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Advanced educational tool for remote control study ⋆

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Abstract: The article is devoted to a problem of training students to new challenges in techniques and technologies. Actual and perspective problem of control via the Internet is considered. The unique arena "Robodrom" is built for studying remote and networked control algorithms through online game. This game is available at URL: http://robodrom.net. It involves students to an education process and demonstrates efficacy of studying algorithms. The mobile robots based on Lego Mindstorms NXT are chosen as plants. Consecutive Compensator is considered as one of the studying control approaches. Some simulation and experimental results are shown.

Keywords: remote control, networked control, adaptive control, input variable delay, mobile robots, robodrom, Lego Mindstorms NXT.

1. INTRODUCTION

Development of the modern techniques and technologies opens many new scientific challenges for researchers and sets complicated tasks for engineers, see Murray et al. (2003). For scientific groups these challenges are subject of daily activities. However, in industry it brings some problems. Growth of these problems is accelerated every year due to tighter integration of hardware and software parts of devices. This integration leads to creation complex integral "mechatronic" systems, see Isermann (2008). The control of the mechatronic systems is difficult task and requires highly skilled engineering and technical personnel. It places the challenge for the educational environment in the universities, see Pasik-Duncan and Verleger (2009), Pasik-Duncan and Chowdhury (2009). Therefore, we can extract continuous process of techniques evolution, training of specialists and solving new issues, see Fig. 1.

One of the actual and perspective direction of researches is networked control systems. Using shared networks, in particular general-purpose networks Intranet or Internet, instead of point-to-point wired connections, reduces time of control system development and increases scalability, facilitates troubleshooting, maintenance, interoperability of devices, and integration of new devices added to the network, see Moyne and Tilbury (2007). The main disadvantages are bandwidth limitations, delay jitter, and packet dropouts.

It may seem that engineering personnel and specialists on telecommunication networks and computational engineering solve such problems successfully. However, mentioned disadvantages does not allow to say about it categorically. In general, real-time control of the real plants via the Internet was impossible until recently. Typically, control

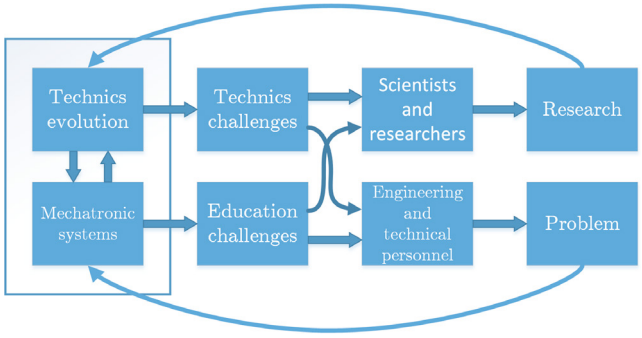

Fig. 1. Process of the techniques evolution and specialists training

systems were limited by telemetric information exchange. Regulators were based on the receiving and processing these data at certain time intervals. This approach is suitable for wide range of time-insensitive applications, including Smart Houses, signaling, data storage, sensor data collection, etc. However, it is not applicable for the real-time control, for example, tele-operation via networks for fire-fighting operations, undersea operations, and automated highway driving.

In case of real-time control, specialists training, who could control technical plants (mechatronic systems) over channel with variable delay and packet loss, should know not only about networks, computational engineering and programming. The problem significant wider and includes knowledge about theory of automatic control, including control of systems with input delay and uncertainties. The integration of knowledge from different fields of science is necessary to successful synthesis of such control systems. Described situation represents on the block diagram in the Fig. 1. Technical personnel have problem with control of technical plant. It creates challenge for universities and academic environment. On the one hand, this environment

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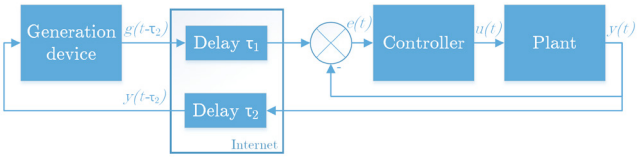

Fig. 2. Structural scheme of the control system via the Internet

trains specialists on actual directions of research and extends knowledge of graduates, on the other hand, conducts research aimed at solving problems of the industry.

