Journal of Engineering and Applied Sciences 12 (Special Issue 11): 9068-9074, 2017
ISSN: 1816-949X

Development of Firmware for Automated Management System of Sounders with High Upgrading Rate

[1]Alexandr Belousov, [2]Iurij Koshlich, [1]Artyom Grebenik and [3]Olga Parashuk
[1]Department of Technical Cybernetics,
[2]Department of Energy Saving and Energy Efficiency,
[3]Department of Electricity and Automation,
Belgorod State Technological University, Belgorod, Russia

Abstract: There is a growing number of Church buildings that acquire electronic bell ringing equipment which makes, it possible to automate the electronic ringing. However, most of current devices do not take into account the temperature conditions which leads to damage of bells. This study describes the approach to the construction of the Automated Management System (AMS) of sounders with high upgrading rate in the case of chime automated management system. The system has a web-based access mechanism. We have also developed the system's self-tuning algorithm which implies execution of a series of test strikes. Specific attention is paid to the selection of the best parameters of the control signal, namely the period and duty factor of the Pulse-Width Modulation (PWM) which was chosen as a means of changing the DC motor speed and the rotation direction. The analysis of experimental studies showed that in order to achieve the loudest sound one needs to vary the period and the duty factor of PWM with regard to the environment. The proposed device has a self-tuning function which eliminates inaccuracies in operation related to the human factor.

Key words: Automated management system, chime, self-tuning algorithm, sounder, web-based access, inaccuracies

INTRODUCTION

The music signal always has sharp level spikes for example, during work on percussion instruments such as kettledrum, drums, bells, triangles, cymbals, tambourines, etc. This study deals with an approach to the construction of an automated management system for one of these instruments the bell.

Presently everything is subject to modernization, even such seemingly conservative part of our world as the Church. Electric lamps successfully replaced the candles and the usual bell towers were replaced with chime automated management systems or electronic bell ringers. The reasons for introducing such systems were connected as a rule with the lack of professional bellmen as well as of course with convenience to perform various chimes without having any skills. The advantage of such systems implies the possibility to train new bellmen for Churches. Rising the automation level can improve the quality of ringing, optimize control and execute remote system control.

Therefore, actuality of application of chime automated management systems in the Church sphere is very high. In addition, it gives the possibility to use the bell tower not only for its intended purpose (to convene parishioners to worship) but also to use it as a chiming clock to chime according to the particular schedule (example, Saint Isaac's Cathedral) or like the emergency chime of bells.

Despite all these advantages, the opposite opinion exists stating that this approach to the creation of bell turret contradicts the existing traditions and cannot be applied (Anonymous, 2009).

There are several types of bells with different design and accordingly with different method of sound extraction. Some bells have fixed clapper they ring by swinging the bell itself. In other cases, the bell is fixed and only the clapper is swinging in other types of bells there is no clapper at all and the stroke on the fixed bell is made using a hammer fixed outside the bell (Klopotarul, 2008; Ivanushkin *et al*., 2003). The bell systems are also classified directly according to the number of bells, their size, shape and weight. All this gives a wide range of different ways and mechanisms which help to extract the sound from these instruments (Anonymous *et al*., 2011a).

Corresponding Author: Alexandr Belousov, Department of Technical Cybernetics, Belgorod State Technological University, Belgorod, Russia

Today the bell towers are equipped with electric bell ringers which can have a keyboard for manual playing, connected with the control unit by means of wires or wireless connection. The operator controls the intensity of the bell's swinging, the clapper or hammer blows depending on the design of the bell. In the latter case, the bell ringer play can be compared with playing piano. The difference is that when you play the piano, you press keys and pianoforte hammers hit the stretched strings while during chime hammers hit the bells.

As an example, the management system, based in Maastricht (Anonymous, 2009) could be regarded as one of the first automated chime management systems used in Europe.

Similar systems were developed in the early Middle Ages and can be considered as forerunners of popular music boxes that produce sounds with a set of dowel pins placed on a spinning cylinder or disc. The melody is played through the drum spinning. Cylinders are usually made of metal. In some expensive models changeable cylinders were used which served as specific music programs and could give the possibility to change the melody. In such systems bells with hammers placed on the outer side are used which is typical for European countries. Originally, the drum, made of two wrought iron wheels with removable dowel pins was connected with the tower clock. Later cylinders were made of yellow metal in the form of single piece.

