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Simultaneous Time Sampling for Heterogenous Multichannel Data Acquisition

Omer Alkelany

Ph.D. Horus University- Egypt

Abstract:

Data Acquisition devices play a vital role in our ubiquitous industrial control systems. This is due to the increasing need to gathered data to aid in automatic decision-making process. Heterogenous analog data require various configurations to be able to reconstruct input data properly. Often, a single analog to digital conversion is used per acquisition channel, but most frequently a multi-channel data acquisition device is used with a constant sampling period for all channels. It is obvious that the dedicated analog to digital converter per channel is expensive choice, especially if the converter device is of high speed. Alternatively, a single analog to digital converter is shared by multiple channels. However, sharing such analog to digital conversion device requires the use of a real-time scheduling algorithm.

In this paper, we firstly present a survey of current real-time multichannel data acquisition sampling techniques. Then, we utilize synthetic signals with different frequencies to study the Simultaneous Time Sampling problem in multi-channel heterogenous data acquisition systems. This problem causes failure of the schedule, thus lead to data loss, or data corruption. Our aim is to compare the effectiveness of such scheduling techniques in addressing such problem. Then, we conclude with a recommendation for a possible solution that can reduce the failure rate of multi-channel scheduling systems that are used for a single analog to digital conversion device.

Keywords:

Industrial Control Systems, Analog to Digital conversion, multi-channel heterogenous inputs, Real-time Scheduling algorithm analysis

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I. INTRODUCTION

Industrial Control Technology is the driving force behind the advancements of Analog to Digital (A/D) conversions. That is because control is done in the digital domain, while the signals in the industry are usually analog (e.g., light waves, sound waves, sensor voltage readings, etc.). In the medical signal processing, another challenge is the diversity of signal specifications in the bioinformatics field (i.e., from low-frequency temperature sensing, to high-resolution imaging). Thus, heterogenous A/D converters are needed. The challenge in heterogenous A/D conversion is the when a single A/D device is used to save cost. In such case, scheduling for the time multiplexor that selects the input channel of A/D converter requires a real-time scheduling algorithm, such as those known for scheduling multiple processes for a single Central Processing Unit (CPU) in multi-tasking, multi-processes computers.

A variety of real-time scheduling algorithms are used in computer science today. Some are static in nature, and some are dynamic. This research paper presents an overview of some of the suitable algorithms for such heterogeneous multi-channel data acquisition, and how they perform in a given synthetic data, which resembles medical data acquisition. Then, we illustrate the potential cases when a Simultaneous Time Sampling (STS) problem occur, and its consequences on the quality of acquired data. Finally, we propose a solution to the STS problem, and conclude and provide insights to our future research work.

II. REAL-TIME SCHEDULING TECHNIQUES

Various scheduling algorithms are evaluated herein to determine how to schedule samples for optimal acquisition of multi-channel input signals. These scheduling algorithms are also known for real-time process scheduling in multitasking operating systems for a single Central Processing Unit (CPU).

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The Nyquist-Shannon sampling theorem states that a signal with maximum frequency component of f Hz, cannot be reconstructed unless the sampling frequency is at least $2f$ Hz [1]. In sophisticated bioinformatic heterogenous data acquisition system applications such as in [2-7], homogenous channels are not expected unlike most signal processing algorithms which make the assumption that samples of a signal are equally spaced.

However, non-uniform sampling techniques exist that relax the uniform interval restriction. One such technique is called Weighted Periodic None-uniform Sampling (WPNS)[8]. Using two A/D converters, the WPNS can estimate the frequency spectrum of a signal that has a higher bandwidth than the A/D converters [8].

A) Weighted Round-Robin

The Weighted Round-Robin (WRR) [9] algorithm cycles through a list of processes and allocates multiple blocks of time to each process for its continuous execution behavior based on its priority. Priorities can be translated into weights, where a high priority process can be given a higher weight. For example, if a process is given a weight of 30,000, it can get 30,000 consecutive blocks of time when assigned to a CPU. Thus, processes with higher weights get more CPU time and the algorithm is successful as long as the sum of the weights does not exceed the maximum number of time-blocks a CPU can serve per second.

