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Model Based Design of Embedded Systems

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Abstract Paper deals with embedded systems for mechatronics products. The problem of design of embedded systems can be solved via using of model based design. Hardware-in-the-loop (HIL) simulation is as device for designing of embedded systems. Simulation model of real product is running in hardware simulator and embedded systems can control the simulation model. This way enables try also dangerous situations.

Keywords: *embedded system, simulation model, design, HIL*

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1. Introduction

Actually, several billions of microprocessors are made per year, but only few percent of them are used a brain of personal computer. Overwhelming majority of microprocessors becomes a part of embedded systems. Embedded systems are special computer systems, which are completely embedded into devices, which are controlled with them. Embedded systems as a basic part of everyday used products as car, printers, cameras, medical devices, gaming devices, washing machine, grass-cutting robots, vacuum cleaner robots, aeroplane, missile rockets, mobile phones, etc. (Figure 1).

Figure 1. Application of embedded systems

Term "embedded systems" is used for:

- Combination of hardware and software for executing of specific tasks.

- Embedded systems is a system which fully or partially autonomously execute tasks depended on human intervention.

- Embedded system is designed for executing of several tasks via using of the most effective way.

- Embedded system is computer system for specific tasks.

Using of embedded systems is practically unlimited and new products with embedded systems are daily introduced in market. This fact still causes that the price of microprocessors, microcontrollers and FPGA chips, fall down. Developing of new product with implemented flexible embedded systems is much cheaper then developing of complicated control structure. Developing of control system via using of embedded system became very simple thing.

Standard personal computer is usable for more purposes (text processing, image processing, internet, email, listening of music, watching the video, playing game etc., but embedded system is used only for one purpose related to product. Striking impact of embedded systems is visible in automotive industry. One car includes several tenths of embedded systems used for various activities as battery management, blind spot detection, air suspension system, parking assistant and self parking system, security system, tire pressure monitoring system, seat control, window lift, emergency brake system, internal combustion motor control, engine cooling system, cruise control, cross-traffic alert system, lane change assistant, collision avoidance system, air condition etc [1-9].

2. Embedded Systems

Tasks of embedded systems is very frequently related to specific time frame and time keeping is marginal important for right functionality of whole product. Very good example of embedded system is auto-pilot in aeroplane, where embedded system has to react very fast during the fly. This is the reason, why real time response is expected from embedded systems.

Embedded systems are applied for controlling of processes and functions of products. It is necessary to obtain amount of information for this controlling and embedded system evaluate these information in running programme and make decision about next activities. Mechatronic product also can communicate with user and can make advice what user should make. This product with embedded system behaves as intelligent system and it is able to automatically decide about its activities (Figure 2). Behaviour of this product is subjected to user, which has possibility to affect to its functions. Besides this, the product can has also other functions unknown for user as checking of product status, check of battery status, user security checking, damage protection, etc. Product should be designed also for unexpected situations caused by user or by others impacts. Key task of mechatronic product is to help to user with safely using of product. Also the product should eliminate bas steps of user, which can be dangerous for product or for user or their environment.

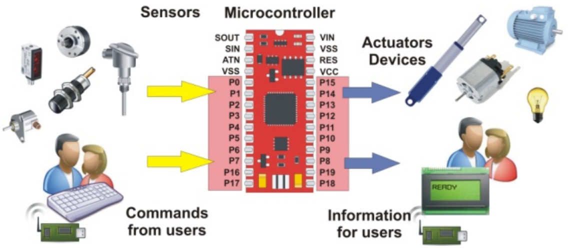

Figure 2. Embedded system with sensors and actuators and input or output human-machine devices

Previous solution of controlling system required amount of logical circuits, timers, buffers, driver circuits etc. Application of embedded systems fully replaces all these systems and provides more flexible and powerful platform. Many improvements can be achieved only via upgrade of control program with minimum intervention to hardware.

Embedded system development is supported also with Matlab/Simulink package with "Embedded coder". Embedded system is also called as "Electronic Control Unit" – ECU or "production control unit. These units are designed with respecting of minimum production costs in serial production. ECU very often consists of system with lower CPU (Microprocessor) performance and low memory and often with fixed point math. Simulation model of controlling is completed in Matlab/Simulink and then "Generator of production code" is used for generating of C-code with quality of hand-written source code on the level of excellent programmers. It also enables the implementation of fix-point math routine and memory optimization for selected microcontroller. Generated C code needs only minor revision and then it is necessary for implementation into target microcontroller.

