The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2021

Volume 16, Pages 98-105

IConTES 2021: International Conference on Technology, Engineering and Science

Panalysis of the Efficiency of the VRS Algorithm in the Transmission of Weather Data

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Abstract: In the first part of this paper a Variable rate sampling, algorithm for prediction has been described. Variable rate sampling systems were used for reducing power demand, by reducing the number of sent samples. In the second part is performed an experiment where is tested algorithm for prediction of data for transmission and transmitted data. For the purpose of this analyze transmission and predictions are performed for temperatures, air pressure, wind speed, and visibility. Prediction on the side of the transmission is performed using three different extrapolations (*mam*, *mab*, and *ng*). At the receiving side reconstruction of the received signal is performed applying Linear, Cubic, Makima, and Spline extrapolations, built into Matlab. A simple reconstruction is also performed, using the last known value for prediction the next value (this prediction is in the paper named Step extrapolation). Objective quality measures SR (correlation coefficient of reducing the number of samples between a number of measured and transmitted samples), and MAE (mean absolute error between the measured and predicted values of temperatures, pressures and visibility values) were calculated. The results are presented in the table and graphically.

Keywords: VRS algorithm, Efficiency, Extrapolations, Low power system

Introduction

Wireless sensor networks (VSN) are very common in modern communications. During operation, they most often use chips of low power (Zhuo et al., 2020) and small dimensions. Chips most often use energy from battery power for their functioning. Due to limited power supply, it is necessary to ensure that the batteries have a long service life. The long life of a battery power source can be provided in two ways. The first way is to install high-power batteries, which limit is the size of the power source itself. Another way is to manage consumption. Consumption management can be achieved by applying a system with reduced consumption (Low-power consumption, LPC). LPC systems are applied in all spheres of society (consumer devices, military industry, medical devices, etc.). A characteristic example of the application of LPC system is measurement (pressure, temperature, river levels, etc.) where there is no constant and stable power source. In these systems, the connection of sensor to the central computer is usually through the radio connection. In order to save energy, i.e. reduce consumption, systems with dynamic consumption management (DPM) are used (Benini et al., 2000). DPM is used to control the power supply by voltage variation (Benini et al., 2000; Wu et al., 2014; Srivastava et al., 1996) or processor clock speed control (Zhuo et al., 2020; Benini et al., 2000; Rizvandi et al., 2017).

Error reduction is accomplished by applying algorithms with Variable-rate sample - VRS (Mark et al., 1981). The algorithm described in (Mark et al., 1981) changes the sampling time depending on the change rate of sampled signal parameters. The sampled signal parameters are compared with a threshold that is defined based

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on the type of the signal. In (Irvine et al., 2003; Milivojević et. al., 2006; Prlinčević et. al., 2021), the VRS algorithm with prediction is presented.

In this paper, the VRS algorithm presented in (Irvine et al., 2003; Milivojević et. al., 2006; Prlinčević et. al., 2021) is analyzed. The algorithm was applied to the signal that was created for measured values, measured on measuring station "Sunčani vrhovi" at Kopaonik mountain, for the period from 01.09. to 30.09.2020. (W. 2 U. 2020).

The gain, that is, energy saving was determined by a coefficient that represents the ratio of the number of measured samples and the number of transmitted samples with the implemented VRS algorithm. The precision of prediction of used extrapolations methods was measured using MSE, which represents error between measured and predicted values for each extrapolation method.

The paper is organized as follow: Section 2 describes the problem description and methodology; section 3 describes the VRS algorithm. In section 4, an experiment was performed, and the results and analysis of the results were presented. The conclusion is given in section 5.

