Wireless Time Critical System's Architecture Development Based on Dynamics of Data

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Abstract **- The following paper presents approach for wireless transmission system development in time critical environment. Proposed approach uses system's dynamic characteristics. Such information allows predicting data transmission bottlenecks on early development stage. This in turns shortens overall development time, by reducing the number of backoffs. Dynamics processing is based on Hammerstein model. Which proposes splitting up system on components, that isolate dynamic/static and linear/nonlinear properties. It allows creating an analytical representation of a system, by using low amount of parameters. System's response is analyzed by treating multiple data flows to model input. The most valuable analysis type is checking boundaries of parameters. The analytical model allows a low effort adaptation to systems architecture changes. The proposed model was tested on real industrial object, with three distributed control stations and more than one hundred sensors/actuators. Created model approved possibility of using wireless communication and pointed out bottlenecks.**

Keywords: **wireless networks, Hammerstein model, time critical, dynamic system, autonomous industrial control.**

I. Introduction

To design or enhance time critical system, developer needs to know system's functionality and planned characteristics. This information not only allows creating analytical model, but also tuning up data transmission parameters. Analytical model gives many abilities for developer. For example checking system's ability to achieve planned functionality and characteristics. As well data transmission type selection and system components regrouping for achieving best functionality.

Analytical analysis of controlled system and controllable object is especially important when utilized methods and hardware are close to their parameters boundaries. Such a situation arises more often in time critical autonomous control systems, where wired networks are substituted by wireless transmission. Analytical model analysis gives ability to implement wireless data transmission in autonomous control systems. This in turns has at least two practical advantages. First – allows creating previously impossible autonomous control in harsh environment (mobile systems, dangerous chemicals area, etc.). Second – economic benefit in absence of wires. I.e. essential decrease in networks installation and service costs. Cable cost per meter in substituted for transmission equipment cost per kilometer. That would be at least two times cheaper for the same distance [1].

The aim of the research described in this paper, is to give ability to analytically evaluating wireless transmission in time critical applications. Following chapters will include current situation analysis, next the dynamic nonlinear system modeling proposal and finally methods implementation and evaluation at the real industrial object – wind tunnel control system.

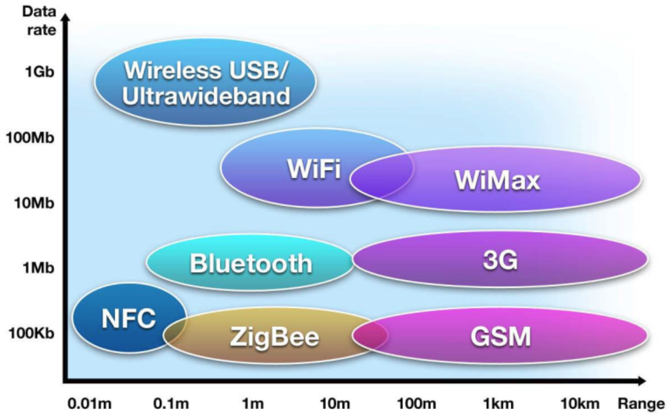


Fig. 1.Wireless networks Data rate vs Range

II. Current situation

By looking at the current wireless data transmission standards and their development trends (fig. 1.), it possible to see their tendency to higher speed and distance. And usually there are no words about expected delay. It could be explained by the fact that people, as the end consumer of such wireless transmissions, are tolerant to delays. As an example, user interface designers assume up to four seconds as highest acceptable delay boundary [3]. Of course every current standard is capable to deliver data with much lower delay.