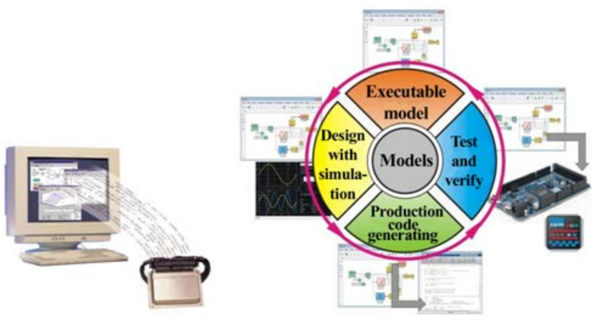

Figure 3. Embedded system design

Process of technical system design is supported via using of system model – "Model based design" [1-9].

3. Model Based Design

Initial stage of mechatronic product design can be supported through the using of model based design. It could help to identify weak places and mistakes in product design. Overall design is then faster and more successful then before. For this reason the model of system is in the centre of product design process during the all stages of product life cycle as requirement definition, own product design, simulation and verification of design and testing of product and also recycling after end of product life. Model simulation results show the problems and it is possible to modify design in early stage of design. Simulation shows if future product will fulfil of customer requirements.

Fast product developing requires the model based design as device for effective product design through the using of:

- Common design environment for all members of team.
- Coupling of product design with customer requirements.
- Simultaneous integration of design testing for continuous identification of errors and repairing of errors.
- Debugging of the algorithm using the multi-domain simulation.
- Automatic generation of software code.
- Developing and repeated using of testing system.
- Automatic generating of documentation.
- Repeated using of design for distribution of system to more processors and hardware devices.

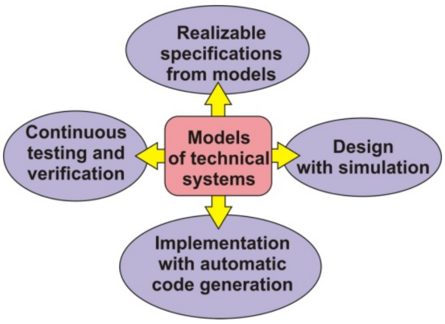

Figure 4. Design of technical system supported with system model

Model of the system has key and important role in development process of technical system (Figure 4). System model is used for definition of realizable specification. Continuous flexible testing during the development process can catch critical errors before the hardware errors. This procedure is simpler than repairing of hardware. Al changes made during the testing are reflected into hardware specification of system model. And also source code for target processor is modified with these modified specifications [1-9].

4. Real Time Testing

Testing in real time includes two kinds of testing:

- rapid prototyping and
- hardware-in-the-loop – HIL testing and simulations (Figure 5).

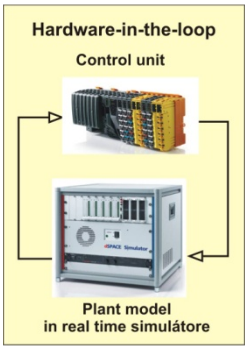

Figure 5. Hardware-in-the-loop – HIL testing and simulations

During the rapid prototyping, real time system is connected with real time hardware. HIL testing develops model of system using the other real time devices. This developing helps to create the control algorithm for planed target processor. Control algorithm can be connected to plant model, which running in real time. Normally, HIL testing is realized in form that, plant system is running as simulation in computer or in simulator (e.g. dSpace simulator etc.).

There are also other types of simulation for model in the loop as (Figure 6):

- "model-in-the-loop" simulation (MIL),
- for software is used "software-in-the-loop" simulation (SIL),
- for target processor is used "processor-in-the-loop" (PIL) simulation.

