhibit similar color values.

Temporal Redundancy: This involves redundancy across distinct data elements or sequences. Compression techniques identify common patterns or similarities among data elements and represent them more efficiently. For instance, in a video stream, consecutive frames may share numerous

similarities. The core theories and techniques underpinning data compression encompass various methods:

Run-Length Encoding (RLE): This approach replaces sequences of identical elements with a single value and a count of repetitions, proving effective for data featuring consecutive repeated elements.

Huffman Coding: This variable-length coding method assigns shorter codes to more frequent symbols, optimizing the representation of data with varying symbol frequencies.

Lempel-Ziv Compression Algorithms: Including LZ77 and LZ78, these algorithms achieve compression by replacing repeated sequences with references to a dictionary or by constructing a dictionary of repeated patterns.

Transform Coding: Techniques like Discrete Cosine Transform (DCT) or Discrete Wavelet Transform (DWT) transform data into a different domain, where redundancy is reduced or concentrated in fewer coefficients. This is commonly employed in image and audio compression.

Entropy Coding: Based on information theory, entropy coding methods such as Arithmetic Coding or Burrows-Wheeler Transform aim to represent data using shorter codes for more probable symbols.

The overarching objective is to represent identical information with fewer bits, thereby reducing the storage space or transmission bandwidth required for the data. Compression finds widespread application in areas like image and video compression, file compression (ZIP, RAR), and communication protocols

METHODOLOGY

The approach for this research is purely original and no actual field work was carried out, as all needed material could be found in past research papers by my predecessors, ranging from the 1990s to 2024, as the industrial sector is at a slow pace when it comes to the implementation of change. A sample of about 10 works across journals, Wikipedia pages, books and conference materials was reviewed during this research to have a deep foundation of what has been done and what can be done, looking for an adequate approach to the subject matter. The relevance of the materials used ranges from single-authored papers to co-authored materials, which may have up to 6 authors who have several of their previous works cited in thousands. Origin of works goes across borders from Iraq to Britain, keeping the scope in view. The methodology of approach to the subject matter was examined to contain relevance to data compression for instrumentation, data compression algorithms, data processing unit, Encoding and Decoding Instrumentation and control. The materials used were obtained from academic databases like Google Scholar, ResearchGate and journal publishers. All works used in this study are cited and referenced using APA format. Relevant information was extracted from the selected studies, which include key findings, algorithm implementation, improvements and key concepts within the scope. Emphasis was placed on extracting methods of approach to the subject matter and the outcome of the approach. Comparative analysis was carried out to highlight a convergence point from the selected studies.

RESULTS AND DISCUSSION

Considering all the various parameters above and the constraints of instruments and control systems, the suitability of adding software data compression is not the best approach, but implementing hardware data compression will need extra dedicated chips to carry out compression. Considering the current time, we live and the advent of the transitory age it has become very normal to add microchips to devices to increase their capabilities, even while companies like and intel are striving to make smaller chips, considering products on thiwr 9nm process which does not need a lot of space to implement. But this technology does not come free of charge, but at a small price in production models. Software implementation of data compression although it is cheaper falls short when it comes to real time data transmission also considering that field instruments do not have a lot of storage space and the language to keep the memory need to a minimum will be “C” which is considered a high-level assembly language and allows for manual memory allocation. So, it comes down to whether the instrument in use needs to communicate in real time or not and if the manufacturer is ready to write complex codes with languages like C, which is already used in the embedded device space. Although software data compression can come in as an added layer to communication protocols for instrumentation and control systems as it

gives an added security and encryption as well as transfer speed in our present age of cybersecurity. The addition of data compression to communication, i.e transmission of data/information, would lead to an added factor when troubleshooting for network or communication issues. This would increase the knowledge base for a technician when problems arise. I still strongly believe with the advancement made in data processing units, which is a hardware approach to remove the strain of performing algorithms on the CPU by big corporations like Nvidia and Intel. Embedding a DPU on field instruments might not be a concept, but something about to happen.

DISCUSSION AND CONCLUSION

Although this field still has space for improvement with dynamic token creation and fast compression. We can see the earlier adaptation of data compression with hardware-based chips like Intel i750, a two-chip graphics processing unit that is used for video capture/compression. The 82750PB pixel processor, a part of the 2-chip Intel i750, is a versatile chip packaged in a 132-pin PQFP running at 25 MHz. It features 57 instructions, eight 64-bit vector registers, a 64-bit ALU, and various components for graphics, video compression, and real-time video processing. Unlike its x86 counterpart, it lacks general-purpose integer registers but has dedicated vector registers. Capable of handling text, 2D and 3D graphics, video compression, and decompression, it supports a 4 GB linear address space and can achieve up to 30 frames per second. Priced at $49 in 1,000-unit quantities, it can compress and store or retrieve and decompress data through a video RAM interface. Additionally, it can decompress high-resolution JPEG images in about one second per image (Wikipedia contributors 2024). Another approach was with fast entropy lossless adaptive compression, which uses Huffman tables to increase the efficiency of the algorithm, although this approach saves power for wireless transmitters, which was its goal. Due to the nature of transmitters and their low computing power, this approach is not efficient. If there is a processor bump to compress data and a software approach is applied, this can lead to misuse of resources. The last approach considered was embedding a Raspberry Pi model. Although this will be the best approach, it falls short in industrial environments where temperatures exceed the constraints of normal, e.g a boiler room or catalytic cracker. The harsh environmental factors will destroy the Raspberry Pi model before it is effectively used. In a paper by Alameda, et al. (2022) we can see the implementation of a data processing chip and how power they are in this case the chip is implemented for telemetry cases after which the data can be used for machine learning purposes which is out of scope but still shows the power of a single onboard data processing unit. These data processing units reduce the workload for edge computers.

Wu, et al (2018) describe the architecture of a data processing unit made with respect to relative database management systems. It is made in a 32nm process, giving it a manageable form factor considering chips using the Zen 3 architecture are made by powerhouse and are within the range of 7nm to 14nm, giving the relatively small footprint. Tiles are implemented to carry out RDMS functions such as join, partition, aggregate, etc. The chip Q100 had 3 different configurations, one for low power consumption, another for high power processing and the last was a balanced approach. This proves to us that although the size may vary, a hardware implementation of a data compression DPU is a possibility for instrumentation and control systems to make use of lZW algorithm. Although for a better compression ratio, a hybrid approach of stacking the Huffman algorithm on top of LZW can be employed.

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