Problem Description

In digital processing systems, the sample rate of an analog signal is determined in relation to the maximum frequency of the analog signal. In most cases, the sampling rate is not variable over time, and therefore the application of the LPC system can reduce the sampling rate in order to reduce energy consumption. LPC systems can be also applied to VSN model if the intervention aimed at energy saving is conducted during the process of sending or receiving signal. This approach would ensure that there are no deviations in a quality of measured and transmitted information. The reduction of frequency of sending signal is realized in time intervals whereas small changes or constant amplitude can be observed on the analyzed signal. The selection the transmitting interval is very important because frequencies of sending samples directly affects the system performance and energy consumption. The sampling rate and sending samples rate can cause losses important information (Banerjee et al., 1970). Errors that occur can significantly affect the decisions made on such information.

Methodology

The application of the VRS algorithm was performed by sending a signal depending on the defined temperatures, pressures and visibility distances threshold. In addition, the VRS algorithm is set up in a way that after a certain time interval with no changes of parameters (temperature), it sends test signal to demonstrate that the system operates. Maximum sleeping time, where system do not send a signal, is defined as one of the parameters of the system.

On the transmitting side, for the purpose of detailed analysis, signal sampling with different sampling steps was performed. The signal transmission prediction was performed by extrapolations shown in (Irvine et al., 2003). The transmission signal is reconstructed on the received side. For the purpose of analysis, on the receiving side, signal reconstruction was performed using the functions for Linear, Cubic, Makima, and Spline extrapolations, built into Matlab. A simple reconstruction is also performed, that was used the last known value for the next value. This extrapolation for the purposes of this paper is called Step extrapolation.

Algorithms

In (Irvine et al., 2003; Milivojević et. al., 2006; Prlinčević et. al., 2021), a VRS algorithm was implemented in the systems for collection and transmission of data, which are battery powered. The connection between the VRS controller and the computer for data processing and archiving (base station) was realized by radio connection. The change of performance of a signal sent from the sensor is as such that the maximum change of the amplitude, the sampled signal of the temperatures, pressures and visibiliti distances, varied in the range from *min* (values) to *max*(values), and the change of sampling time was varied in the range from t_{min} to t_{max}.

Measured values $x(t)$ is converted, in sensor, into electrical signal $y(t)$. The sampling of the signal is conducted in the time interval t_n, where n=0,1,2, ..., and generates the signal y_n. After the sampled values y_n in the time t_n

prediction y_{n+1}^{p} was performed. At the time t_{n+1} the sampling of the signal y_{n+1} is performed, which presents the real value of the signal. Prediction error depends on sampling time h in $f(t,y)$. The prediction value can be defined as:

$$y_{n+1}^{p} = y_n + h \cdot f\left(t, y\right), \tag{1}$$

where $f(t,y)$ is predicted value between known values (t_n, y_n) and (t_{n+1}, y_{n+1}).
Different numerical methods for calculating $f(t,y)$ have been developed, which can be generally classified in two groups:

a) single step method (Euler method, Runge-Kutta method, ...); and
b) multistep method (Adams-Bashforth method, Adams-Moulton method, ...)

The prediction formula, based on the Adams-Bashforth formula of the fourth order (AB4), is (Rizvandi et al., 2017):

$$y_{n+1}^{ab} = y_n + h \cdot \left(\frac{55 f_n - 59 f_{n-1} + 37 f_{n-2} - 9 f_{n-3}}{24} \right). \tag{2}$$

The following three formulas are used for reconstructions of received signals. Adams-type formula, which contains only y values, is (Irvine et al., 2003):

$$y_{n+1}^{mam} = \frac{509 y_n - 534 y_{n-1} + 336 y_{n-2} - 146 y_{n-3} + 27 y_{n-4}}{192} , \tag{3}$$

where y_{n+1}^{mam} is a prediction using the modified combined Adams method?

The prediction formula based on the combined Adams-Bashforth-Moulton method is:

$$y_{n+1}^{mab} = \frac{79 y_n - 114 y_{n-1} + 96 y_{n-2} - 46 y_{n-3} + 9 y_{n-4}}{24} . \tag{4}$$

The prediction method, fourth-order N–G, backward differencing polynomial is (Irvine et al., 2003):

$$y_{n+1}^{ng} = 5 y_n - 10 y_{n-1} + 10 y_{n+2} - 5 y_{n-3} + y_{n-4} , \tag{5}$$

where y_{n+1}^{ng} is the result of extrapolating the N–G interpolation polynomial.