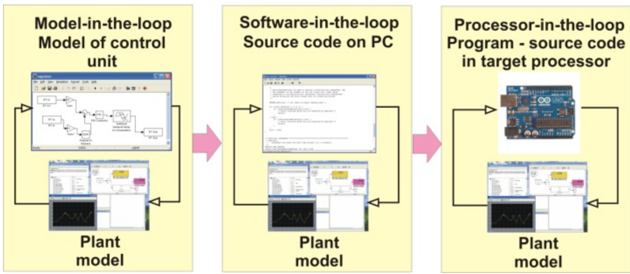

Figure 6. Design of technical system supported with system model

HIL simulation is used in the first place for complicated controlling tasks and for systems, which needs big realization costs, where unsuccess means giant economic loss or dangerous for human (automotive aeroplanes, army devices, space devices, nuclear power plants, etc.). For the mentioned reasons, the initial stage of design uses the control system with not real system (real system is substituted with simulation model running in hardware simulator). Hardware simulator is a special fast and powerful hardware for model running and also input/output quantities are simulated. Hardware simulator often includes AD and DA converters, digital inputs and digital outputs, counters etc. as additional cards. It means that real sensors and real actuators can be connected to hardware simulator. Possible unsuccess of simulation will warn us for errors and weak places in system. We can modify them for removing of the problems and again we can start simulation. All these actions can be repeated many times without massive damages obtained from tests with real products. These procedures are repeated up to moment when all errors are removed. After that the HIL simulated object can be substituted with real object.

HIL simulation is very close to real experiment, because HIL simulator can be connected with real sensors and actuators. This way enables also simulate the error stages, which are not possible to obtain in real object experiments (ultra cold or ultra hot temperature simulation, radiation influence, etc.).

Automotive ECUs (Electronic control units) are tested also with HIL simulator before using in real car. The hardware and software by dSPACE and MathWorks enable the HIL simulation with precision model of product.

HIL simulation is inseparable part of product design almost in automotive and aeroplane developing. Developing of ECU with HIL simulator is very important, because the controlling loops are very fast in automotive mainly in F1. There is also very fast data transferring and also fast interfaces with high transfer speeds are used.

HIL simulator is often as multi core system with more processors and also all types of input and outputs are available. Also special types of interfaces are available as CAN bus, Profibus, FlexRay and also many accessories are available for HIL simulators. It depends on purpose of HIL simulator [1-13].

5. Design of Two Legged Robot with ECU

The main problem of two legged robot is swinging motion, which affects to use of sensors for obstacle avoidance or CCD camera for path planning. Designed variants have common significant novelty, that base plate (place for sensors, CCD camera or manipulator) is stabilized. Robot doesn't have to do swinging motion during the locomotion. It means that obstacle sensing, manipulator end-effector handling and video capturing is easier, than before. Base plate is also maintained in equal high over the ground. Also, it is possible to change desired value of high of base plate. Designed variants differ mainly in count of actuators and kinematic arrangement.

Selected basic kinematic arrangement has 4 DOF (Figure 7). Two DOF are realized with linear links and parallelogram mechanism. Parallelogram mechanism ensures the parallelism of feet and ground.

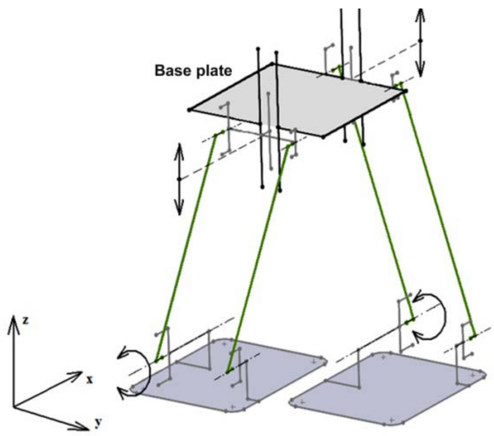

Figure 7. Kinematic arrangement of legged robot

Simulation model has been done and result of simulation of walking is shown on Figure 8.

On the base of simulation result, the ECU scheme and printed circuit board – PCB has been developed (Figure 9).