When you enable the tower clock (usually every hour), the drum starts spinning. Once one of the pins passes under the lever, the hammer starts to lift. The hammer falls back on the bell when the pin is passed as a result, the lever is returned to its starting position due to the return spring. Currently, in such systems the drum that produces typical sound during spinning, the use of which is associated with certain disadvantages has been replaced by the plastic tape with holes, supplanting pins. Levers were replaced by electromagnetic relays and controllers started to provide system management.

In the Trinity Episcopal Church such system is represented by four beautiful bronze bells made by famous Meneely Bell Company of West Troy, NY in 1895. The largest bell weighs 2,000 pounds.

Hammers were mounted by means of mounting brackets. Chime is performed every hour and it is possible to use bells both individually and jointly. Chime is automatically controlled through the Chime Master Millennium Bell Control System and manually with a manual wireless remote operating panel.

Another example of such a system is the automated bell turret at the Church of the Archangel Michael in Arkhangelsk. The system comprises 15 bells and is able to play up to 59 canonical chimes.

The "Electronic bell ringer" system installed in the Svyato-Uspenskiy men's monastery of Lipetsk allows simulating all the movements of the arms and legs of the ringer while adjusting power and time to strike the bell. The system is controlled by pressing one of the switches, each of which corresponds to a certain type of chime (Anonymous, 2013).

St. Alexander Nevskiy Cathedral in Simferopol has a two-storied bell turret which includes a large number of bells which in turn complicates the management process. Besides clappers, the bells weigh up to several hundred kilograms. The installed automated system cannot completely replace the ringer but makes his work easier. This system makes it possible to activate all the bells at the same time through the stretches and the pedals (Anonymous, 2015).

Presently, the Russian market offers quite limited choice of chime automated management systems and usually most of them, like their European analogues do not have the self-tuning option but are only able to play tunes which are stored in ROM base. This requires periodic manual tuning control of the sound by changing the program or modernizing the equipment which in turn requires certain knowledge and skills. However, not all of these systems consider the environmental impact, namely the temperature which is important during cold winter or hot summer. System management is carried out mainly in two modes either manually or through a mobile phone on GSM channel. It is not always accessible because it requires writing understandable customer applications for various mobile platforms, allowing one-click system management instead of writing SMS-messages. Furthermore, it should be noted that the prices of such systems are often unreasonably high. Table 1 shows some characteristics of such systems, for convenience.

The developed system is deprived of such disadvantages because it provides self-tuning parameters due to the presence of feedbacks on the outside temperature and the sound amplitude as well as the web-based access availability in addition to control by means of SMS-messages, that provides cross-platform of client-side of the system (Table 2) (Belousov *et al*., 2012).

The main feature of this study is that structuring of the chime management system is considered from the perspective of the theory of automatic control which allows applying the methods of this theory and relevant principles to the system which is being developed. In particular, the application of the principles of management with regard to deviation and perturbation allows providing the best system performance under varying environmental conditions. The algorithm of the system self-tuning based on the principle of management with regard to deviation, allows to take into account the tension of the rope (cable wire) to ensure the best

Table 1: Brief comparison of the chime automated management systems

System	Possibility of remote control through GSM	Possibility of remote control through GPRS	Possibility of remote control through radio channel	System self-tuning	Consideration of environmental impact	Existence of midi keyboard/ remote control panel
1	-	-	-	-	-	-
2	-	-	+	-	-	-
3	Optionally	-	-	-	Optionally	Optionally
4	-	-	+	-	-	-
5	-	-	+	-	-	Optionally
Developing system	+	+	-	+	+	-

Table 2: Conditions for experiments and results of measurements

	Conditions for experiments		Results of measurements				
Experiment series No.	x_1 (duty factor) (%)	x_2, mc (period)	A1	A2	A3	$\bar{A}_1$	S_1^2
1	98	200	221	214	223	219.33	22.33
2	93	300	151	153	149	151.00	4.00
3	88	400	93	104	95	97.33	34.33