In heterogeneous bioinformatics data acquisition systems, a time block can be thought of as a sample period then the WRR algorithm's performance is evaluated. That is, the A/D is treated as the CPU, and its allocation to convert a particular input channel becomes equivalent to processor block of time. This is called time-interleaved, or time multiplexed sampling [10-15]. In the over simplified, very common case, the WRR algorithm reduces to simple Round-robin algorithm when all inputs are homogenous (i.e., require same sampling frequency, as in the case of the 12 lead ECG data acquisition), and in such case, all input signals would have the same weight, i.e., they are all sampled at the same rate. In other words, when a heterogeneous set of signals which have different sampling rates, it would require the weights to be unequal.

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This will create a sampling pattern that would not be acceptable for a data acquisition application. An illustration of the system components is shown in Figure 1.

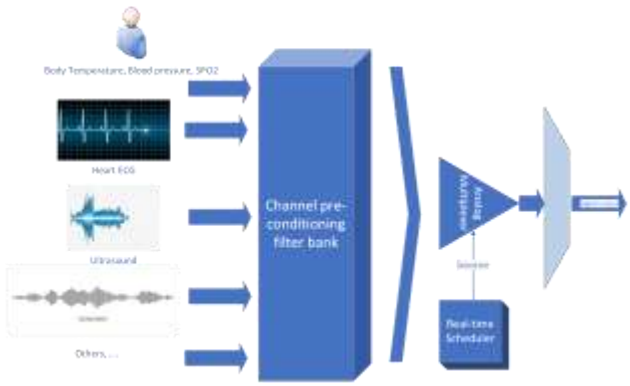

Figure 1: Illustration of a biomedical multichannel heterogenous Data Acquisition with a single A/D converter

The problem comes from the need to have constant sample periods when sampling signals. To illustrate the problem, consider the simple case of sampling a faster signal that has a weight of 30,000 and a slower signal that has a weight of 2. The repeating schedule pattern will be 30,000 consecutive samples of the fast signal and then 2 samples of the slow signal. This not only yields long gap, but more seriously, introduces an unequal delay between samples acquired of the same channel. This will yield corrupt, unusable data because each signal's sampling frequency is not constant and therefore WRR scheduling is not a viable solution for heterogenous multi-channel data acquisition when different sample rates are required.

B) Earliest Deadline First

The Earliest Deadline First (EDF) [16] scheduling algorithm selects first the process which has the earliest deadline. It was described by Liu and Layland in 1973 and is known to have a utilization upper bound of 100% [16].

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Consider a set of periodic processes where each process has a deadline in time domain that stipulates its next finish of execution on a periodic time schedule. Thus, according to EDF, the process with the earliest deadline will be scheduled first, regardless of its duration, in an effort that it meets its deadline. No other processes will be scheduled while this process is executing. A change in which process is executing will occur only when either a process completes or a new process is added to the process list.

This technique can be applied to sampling by computing each channel's deadline according to its desired sample period. Initially, deadlines for all channels are calculated by adding their sample period to time zero. The example in Figure 1 shows a schedule generated using EDF for two channels with sample periods of $\tau1=10$, $\tau2=15$ (in ms) and assumes the availability of a fast enough A/D converter with a sampling period of at least 5 ms. Faster A/D converters are more expensive than slower ones [17-19]. Wait states are shown as X's on the horizontal axis. Deadlines are shown as diamonds on the figure. In the figure, we denote that a sample is being taken by placing a circle on the time-line. Thus, according to this notation, a channel meets its deadline if a sample is taken exactly on or before a diamond is met. In this example EDF produces a repeating pattern with a period of 30 ms, which is Least Common Multiple (LCM) of all the sample periods. Two repetitions are shown in Figure 1.

It is shown in Figure 2 that both channels meet their deadlines. However, the sample period of channel 2 is not constant (i.e., 10 ms or 20 ms as is the case for channel 1 (i.e., always 10 ms). This would yield corrupt data and is not a viable solution for sampling signals. In process scheduling for a CPU, this EDF schedule passes successfully, but fails if it is applied to the given example of heterogenous biomedical data acquisition.

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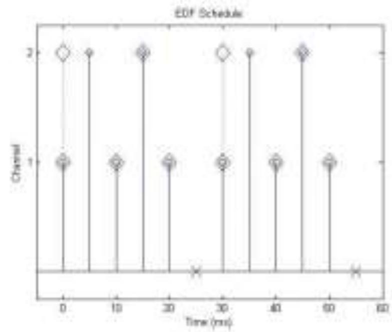

Figure 2: Illustration of a failure in EDF, non-homogenous sampling period for channel 2

C) Rate Monotonic Algorithm

The Rate Monotonic Scheduling (RMS) Algorithm orders processes, or input channels in DAQ applications based on their rate, which is how often they need to run. It was described by Liu and Layland in 1973 and is shown analytically that it has a utilization upper bound of 69.3% [16]. Processes that have a shorter cycle, or higher rate, are considered of high priority. The cycle duration of a process is defined as the time between its start time, and when it must run again. This RMS algorithm is suitable for high-speed multiplexed data acquisition systems such as in [17-19].

