Testing Microcontroller Based Physical Systems Using Finite Transition Models

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***Abstract* – Many devices of controlling parts of physical systems are implemented on the basis of microcontrollers. Such critical systems are needed to be tested thoroughly. This paper contains experimental results on testing controlling parts of laser based physical systems. We consider generators of synchronizing pulses for controlling important parts of the laser system. Test derivation is performed using the model of a timed transition system with finite number of states. We then generate a number of mutants for a microcontroller part and the performed experiments clearly show that timed Finite State Machine based test suites have a good quality as they allow to detect most frequently occurring faults in considered systems.**

***Index Terms* – Finite State Machine with time-outs, finite automata with time guards, physical systems, testing.**

I. INTRODUCTION

LASER SYSTEMS have complex and multicomponent structure. Many devices of controlling part of such systems are based on microcontrollers. The latter allows a good flexibility in setting such systems. In complex systems, controlling signals from these devices are submitted to controlled devices such as cameras, for example, or to other devices for controlling or amplifying powerful signals. Microcontroller based components such as (re)switching generators determine the coordinated interconnection of all system's parts, and thus, these components are critical. Correspondingly, the quality of a whole laser system depends not only on physical characteristics of devices but also on the quality of microcontroller programs. A small mistake by a programmer is crucial for the correct functionality of a whole system. Thus, every microcontroller together with its program has to be tested thoroughly.

We describe the behavior of the whole system by the model of timed Finite State Machine (TFSM) [1] or timed automaton [2]. We described and tried a similar approach in [3, 4]. In order to apply well-known test derivation methods, for example, a transition tour method, we translate a timed FSM into a classical FSM. The testing process is performed automatically using an additional microcontroller.

II. PROBLEM STATEMENT

In this work, we consider test derivation for two systems that are switching generators.

The first one is a microcontroller system, generating pulses for controlling the CCD camera that makes snapshots of oscillating bimorph piezoelectric plate. The system operates as follows. There is a rectangular signal as an input of a microcontroller. The microcontroller outputs short pulses according to the input signal. Short pulses could be generated by rising and falling edges of an input signal. The input signal is submitted simultaneously to the microcontroller and the plate making the latter oscillate. The camera makes snapshots of a plate's position by the pulses from the microcontroller's output. The main restriction of the system is that the frequency of output pulses cannot be more than 50 Hz. Thus, the input signal is handled as follows. If the input signal frequency is less than 25 Hz, then the output short pulses should be generated by each rising and each falling edges. If the input's frequency is more than 25 Hz, then the output pulses are generated only by rising or falling edges by constantly skipping odd numbers of input signal edges.

The second system is a part of a system for controlling pumping source of a bromide of copper vapor laser. The control system forms two series of pulses, alternately unlocking two power transistors. Through an open transistor, the storage capacitor is charged. After locking transistor, delay follows and then thyratron commutes by the pulse at the third pin of the microcontroller, and the storage capacitor is discharged to the discharge tube. There are parameters of pulse duration and pauses between pulses regulated by values of the voltage at the ADC pin of the microcontroller. Time diagrams of functioning of considered systems are shown at Fig. 1.

We chose the following parameters of described systems to test. It is a correctness of time intervals between the generated pulses and the stability of generating pulses.

We use models with finite number of transitions as system specifications. For the first system we chose Finite State Machine (FSM) with input and output time-outs [1, 5,