Table 1. Typical industrial applications delay requirements

Application	Max delay (ms)	Cycle time (ms)	Packet loss limit
Local control	**10..20**	20..30	$< 10^{-9}$
Global control	20..30	30..100	$< 10^{-9}$
Diagnostic and monitoring	>100	>500	$10^{-9} – 10^{-9}$
Mobile operators safety	**10..20**	10..30	$< 10^{-9}$

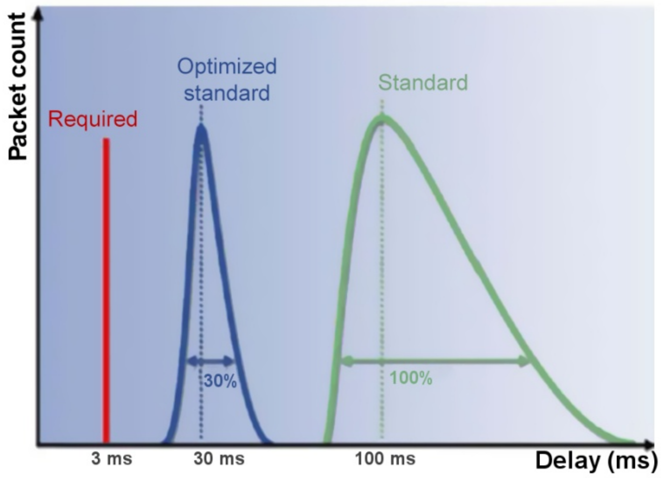
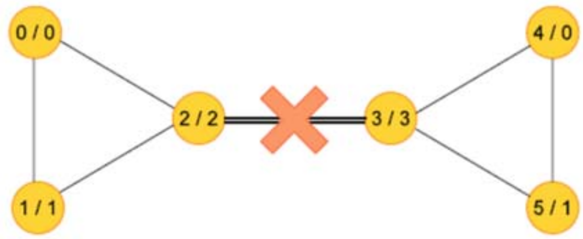


Fig. 2. Standard protocol delay vs optimized and required

Higher demands are for synchronous transmission of audio and video. The highest of them is lip sync – audio stream synchronization to match motion seen in video. In this case acceptable delay is bounded to 60ms [5]. It is still achievable task for existing standards that use quality of service (QoS [6]) techniques. Therefore it is possible to say that current wireless standards could satisfy users' needs in the terms of delay.

Different situation in the field of autonomous industrial control systems. Their demands to data transmission delay are much higher than in typical home&office applications. The table 1.contains typical industrial control applications requirements to transmission delay. As could be seen local control and safety tasks demand up to 10ms delay bound. By using non-modified standard data transmission techniques it is not possible to achieve such a low delay. Typical delay of standard methods is around 100 ms. By using QoS and some other techniques it is possible to lower delay two to three times, that makes might be enough for some applications. Still it might be enough at the applications where are demands for high stability and predictability of the delay. To illustrate such a problem we can use fig. 2. The green line is current situation while using standard solutions. For sure, mean delay and its stability are unacceptable for control tasks. The blue line shows improvements by using prioritization techniques. Still it may not be enough for some applications, like local control and safety (table 1.). Required delay and stability is depicted by red line, that marks 3ms delay with stability better than 1%. As it could be seen there is a need for different approach for data transmission technique to achieve requirements. As it was shown in previous papers, hybrid TDMA media access algorithm could provide 3.3 ms delay. Therefore arisesboundary problem. Since some industrial control applications requirements are close to 3.3ms delay. And that is interesting situation for the research.



g	r	Fast Clock Cycle Length	Slow Clock Cycle Length	CPU Time	Peak Memory Usage
2	0	1	1	Memory Exhausted	
2	0	99	100	457.917 s	2,404,956 KB
2	1	99	100	445.148 s	2,418,032 KB
3	0	99	100	416.796 s	2,302,548 KB
3	2	1	1	Memory Exhausted	
3	2	99	100	22.105 s	83,476 KB
3	2	451	452	798.121 s	3,859,104 KB
3	2	452	453	Memory Exhausted	
4	0	99	100	424.935 s	2,323,004 KB
4	1	99	100	464.503 s	2,462,176 KB
4	2	99	100	420.742 s	2,323,952 KB