VRS Algorithm

The VRS algorithm (Irvine et al., 2003) implementation is based on that, we either halve or double the step size, depending on whether the most recent sample was outside or inside a given tolerance compared with the predictions described in (3), (4) and (5). That is, is doubled if the prediction is sufficiently accurate and halved if the prediction is inaccurate:

1) *Step Size Doubling*: The system requires that nine successive equispaced data values are stored in a first-in-first-out (fifo) structure. A calculation for y_{n+1}^{p} is performed using (3). At the next sample time, y_{n+1} becomes y_n and so on, and the previous value of y_{n-8} is discarded from the fifo. If the new value for y_n is within *tol/2* for the predicted value, the sample step h is doubled. Once the process of doubling h is complete, only four more samples must be taken before can be doubled again. However, can be halved on the next sample if required because only five readings are required.

2) *Step Size Halving*: To halve, the interpolated values of $y_{n-1/2}$, $y_{n-3/2}$, $y_{n-5/2}$, and $y_{n-7/2}$ must be calculated to refill the fifo with values at the new sample rate. Again, this can be achieved using the N–G fourth-order backward differencing polynomial in (5).

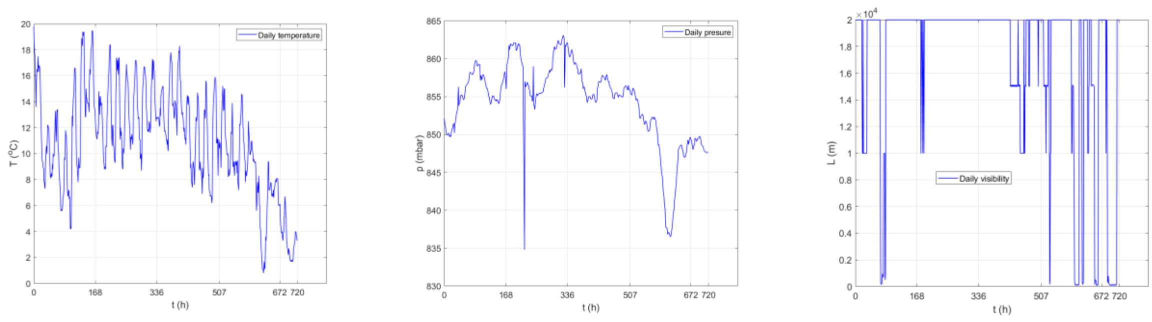
The VRS algorithm is implemented in the system as follows (Irvine et al., 2003):

/* *tol* tolerance */
/* h_{max} maximum sampling step */
/* h_{min} minimum sampling step */
Set *tol*
Set h_{max}
Set h_{min}
Set $h = h_{min}$
Read the first nine values $y_{n-8},\dots,y_n$
Until data
  Calculate y_{n+1}^p
  Read y_{n+1}
  Set $y_{n-8}=y_{n-7},\dots,y_n=y_{n+1}$
  If $\left|y_{n+1}^p - y_{n+1}\right| \geq tol$ **then**
  If $h>h_{min}$ **then** halve *h*
  else if $\left|y_{n+1}^p - y_{n+1}\right| < tol/2$ **then**
  If $h<h_{min}$ **then**
  If duplicating the last four values
  then duplicating *h*
  else do not change *h*
Loop

Experimental Results and Analyze

Experiment

In order to test the VRS algorithm application in the systems with reduced energy consumption, the base of single values of temperature, pressure, and visibility was created. The Base is created for September for the mountain Kopaonik where the values are taken from the measuring station "Sunčani vrhovi". The measured single values of temperatures, pressures, and visibility distances are for a time interval of 1h. Figure 1.a shows scale of all measured temperatures, figure 1.b shows scale of all measured pressures, and figure 1.c shows scale of all measured visibility for September 2020. For the requirements of the experiment, the signal was varied in a way where the change of temperature sampling was performed in the range from T_{min} = 0.01°C to T_{max} = 2°C, the change of pressure sampling was performed in the range from p_{min} = 0.01 mbar to p_{max} = 2 mbar, the change of visibility sampling was performed in the range from L_{min} = 5 m to L_{max} = 500 m, and the change of sampling time was varied in the range from t_{min} = 1h to t_{max} = 4h,



a) b) c)