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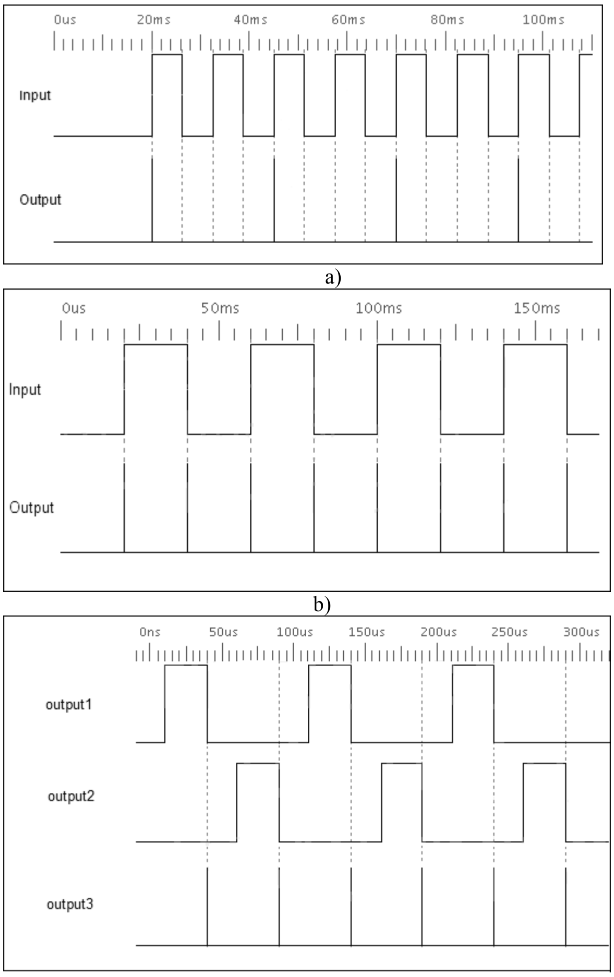
6] or simply timed Finite State Machine. Time-outs help to describe states of the system in which a number of pulses are skipped to avoid a possibility to exceed 50Hz frequency. The corresponding FSM has 29 states and 34 transitions. The input alphabet of the system is presented by {RE, FE}, where RE – rising edge of an input signal, FE – falling edge of an input signal. The output alphabet consist of actions {P, nul}, where P is a pulse at the output of the microcontroller and nul is an absence of response. As a unit of a time frame, 1 millisecond is chosen. The value of timeout T1 is 20 time frames.

For the thyratron system specification we chose an automaton with time guards [2]. The values of time guards define the duration of pulses and pauses between them.

The set of actions in described model contains following symbols: 1_RE, 1_FE, 2_RE, 2_FE, 3_RE, 3_FE, where 1_RE is a rising edge of a signal at the first pin of the microcontroller, 1_FE is a falling edge of a signal at the first pin of the microcontroller, 2_RE, 2_FE, 3_RE, 3_FE are corresponding actions for the second and third pins of the microcontroller. The developed system has 9 states and 9 transitions.



a)

b)

c)

Fig.1. Time diagrams of systems: a) CCD camera control system; input signal frequency is 80Hz, b) camera control system; input signal frequency is 25 Hz c) thyratron starting system

The timed automaton was translated into a classical automaton [5]. For different values of pulse duration and pause between pulses different number of intermediate states were introduced in the model. For three different combinations of pulse duration and pause values, the automaton has 31, 29, and 31 states correspondingly:

1) a1 – 15 us, b1 – 40 us,
2) a1 – 30 us, b1 – 20 us,
3) a1 – 40 us, b1 – 15 us,

where a1 is the duration of pulses at the first and second pins of the microcontroller, b1 – the pause between falling edge of a pulse at the first pin of the microcontroller and a rising edge of the pulse at the second pin of the microcontroller. As a time frame we have chosen 5 us.

Flow graphs of considered systems are shown in Fig. 2 and Fig 3.

III. EXPERIMENTAL SET UP

To derive test suits for systems described above according to their formal specifications, the software toolset FSMTest [7] was utilized. This toolset contains software implementations of a number of formal methods for deriving complete test suites for different kinds of Finite State Machines. The classical FSM for the camera control system has 93 states and 181 transitions. The test suite derived by a transition tour method consists of 252 symbols. The number of test sequences is 20. For each of three automata of the thyratron starting system the returned test suite has one test sequence with 31, 29, 31 symbols correspondingly.