Fig.3. UPPALL modeling results

To create autonomous control system with wireless data transmission we need to check control system's and controllable object's characteristics. One of the possibilities is to model control system. This approach is widely used in time critical transmission systems. Still there are some drawbacks. One of the problems is so called "state space explosion", when processed state space grows exponentially with the increase of modeled objects count. Later there will be an example of such problem. Second problem that should be solved is infinite analog signal digitalization. Since usual technique of using discretization frequency as double of maximal signal frequency is not acceptable. Next chapter will describe the

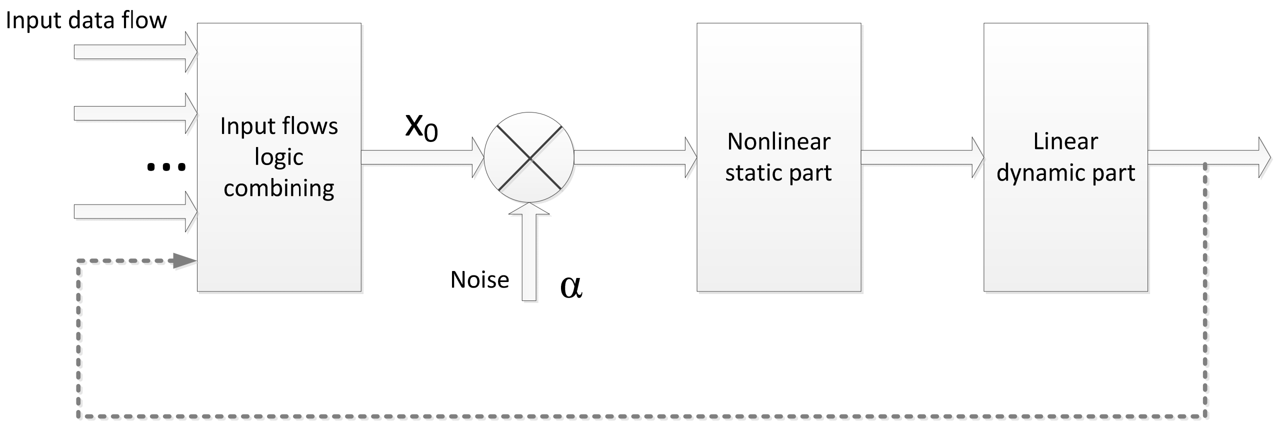


Fig.4. Dynamic nonlinear system modeling scheme

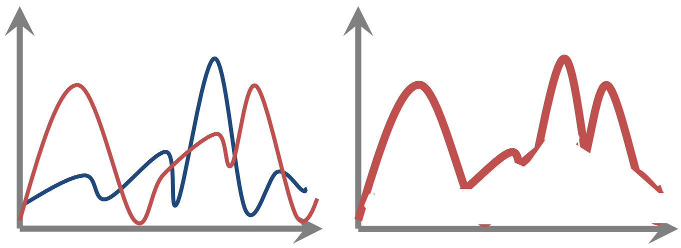


Fig.5. Proposed model's inputs presenting as envelope function

way for significant decrease of analog values that need to be processed. As well proposed modeling approach should make it possible to combine analog values and discrete events in the way to make them compatible will model analysis. At last, but not least is the fact, that most modeling approaches use probability theory for specification of input data. And in that way the dynamics of input data, i.e. its temporal characteristics are not taken in mind.

Let's start with first problem – state space explosion. As an example we will use UPPAAL [8] modeling tool. As could be seen from fig. 4.the network with only six nodes is modeled more than 10 minutes and requires ca. 3GB of memory. In addition, in some cases memory is exhausted. That is unacceptable, since in industrial area amount of nodes reaches several hundreds and more. The core of the problem lies in processing all atomic states of the algorithm. Since the possible combination amount is high and everyone is processed it takes a lot of computational resources. The question is do we need to have information about all possible combinations? One of the possible ways to solve this problem is limiting processed states by substituting input data with its probability function. For example, in queue theory we could set one element processing time, maximal queue length and calculate system state for every input's probability function.