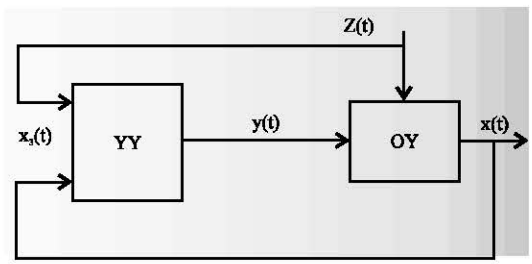

Fig. 1: AMS structure, built upon the combined management principle YY (MD): Management Device, OY (OM): Object of Management, x_3: given value of the management quantity, y management impact, Z: external perturbation impact, x: management quantity)

possible sound of bells and the presence of a temperature sensor provides the management principle with regard to perturbation the principle of compensation.

The principle of management with regard to perturbation is implies that the control system monitors the perturbation factor which in this case is the temperature of the environment and having regard to this factor the system builds control algorithm in such a way that the effect of this factor on the system is compensated. Thus, there is a combined management principle (Fig. 1).

The study suggests approaches for dynamic management of digital management system self-tuning (Mintarno *et al*., 2011). The suggested self-tuning algorithms provide definition of such process-dependent parameters as supply voltage, stroking frequency. The application of the mentioned approach within the designed system is limited by specific properties of firmware platform.

The study suggests PWM-management through installing the system using four interacting fuzzy controllers. The construction of these controllers and the results on the modelling experiment are provided (Vas *et al*., 1997).

The study describes basic features of adaptive management systems, one of them implies lack of necessity to have large volume of initial information to generate the management signals (Zervos and Dumont, 1988).

The study attempts to develop the new multi parameter self-tuning PID (Proportional-Integral-Differential) pitch and yaw angle regulators under parametrical ambiguity and external perturbations (Sahu and Pradhan, 2014). PID parameters are real-time updated. The model is identified upon the regressive model which parameters are calculated upon the least squares method. The obtained results show the advantage of the suggested regulator as compared with regulators with fixed coefficients given the external impact.

The study considers the approach to designing the self-tuned regulator upon the iteration learning process (Noack *et al*., 2014). As compared with standard approaches, the suggested method implies two main steps. The first step is to calculate the input variable upon the ILC (Iterative Learning Control) algorithm and the second one to optimize the feed forward regulator under given parameters. The operability and efficiency of the suggested method are shown upon the use of the imitation model.

MATERIALS AND METHODS

The information interaction scheme is shown on Fig. 2. The system has two sensors: the first (D1) takes the temperature of the environment. The impact force at the bell depends on this temperature (under low temperatures and high impact force can break the bell), the second (D2) responds to changes in the amplitude of the

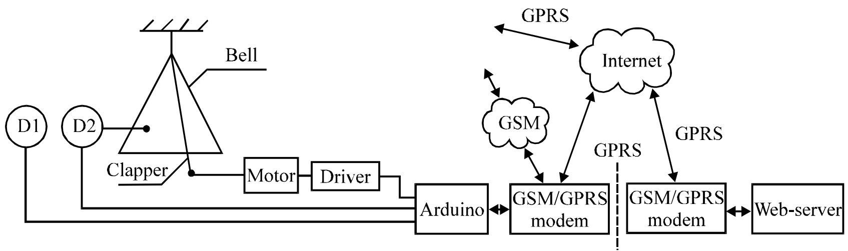

Fig. 2: Scheme of the information interaction. D1: temperature sensor, D2: sound sensor, IM: executing mechanism

impact, creating a feedback on amplitude and frequency of the audio signal. Both sensors are connected to the controller which in turn, depending on the data obtained from sensors and given the start signal, controls the direct current motor impelling the clapper by linkage system. Besides, it means that it is possible to control such system using GSM-channel that requires GSM-module connected with the controller and having access through a web-interface which implies the running server (Glagolev *et al*., 2013).