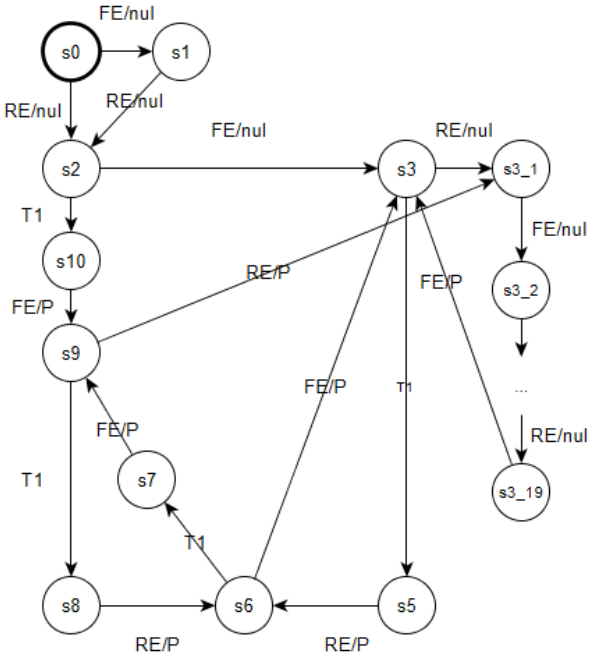


Fig. 2. Flow graph of the CCD camera control system.

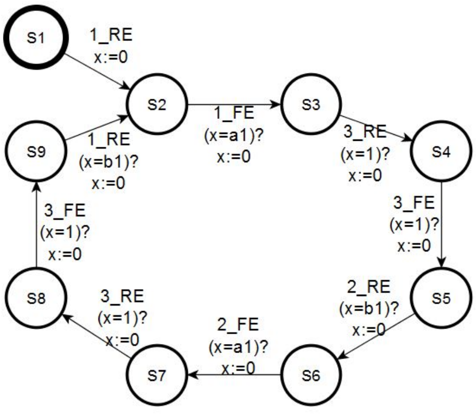


Fig. 3. Flow graph of the thyratron starting system.

IV. RESULTS

In order to apply test sequences to a system under test, the program for an additional microcontroller for applying preloading sequences of test signals into the memory was developed. Output responses of the system under test were also processed using a second microcontroller.

Test sequences obtained using FSMTest toolset were automatically applied to implementations. Output responses of the system to input sequences were recorded in a text file and compared with the expected output responses.

Using tests derived according to the constructed specifications, no faults were found in the implementations under test.

To assess the fault coverage of the constructed tests with respect to the most frequently occurring faults in programs for microcontrollers, mutation testing was carried out. The following types of faults were considered: 1) incorrect setting of the prescaler of the clock frequency of the microcontroller's timer; 2) faults in the assignment of the microcontroller's input/output ports 3) faults in the source code for microcontroller's program. The following types of faults were considered: a) replacing arithmetical operations (« + » by « - » and vice versa, « * » by « / » and vice versa), replacing relational operators (each operator of « > », « < », « == », « != » is replaced by each of the rest). For the camera control system there were generated 16 mutants of the first type, 3 mutants of the second type, 11 mutants with arithmetical faults and 24 mutants with relational operators faults. For the thyratron starting system there were generated 16 mutants with clock frequency setting faults and 3 mutants with the input/output pin assignment faults. All of these faults were detected using developed test suites.

IV. CONCLUSION

In this paper, we have presented the application of finite transition model based test derivation to generator systems based on microcontrollers. Namely, the transition tour method was applied to two microcontroller based components of laser systems.

Mutation testing clearly shows that tests derived using Finite State Machine based approaches turn out to have high quality. It is also possible that formal models should be refined in order to detect some faults in implementations under test.

In the future, we plan to lower the level of abstraction of specifications in order to introduce additional parameters that are primarily responsible for the temporal aspects of systems. In this case, it will be possible to derive additional test sequences to verify the additional properties of given implementations.

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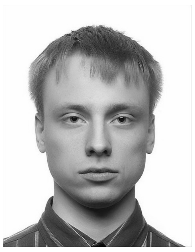

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