RMS

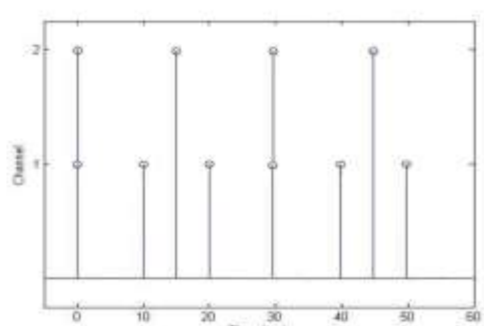

Figure 3: Illustration of a failure in RMS, Same Time Sampling for channel 2

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Using the same two channel example of the previous section, we find that in Figure 3, that RMS schedules the two channels slightly different than EDF. We note that some samples are scheduled on the same time such as in times 0, 30ms, and so on. This repeats each 30ms, which is the LCM of $\tau1=10$, $\tau2=15$ ms.

III. Synthetic Signals for Comparison and Evaluation

Consider for illustration purpose a four channel heterogenous data set with sample periods of $\tau1=50$, $\tau2=100$, $\tau3=200$, $\tau4=200$ (in ms). Note that in such example set, the rates for channels 3 and 4 are equal. A possible schedule of this data set can be shown in Figure 4. In this Figure, we note that channel 4 is sampled too much, which can result in corrupted data reconstruction.

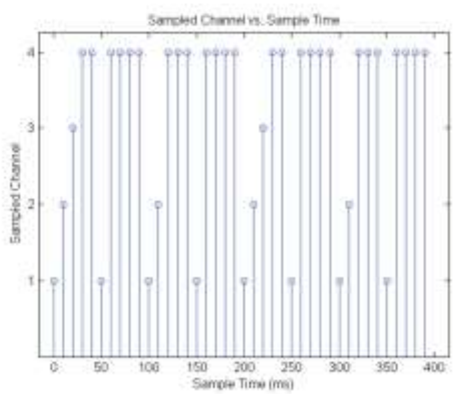

Figure 4: Illustration of a 4-channel RMS, with repeated samples on channel 4

A possible modification to the RMS result can be done as shown in Figure 4. To make this schedule successful for heterogenous A/D conversion, a designer must stipulate that all idle states are deliberately not used for data acquisition, to maintain equal time periods between all samples for all different channels. This is denoted in Figure 3 by the circles on the horizontal axis.

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IV. DATA ACQUISITION EVALUATION

Multiple surveys have been done to evaluate the state of the art of the A/D conversion systems for Data Acquisition systems such as in [20-22]. A single A/D converter can only sample one channel at any given time, once per sample period. When generating a sampling schedule, two or more channels cannot be sampled during the same sample period. This case would result in a Simultaneous Time Sampling (STS) problem. Hence, it is required to generate a schedule where only one channel is sampled per sample period. Figure 2 shows a case where STS was a problem for channel 3, on times 0, 30 ms, and repeats with a period of 30 ms, which is the LCM of $\tau 1=10$, $\tau 2=15$ ms.

Table 1 shows a comparison of available Data Acquisition (DAQ) systems which are widely used in the biomedical or general industrial control systems. We note from the table that the none-multiplexed are more expensive compared to the multiplexed systems. Thus, the multiplexed systems (i.e., the ones of single A/D converter, and real-time schedulers) are the focus of this research paper.

Table 1: Comparison between existing DAQ systems [23-26]

Device	Sampling	Multiplex	Networked	Cost
NI 9215 [24]	4-channel differential	No	Ethernet, Wi-Fi	$794
DATAQ DI-155 [25]	4-channel differential	Yes	None	$150
DATAQ DI-710 [26]	16-channel, single or 8 differenti	Yes	Ethernet	$499

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HDAQ [23]	32-channel single Max 1 MSa/s total 12-bit resolution Range: 0.0 V -	Yes	Ethernet	$220

Since in RMS, channels are assigned priority based on their sampling rate, it is possible that two or more channels are scheduled on the same time. This would be a reason for failure of the A/D acquisition if using a single multiplexed converter.