DC motor with a permanent magnet having the following characteristics serves as an executing mechanism:

- Power 60 W
- Consumption current on a high speed no more than The 6.5 A
- Armature speed 3800 rpm

The H-bridge is used with a view to control the speed of the engine and have the same direction of rotation (Horowitz and Hill, 1989). The device has the power-switching module because the microcontroller that controls its operation is not able to with stand the current sufficient to open the used transistors (Shiklai scheme or “Darlington’s complementary transistor”).

The distinctive and the most important feature of the developed system is the ability to self-tuning which simplifies the execution of commissioning works. This system also allows automatic adjusting the parameters of the operation algorithm in a changing environment (e.g., cable stretching). The developed STC algorithm shown in Fig. 3 in the form of block diagram, consists of an execution of set of test hits with sequential changes in period (T) and pulse ratio (S) of PWM (Pulse Width Modulation), processing the obtained data array and automatic determining the most suitable signal parameters produced by the controller. Consequently, we have the self-tuning system without reconstruction or modification of the program code (Holmes and Lipo, 2003).

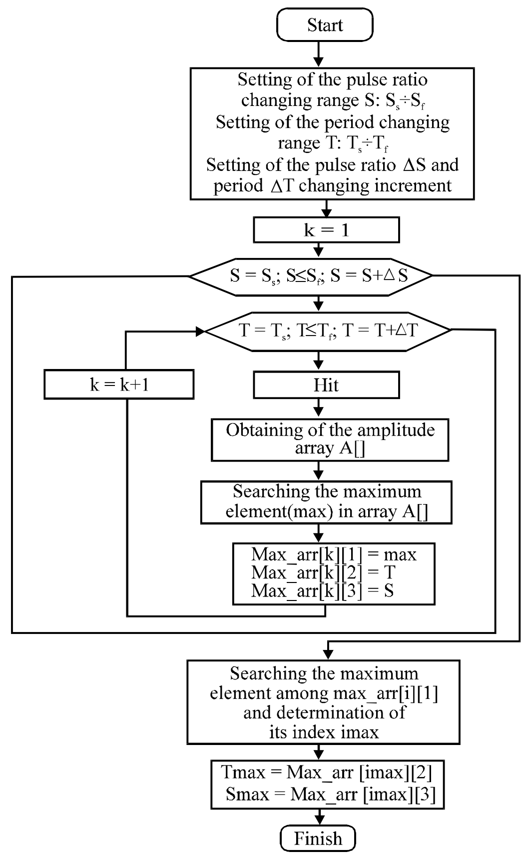

Fig. 3: STC algorithm

RESULTS AND DISCUSSION

Before starting to plan the experiment, one should make sure that the experiments are reproducible. For this purpose, there have been several series of parallel experiments in the given range of impact factors change. The results of these experiments are summarized in Table 2. For each series of parallel experiments, we calculated the arithmetic value of the response function. In order to carry out the experiments with the required degree of reliability, it is sufficient to carry out three experiments (N = 3). The estimated value of cochran’s criterion is calculated according to Eq. 1:

$$G_p = \frac{\max s_j^2}{\sum_{j=1}^{N} s_j^2} = 0.567 \quad (1)$$

The relevant value of cochran's criterion found for N = 3, f = k-1 = 2, P = 0.95, G = 0.871. The condition G_p≤G is satisfied, therefore, the experiments can be considered reproducible.

In order to determine the number of experiments needed to ensure the reliability of the reached results, we used methods of the theory of probability and mathematical statistics. First, one needs to determine the accuracy of experimental measurements of the audio signal amplitude during field study (**δ**).

Then, it is necessary to determine the standard deviation of the amplitude of the acoustic signal (**σ**) pursuant to Eq. 2:

$$\sigma = \sqrt{\frac{\sum_{1}^{n} p_i (AH_i - \overline{AH})^2}{n}} \quad (2)$$

Where:

- n = The number of measurements (test, preliminary)
- AH_i = The value of i measurement (the amplitude of the audio signal)
- $\overline{AH}$ = The middle arithmetic value of the measurements (the amplitude of the sound signal)
- p_i = Number of identical measured values

Then, the number of experiments is defined by Eq. 3:

$$N = \frac{U_{кр}^2 \cdot \sigma^2}{\delta^2} \quad (3)$$

where, $U_{cr} = F(F_{cr})$ is the value of the critical range of F-allocation (table value) of the Laplace function:

$$F_{cr} = (1-\alpha)/2 \quad (4)$$

where, **σ** standard deviation (value of the amplitude of the sound signal); **δ** accuracy of measurement (value of the amplitude of the sound signal); α = 0.05 significance level U_{cr} is F (0.95/2) = F (0.475) = 1.96.