Figure 1. Base of daily values (for September, hourly - 720 h): a) scale of temperatures, b) scale of temperatures, and c) scale of visibility

The minimum sampling time of temperature sending signal is t_{min} = 1 (h). This time is in line with intervals of temperature measurement at the sampling site. Maximum sampling time is limited at t_{max} = 4 (h) The measured temperatures had values rounded to one decimal place so that the tolerance values of sending samples were from 0.1 °C to 2 °C. The principle of operation of the VRS algorithm is shown in Figure 2.

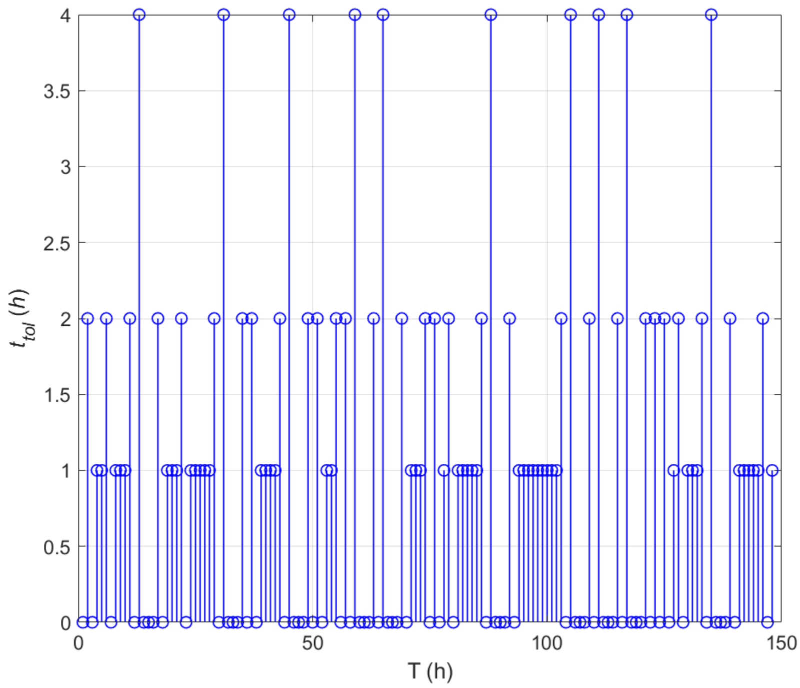


Figure 2. Principle of functioning the VRS algorithm, presented for temperatures in second week in September.

The effect of the VRS algorithm is observed on the reduced number of sent samples during the defined sending interval, and all in accordance to the parameters of the signal y(t). The Sample Ratio (SR) is introduced as a measure of reduced the number of data sent to the recipient:

$$SR = \frac{N_s - N_{s\_vrs}}{N_{s\_vrs}} \cdot 100\% \tag{6}$$

where N_s is number of samples at a constant sampling step, N_{s_vrs} number of samples at application the VRS algorithm.