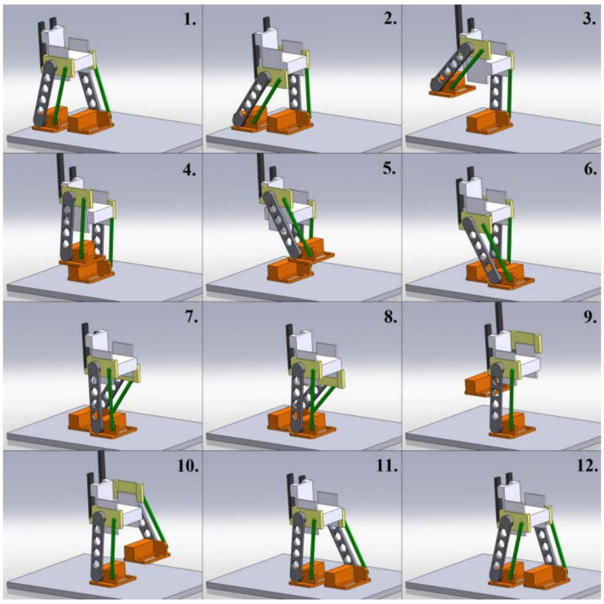

Figure 8. Walking simulation with CAD model of kinematic arrangement – variant C

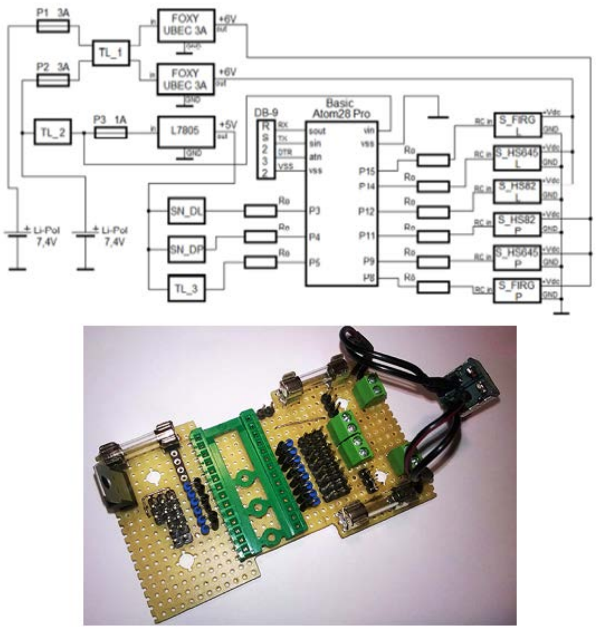

Figure 9. ECU board scheme and PCB

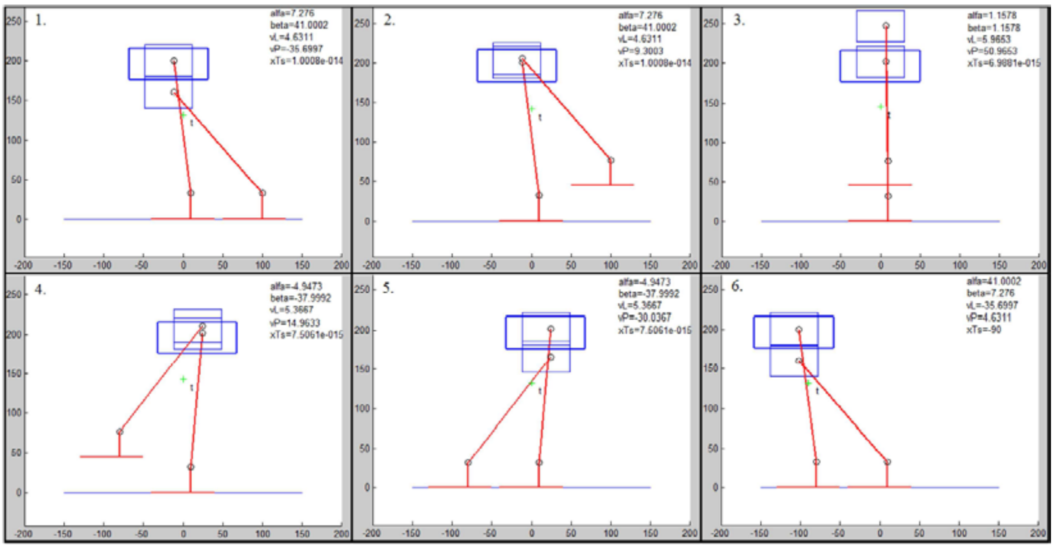

Figure 10. Simulation of robot locomotion

Stability and locomotion simulation were obtained from simulation in Matlab (Figure 10).

6. Conclusion

Impact of model based design lies on fact that time developing of product is shortened what has direct influence to product price and saleability. Other indisputable fact is that these products have been already tested in phase of development through the difficult tests. It ensures the higher safety and reliability of these products. Very high percentage of products is mechatronic and this type of design is mainly dedicated for them [14-19].

Acknowledgements

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