III. Hammerstein Model

Our task is to prove whether data transmission algorithm is capable ensuring required delay and stability. Therefore, it is enough to check overall system stability and not all atomic states. For achieving specified functional, we will use model's dynamic data processing. Input signal is treated as continuous signal with variable amplitude and frequency. To convert discrete data (packet length) to continuous signal, we will treat packet length as signal's amplitude and keep existing

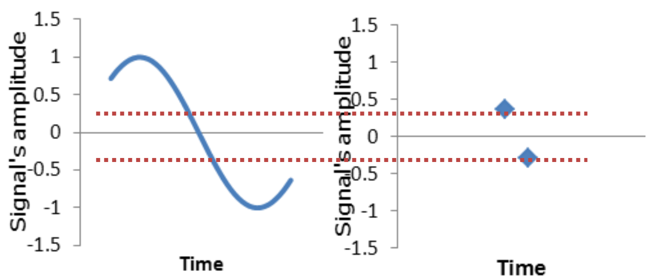


Fig. 6. Analog function converting in two points state space

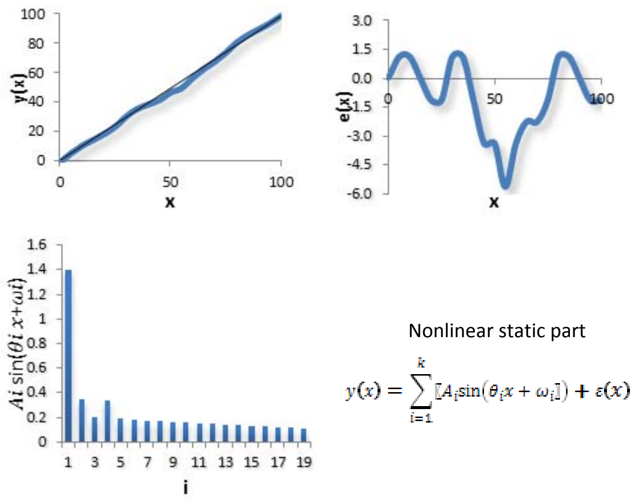


Fig.7. Proposed method's signal processing sequence

continuous time as second parameter. The applicability of proposed method is limited to continuous data flow. I.e. if interval between packets is less than packets length (processing time).As well, analyzed object should comply with Hammerstein model.

Second problem mentioned earlier is dealing with discretization of continuous analog signals. The common way is using double discretization frequency for storing signal. Since we know the area of application of our system, we are able to decrease amount of meaningful states of the analog signal. By generalizing [9] analog value control methods in industrial area it is possible to say the most common is two points regulation method. That leads to simplifying continuous analog signal to two points (fig.5.).

Let's have a look how to formalize real complex system. It is known, that most real life object have nonlinear and dynamic parameters. It is hard task to formalize such a system by using nonlinear systems theory. To simplify this task, we propose using Hammerstein model [10]. By using static parameters decomposition, it is possible to compute output signal from any input. To treat dynamics, proposed method uses differential equations. As a result, system is described with relatively low amount of parameters. Moreover each parameter could be analyzed and measured experimentally.

Complying with classic Hammerstein model, modeled nonlinear dynamic system (NDS) should be divided in two parts: nonlinear static part (NS) and linear dynamic part (LD) ()fig. 3.. System receives continuous signal in its input. By using input flow logic combining (see scheme at fig. 3.) we create enveloping curve of all input signals (fig 4.).

To extract system nonlinearity in NS part, we are using linear regression. As a result we obtain linear part and nonlinearity y(x)=ax+b+e(x) (see fig. 7).