As an objective quality measure between measured value of the signal (temperatures, pressures and visibility distances) and reconstructed value of the signal, the mean square error – MSE was used:

$$MSE = \frac{1}{N}\sum_{n=0}^{N-1}\left(y(n) - y_{rek}(n)\right)^2 \tag{7}$$

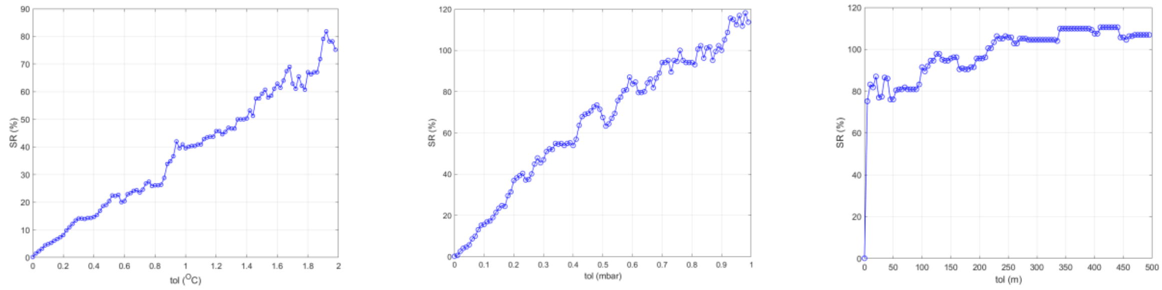
and Normalized correlation coefficient:

$$NC = \frac{\sum_{n=0}^{N-1}\left(y(n)\cdot y_{rek}(n)\right)}{\sqrt{\sum_{n=0}^{N-1}\left(y(n)\right)^2}\cdot\sqrt{\sum_{n=0}^{N-1}\left(y_{rek}(n)\right)^2}} \tag{8}$$

where N is the number of samples in the defined time interval.

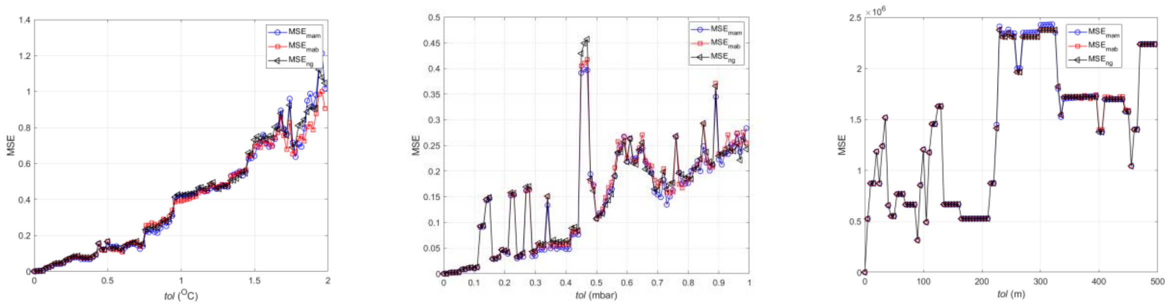
Results

The result of the effect of applying the VRS algorithm for varying temperatures, pressures and visibility distances are presented in Figure 3. Tolerance of the temperature values was varied in the range from 0 to 2^{o}C with the step of 0.1^{o}C, fig 3.a. Tolerance of the pressure values was varied in the range from 0 to 1 mbar with the step of 0.1 mbar, fig 3.b. Tolerance of the visibility distance values was varied in the range from 0 to 500 m with the step of 5 m, fig 3.c. Figure 4 shows a comparative diagram of MSE for all three prediction methods (*mam*, *mab* and *ng*). Figure 5 shows the values for objective measurement of quality NC for three applied predictive methods.



a) b) c)

Figure 3. Sample ratio for applied VRS algorithm for: a) temperatures, pressures, and visibility distances.



a) b) c)

Figure 4. MSE for applied prediction methods for: a) temperatures, pressures, and visibility distances.