Experimental research has suggested the dependence of the sound amplitude on the control signal parameters which is shown in the diagrams presented by Fig. 4 and 5. The diagrams show that the loudest sound is achieved with a maximum pulse ratio of the control signal. With increasing time of the signal injection, the sound amplitude also increases but there is some period value T_{cr}, after which the increase in the period leads to the decrease in the sound amplitude.

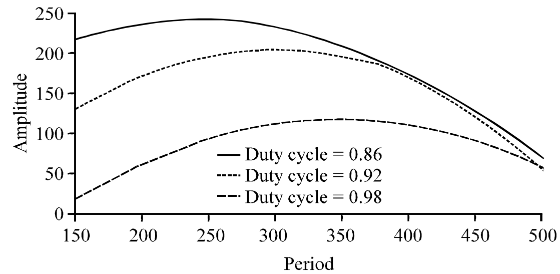

Fig. 4: Dependence of the amplitude on the control signal modulation period

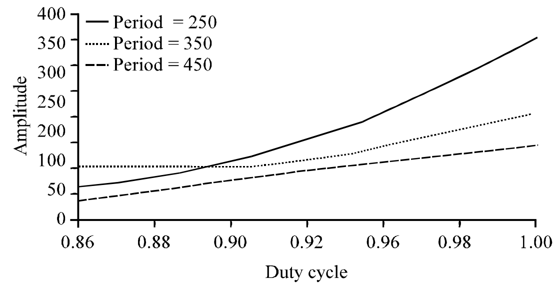

Fig. 5: Dependence of the sound amplitude on the control signal pulse ratio

Summing up the previously mentioned in order to achieve the best sound quality (maximum volume), for example, it is necessary to choose the period value $T = T_{cr}$ and the pulse ratio value of the control signal should be also maximized.

The suggested system control algorithm as well as the developed structure are not unique and are widely used in the design and setting algorithms for automated management systems. However, the use of approaches and methods of control theory for such systems allows us to look once again at the design process of their structures and automation, streamlining of these processes using standard methods and approaches as well as providing a high quality. For example, using the principles of management by exception and the perturbation allows greatly increase the degree of automation of management processes automation peal by the presence of feedback and before the effect of disturbances on the controlled process. Thus, a slight complication of the structure of the system and its software allows for the possibility of taking into account the influence of the ambient temperature to prevent accidents and automation of system settings, limiting the need for human intervention in the functioning of the system to the installation of the equipment, its primary setting and decision-making on the start-up/stop. Similar devices have the beat-changing function (Ivanushkin *et al*., 2003) but the lack of a temperature-reading system does not allow calculating the impact force accurately. This can lead to the damage of the bell.

The use of automated systems to control the ringing of bells is a logical development of this area, since, the process itself as a blow ringing the bell tongue is a basic mechanical and does not require the presence of a person and control algorithms similar systems in the simplest case, the open loop control are nothing more than a set of actions for on/off actuator in which role can be different types of engines (Ivanushkin *et al*., 2003), for certain periods of time. Development and implementation of such systems in Russia and abroad will automate the process of bell ringing, will provide additional advantages in sound quality, the ability of the remote control and prevent possible accidents during the cold periods.

CONCLUSION

The developed automated chime management system has a number of competitive advantages as compared with similar systems. The main advantages are the possibility of self-tuning, consideration of the temperature of the environment and management through web-interface which implies cross-platform use of the system from the part of the client. The use of the system will allow automating the chime process, there will be no need for a professional bellman at the Church; this system will also, significantly reduce the time required for the system setting and will enable remote control. The principle of system construction, executing mechanisms, sensors and control device used in the system, due to their relative cheapness will reduce expenses on the creation and installation of the system not >20% in comparison to its competitors. Of course such system has some disadvantages, for example, each bell has only one sensor which is a piezoelectric element that indirectly measures the sound amplitude through bell oscillation amplitude during the impact. This problem could be solved through installing additional sound sensors working on other principles which will provide measurements that are more accurate. This is important on the self-tuning stage. However, this in turn, causes increase of costs due to the need to increase the assortment of the sensors themselves as well as the need for additional expansion boards for control devices because of the limited number of inputs/outputs. Such simplification is not critical and does not affect fundamentally the quality of the system which predetermines its high level of competitiveness.