Now function e(x) holds all system nonlinearities (fig. 6.). To proceed we will use Fourier transformation on function e(x). Assuming that function e(x) is integrable we receive sinusoids row (fig 6.). To simplify analytical description, we will limit significant components amount and express it as

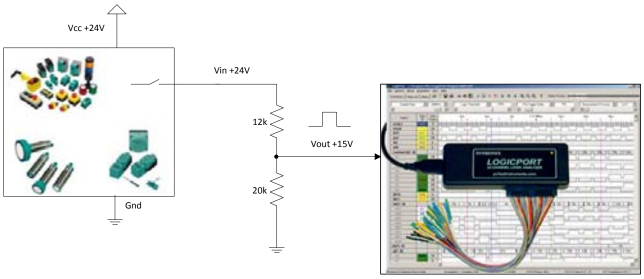


Fig.8. Signals measuring setup

follows $\sum_{i=1}^{k} [A_i \sin(\theta_i x + \omega_i)]$ that leaves ε(x) as insignificant reminder.

As a result overall function is as follows: y(x) = (ax + b) + $\sum_{i=1}^{k} [A_i \sin(\theta_i x + \omega_i)]$ + ε(x).

Overall procedure is as follows:

– Decide significant limit for sinusoids,
– Experiment with constant amplitude and frequency test signal,
– Verify model against real object,
– Modify models components if required,
– Compute equations.

IV. On site testing

To test proposed system, authors used real industrial object – Vertical Wind Tunnel in Finland [11]. It appeared to be good example of time critical system. System has 143 sensors and actuators and control is decentralized among three programmable logic controllers. Testing aim was to create and verify analytical model against real object. And to check if a system allows using wireless data transmission instead of existing wired one. Wireless data transmission method was previously described in papers [12], [13].

As a first step, real input signal parameters were obtained. Authors used a 34 channel logic analyzer connected to programmable logic controller's inputs and outputs. To match 24V signal to TTL logic voltage of analyzer [14], simple voltage divider was used (Fig.7.). Data was obtained during three days of testing. During this time, every system state was analyzed. For processing collected data FRAD [15] tool was used. By using this tool, it was possible to analyze and visualize huge amount of collected data. It helped to solve several problems. For example, some signals were affected by "contact bounce" problem. It shows up as high frequency change of signal state (high/low). By using histogram we could see two "spikes", one of them was higher than 100 Hz. These frequencies were treated as noise and were filtered [16]. The result of measuring is summarized in table 2. As it could be seen, the top frequency is for analog control and encoder signals.

TABLE 2.

WIND TUNNELS DIGITAL AND ANALOG SIGNALS FREQUENCY

Input type	Group type	Frequency measuring method	Max frequency (Hz)
Digital inputs	Operator controlled buttons	Change of active state	2
Digital inputs	Encoders	Change of active state	90
Remote station digital inputs	Valves' state (Opened/Closed)	Change of active state	0.05
Remote station digital inputs	Valves' state (Opened/Closed)	Change of active state	0.05
Analog inputs	Outlet hatch sync	PID time constant	110
Analog outputs	Motor speed	Frequency drive parameters	150

By inputting following signals as the input of proposed model, the model shown one critical point. Despite the fact that maximal frequency is observed at analog signals, system critical point was at encoder and valves control group. Since valves' control and encoders' output signals where transferred at the same wireless channel, at some moment existing transmission frequency was not enough. After regrouping signals and separating valves from encoders, model shown acceptable transmission frequency. That proved possibility of substituting wired network with wireless transmission.

V. Conclusions

Presented formalization method proved that Hammerstein model is adequate to formalize real industrial object. Model provides possibility to describe nonlinear and dynamic object by small set of parameters. On-site testing on real wind tunnel control system proved that model is adequate and helps figuring out critical point in term of data transmission frequency and delay. As well, model proves that it possible to use wireless links for time critical data transmission.