2. REMOTE CONTROL

Systems with variable input delay are usually used in control theory as mathematical model for these systems. Furthermore, packet loss and corruption also can be represented as additional time-variable delay for reliable protocols, for example, the Transmission Control Protocol (TCP), which repeats transmission in such cases.

The problem of control system with the input delay is old enough. There are many different solutions for it. The most comprehensive review of classical approaches is Gu and Niculescu (2003). The review of control methods via network in the papers Gupta and Chow (2008), Gupta and Chow (2010), You et al. (2015) are given. The ideas and short networked control systems history are considered. The Monograph Krstic (2010a) is devoted to solve various delay problems. In paper Krstic (2010b) variable delay is considered. Significant part of review Andrievsky et al. (2010) is about Data Rate Theorem, which is about minimal require bandwidth for stability of a closed-loop system, also tasks of control over telecommunication networks and some results for nonlinear systems are considered. In Pyrkin et al. (2010b) and Pyrkin et al. (2010a) problem of control for linear plant with input delay is considered. Some papers, for example Kim et al. (2006), are devoted to synthesis of command predictor, which allows to predict necessary control signal for systems with packets loss and large delays in control channel. In Ananyevskiy et al. (2014) task of synchronization of two pendulums on carts over Intranet is considered, speed gradient method is used. In paper Ananyevskiy (2015) control method timecheck denial gain systems is suggested.

This work is based on Shavetov et al. (2014b), Shavetov et al. (2014a) and devoted to control dynamic plants with parametric uncertainty and variable delay in the context of student education. The Internet is the typical example of general-purpose network with a time-varying delay. The structural scheme of the control system is shown in the Fig. 2.

In the scheme $y(t)$ is the output variable, $u(t)$ is the control signal generated by controller, $g(t)$ is the reference signal, $e(t)$ is the output error. This structural scheme has two control loops. The first loop is not affected by the delay, because it is located in the plant, for example, programmed in the microcontroller, and performs operational current control of the plant (actuators of plant). The second control loop is closed via the Internet and has two delays τ_1 and τ_2 at the input and output channels correspondingly. The reference device generates reference signal $g(t)$ for the plant based on the output $y(t)$. An user (operator) can be considered as reference in the case of tele-operation. Delay in the feedback channel τ_2 is caused by delay of video broadcasting from a plant technical vision system (feedback is closed "virtually" by camera), user response time and telecommunication delays. Delay in the input channel τ_1 is caused by telecommunication delay only.

Fig. 3. Arena "Robodrom"

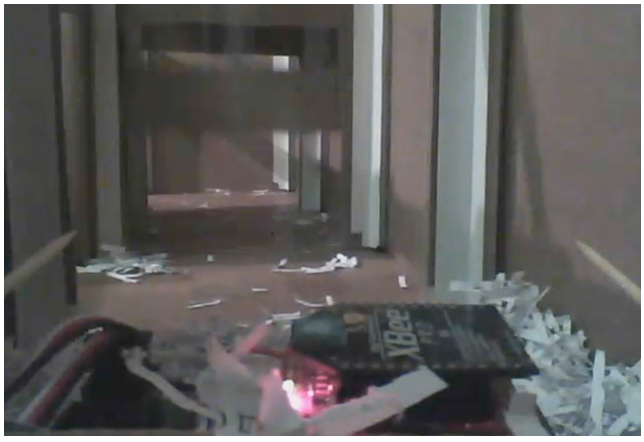

Fig. 4. First person view in the game

The purpose of control is generate signal $u(t)$ that provides convergence output variable $y(t)$ to reference signal $g(t)$.

3. ARENA "ROBODROM"

To investigate remote control approaches via the Internet in our laboratory a special arena "Robodrom" was built, which is shown in the Fig. 3. Size of the arena is 3x2 meters.

In the arena students carry out experimental tests of control algorithms during laboratory works. Interaction between users and arena is realized through web site http://robodrom.net/ and looks like online game. In the first version, it was a game "Labyrinth". The purpose was design control law for Parallax Boe-Bot mobile robot, see Parallax (2016), in labyrinth and reach the finish. First person view from a camera on the robot is shown in the Fig. 4.

The Labyrinth is a slow game. To test and compare different algorithms more efficiently game should be more dynamic and active. "Tag" is chosen as base for current