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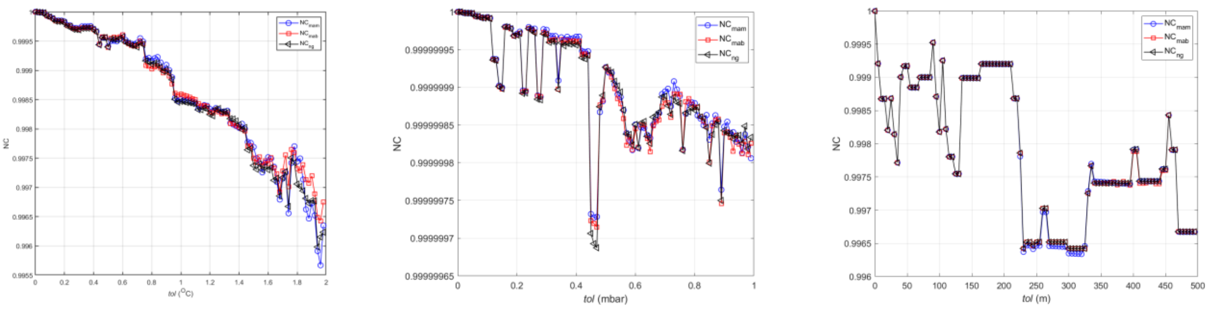

a) b) c)

Figure 5. NC for applied prediction methods for: a) temperatures, pressures, and visibility distances.

Analysis of Results

Based on the results shown in diagram presented on Figure 3.a, it can be concluded that with the increase of the sample rate temperature tolerance, the positive effect of the application of the VRS algorithm increases. Maximum SR is SR = 82 %. Based on the results shown in diagram presented on Figure 3.b, it can be concluded that with the increase of the sample rate pressure tolerance, the positive effect of the application of the VRS algorithm increases. Maximum SR is SR = 119 %. Based on the results shown in diagram presented on Figure 3.c, it can be concluded that with the increase of the sample rate visibility distance tolerance, the positive effect of the application of the VRS algorithm increases. Maximum SR is SR = 110 %. The higher value of SR indicates the lower energy consumption for signal transmission, that is, the smaller number of samples was sent.

Analyzing the values for MSE, presented on diagram shown in Figure 4, it can be concluded that as the tolerance of the sampled rate of measured values increases, the error that occurs with prediction also increases. The error that occurs is in small values, i.e., for maximum tolerance, MSE has a value of approximately

MSE = 1.2 (for temperatures), MSE = 0.45 (for pressures), MSE = $25x10^6$ (for visibility). Also, with results presented on Figure 4 it can be concluded that the three-prediction methods, *mam*, *mab* and *ng*, are with approximately the same errors.

Analyzing the values for NC, presented on diagram shown at Figure 5, it can be concluded that as the tolerance of sampled rate of measured values increases, the value for NC decreases, which implies that the error between the actual measured temperature and the predicted temperature increases. The correlation between the measured and predicted values for maximum used tolerance is approximately NC = 0.9955 (for temperatures), NC = 0.9999997 (for pressures), NC = 0.9965 (for visibility), which is an extremely good correlation.

Conclusion

Using the experiment, the paper analyzes efficiency of VRS algorithm for transmission of values for temperatures, pressures and visibility from measurement station "Sunčani Vrhovi" on the mountain Kopaonik for September. Using the experiment, the results of objective quality measures of VRS algorithm (SR, MSE and NC) are obtained. Based on the values of objective measures, it can be concluded that application of the VRS algorithm for the reduction of energy consumption through the reduction of the number of sending samples, gives positive result. For parameters that have a small range of value changes, higher SR is obtained, a smaller number of samples are sent, the saving in energy consumption is greater. For example, for sampling tolerance of the temperature of 2^oC, the gain in reduction of sent samples in amount of approximately 80% was observed. For sampling tolerance of the pressure of 1 mbar, the gain in reduction of sent samples in amount of approximately 120% was observed. For sampling tolerance of the visibility distance of 500 m, the gain in reduction of sent samples in amount of approximately 110% was observed. For smaller sampling values the MSE is smaller, signal isrekonstructed with higher precision. Based on presented results, it can be concluded that VRS algorithm, in which the reconstruction of the signal on the receiving side is based on the *mam*, *mab* and *ng* prediction method, can be used for application in real - time operation systems

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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To cite this article:

Prlincevic , B. & Milivojevic, Z. (2021). Panalysis of the efficiency of the VRS algorithm in the transmission of weather data. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 16*, 98-105.