In the previous examples, each channel's sampling frequency is already a factor of the A/D converter's sample frequency. If this was not the case, the schedule generated can be subject to the STS problem.

V. PROPOSED SOLUTION

The conventional RMS can be modified by inserting shifts to avoid STS problem. This can be done when channels are ordered descending based on their priority (higher priority for smaller sampling period) and then in ascending order by channel number if two or more channels have the same priority. We name this solution the Modified RMS. To guarantee schedule repeatability and no STS problems, the second modification to RMS is to make sure that each sample frequency is chosen as the smallest factor greater than or equal to the desired sample frequency of each channel. The minimum schedule length is determined by finding the Least Common Multiple (LCM) of the sample periods of all channels. Finally, some channel's sampling pattern must be shifted to avoid STS events. This can be done by letting the highest frequency channel have a shift of zero and assigning each consecutive channel the shift corresponding to the first open sample period with respect to previously assigned channels. Further numerical illustration of this shifting approach follows.

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Given that the sum of all chosen frequencies doesn't exceed the maximum sample rate of the A/D Converter, we can make sure that a schedule will be found. Thus, according to our Modified RMS, a sample time shift α of 1ms to channel 2 can result in a movement of its samples to times: 1, 16, 31, 46 ms, and so on. This requires that the A/D converter sampling frequency of at least 1 ms. Figure 5 shows how with our introduced shift (α), there will be no collision in sampling channels 1, 2, and that the STS problem is avoided.

If the sample number is denoted by i, and the sample time is denoted by Sn, where n is the channel number. For the STS to happen, $S_1=S_2$. But, our Modified RMS for the given two channels yields:

$$S_1=10i \tag{1}$$,

$$S_2=\alpha+15i \tag{2}$$,

for a shift of α=1. It is worth mentioning that there is no solution for the two equations (1) & (2) for integers i>0, (the single point intersection for the two lines defined by equations 1, 2 is (-.20, -2), which is not valid for integer sample numbers, nor is a realistic for sampling time). The optimal value of α, and its calculation is the subject of future work. We assume that all input channels are periodic and the interval between sampling requests is constant. This is typical in the application of signal sampling in biomedical DAQ systems in particular or industrial applications in general.

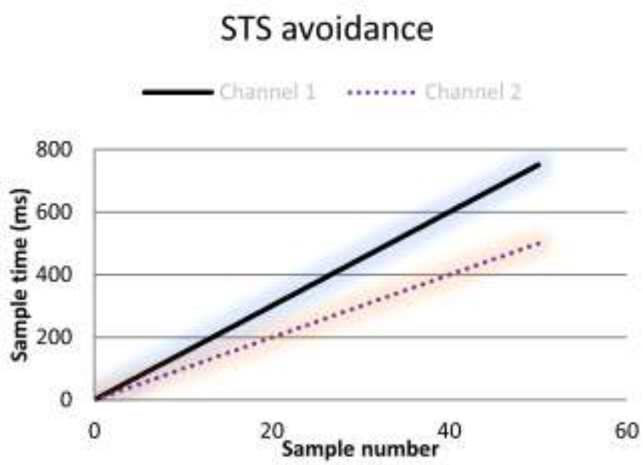

Figure 5: Illustration of STS avoidance for two channels

The proposed Modified RMS works with the following further assumptions:

- Each channel must be sampled before the next request occurs. This means that only one signal can be sampled during any sample period. Any other case would result in an STS problem.
- All channels are independent and no channel depends on the initiation or completion of another.
- The run-time for each channel sampling is constant. This is true in this application because the sample period of the A/D converter is constant. The run-time for a task can be considered the duration of one sample period.

VI. Conclusion and Future Work

In this paper, we presented the need for heterogenous multi-channel data acquisition system such as in the biomedical field. As the price of A/D conversion increase with the required speed of acquisition, industry presents a solution of multiplexed, i.e., shared in time, A/D converter.

We the illustrated a problem with the real-time scheduling algorithms when used to schedule such shared, single A/D for multi-channels. We named this problem the Simultaneous Time Sampling (STS) problem. When it happens, failure of the data acquisition becomes inevitable.

Thus, we proposed a novel solution to the STS problem via the introduction of a Modified RMS algorithm. Also, we illustrated a preliminary mathematical illustration of the STS avoidance approach presented in the previous section.

A detailed mathematical model of our Modified RMS, its thorough evaluation, comparison, and design will be the subject of our future research work.

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