REFERENCES

Anonymous, 2009. Church specialties the new England bellman. Trinity Episcopal Church, New York, USA.

Anonymous, 2011b. Carillon and chime designs and maintenance. Organtek, Nox County, Tennessee.

Anonymous, 2011a. The bells are the sound of the city. Resonance Network, Inc., Atlanta, Georgia. https://resonancenetwork.wordpress.com/2011/01/25/the-bells-are-the-sound-of-the-city/

Anonymous, 2013. [Electronic bell-ringer from Lipetsk takes part in the All-Russian chime]. Lipetsk Media, Russia. (In Russian) https://translate.google.com/translate?hl=en&sl=ru&u=http://www.lipetskmedia.ru/news/view/26131-_Aelyektronniii.html&prev=search.

Anonymous, 2015. [The Crimean orthodox church got automated bell turret]. NTV, Moscow, Russia. (In Russian)

Belousov, A.V., S.N. Glagolev and J.A. Koshlich, 2012. Realization of web-based access to technological parameters in the system of distributed power consumption objects monitoring. Innovative Inf. Technol., 27: 373-375.

Glagolev, S.N., A.V. Belousov, Y.A. Koshlich and A.B. Bystrov, 2013. Energy consumption objects monitoring systems-problems of web-based access to technological information. Am. J. Econ. Control Syst. Manage., 1: 6-9.

Holmes, D.G. and T.A. Lipo, 2003. Pulse Width Modulation for Power Converters: Principles and Practice. John Wiley & Sons, New Jersey, USA., Pages: 725.

Horowitz, P. and W. Hill, 1989. The Art of Electronics. 2nd Edn., Cambridge University Press, Cambridge, England, UK., ISBN:9780521498463, Pages: 1125.

Ivanushkin, V.A., D.V. Isakov, V.N. Kozheurov and F.N. Sarapulov, 2003. Automated electric drives of bells with linear induction motors. Proceedings of the 2003 Conference on Ural-Siberian Scientific and Practical, June 23-24, 2003, Hostel Nikolskiy, Yekaterinburg, Russia, pp: 204-205.

Klopotarul, L.D., 2008. Master of the art of bells. Ru.Clopote.Md., Russia.

Mintarno, E., J. Skaf, R. Zheng, J.B. Velamala and Y. Cao *et al*., 2011. Self-tuning for maximized lifetime energy-efficiency in the presence of circuit aging. IEEE. Trans. Comput. Aided Des. Integr. Circuits Syst., 30: 760-773.

Noack, R., T. Jeinsch, A.H.A. Sari and N. Weinhold, 2014. Data-driven self-tuning feedforward control by iterative learning control. Proceedings of the 2014 IEEE 23rd International Symposium on Industrial Electronics (ISIE), June 1-4, 2014, IEEE, Istanbul, Turkey, ISBN:978-1-4799-2400-4, pp: 2439-2444.

Sahu, P. and S.K. Pradhan, 2014. Multi variable self tuning PID control of a twin rotor MIMO system. Proceedings of the 2014 International Conference on Advanced Communication Control and Computing Technologies (ICACCCT'14), May 8-10, 2014, IEEE, Ramanathapuram, India, ISBN:978-1-4799-3915-2, pp: 381-385.

Vas, P., A.F. Stronach and M. Neuroth, 1997. Full fuzzy control of a DSP-based high performance induction motor drive. IEE Proc. Control Theory Appl., 144: 361-368.

Zervos, C.C. and G.A. Dumont, 1988. Laguerre functions in stochastic self-tuning control. IFAC. Proce. Vol., 21: 111-116.