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Dmitrijs Bļizņuks, Valerijs Zagurskis. Laika kritiskās bezvadu datu pārraides sistēmas arhitektūras veidošana uz dinamiskās informācijas bāzes
Raksts piedāvā jaunu pieeju bezvadu pārraides sistēmu veidošanai, izmantojot kontroles sistēmas analītisko modeli. To varēs lietot vadības sistēmās, kuras nodarbojas ar laika kritiskajām sistēmām. Ņemot vērā sistēmas dinamiskās īpašības, ir iespējams iepriekš noteikt kritiskos punktus bezvadu datu pārraides sistēmā. Kas savukārt ļaus samazināt kopējo sistēmas izstrādes laiku, jo problēmas ir iespējams novērst jau pirms pārraides sistēmas izveides. Tā kā pārsvarā reālo vadības sistēmu pamatā ir nelineārie un dinamiskie procesi, ir grūti veidot to formālo aprakstu. Lai atvieglotu formalizācijas procesu, tiek izmantota Hameršteina modeļa bāze. Tā piedāvā atdalīt sistēmā nelineāro statisko daļu no lineārās un dinamiskās. Rezultātā var izveidot sistēmas analītisko modeli, izmantojot nelielu parametru skaitu. Sistēma tiek testēta, novietojot ieejā vairākas ieejas plūsmas, kuras modelī tiek apstrādātas un no tām tiek izveidota apliecošā līkne. Visefektīvāk ir analizēt sistēmas robežparametrus, kad viņu iespējas tuvojas maksimālajām. Izveidojot modeli un verificējot to, turpmāk ir iespēja ieviest arhitektūras izmaiņas un pārbaudīt sagaidāmo sistēmas reakciju. Piedāvātā formalizācijas sistēma bija testēta reālā industriālā objektā – vēju tunelī. Vēju tuneļa vadībā ir 143 sensori un aktuatori, kuru darba frekvence sasniedz 150 Hz. Vadība ir sadalīta starp trim stacijām, tāpēc objekts kalpo kā labs piemērs kritiskajai laika sistēmai. Izveidojot sistēmas modeli, tika atrasts sistēmas problemātiskais punkts, kur nepieciešamā datu pārraides frekvence pārsniedz bezvadu datu pārraides sistēmas iespējas. Pēc sensoru un aktuatoru pārgrupēšanas slodze tika sadalīta un nevienā punktā sistēmas frekvence nepārsniedz iespējamo. Kas arī pierāda, ka šajā objektā ir iespējams lietot bezvadu datu pārraidi un aizvietot esošo vadu tīklu.

Близнюк Дмитрий, Валерий Загурский. Разработка архитектуры беспроводной критической ко времени системы, используя динамику данных
Статья предлагает новый подход к разработке беспроводных систем передачи данных, применяя аналитическую модель системы контроля. Предлагаемый подход может быть использован в системах управления, являющихся критичными ко времени. Используя динамические характеристики системы, можно заранее определить критичные точки проектируемой беспроводной сети, что в свою очередь уменьшает время, необходимое на разработку, так как проблемы можно обнаружить уже на стадии проектирования. Так как большинство реальных систем управления являются нелинейными динамическими системами, составить модель такой системы довольно сложно, используя теорию нелинейных систем. Предлагаемый метод основывается на методе Гамерштейна, что подразумевает разделение системы на части с нелинейно-статичными и линейно-динамичными характеристиками. В результате можно составить аналитическую модель системы, используя небольшое количество параметров. Система управления проверяется подав на ее ход множество потоков данных от элементов системы. Модель объединяет входные потоки и использует огибающую функцию. Наиболее значимый результат можно получить, тестируя пограничные состояния системы, когда параметры систем оказываются близко к своему теоретическому пределу. Создав и проверив модель, в дальнейшем есть возможность вносить архитектурные изменения и проверять реакцию системы. Предлагаемый метод был протестирован на реальном индустриальном объекте – ветровом туннеле, система управления которого включала 143 датчика и актуатора, максимальная частота которых достигала 150 Гц. Также система управления была распределена между тремя узлами, что делает ее хорошим примером критичной ко времени системы. Составив модель, была определена критическая точка системы, когда частота появления данных от сенсоров была больше, чем максимально возможная в беспроводной сети. После перегруппировки узлов и последующей проверки, было подтверждено, что существующую проводную сеть можно заменить беспроводной.