

## APPLICATION OF MODEL-BASED DESIGN IN ALGORITHMS' PROTOTYPING FOR EXPERIMENTAL ACORN SCARIFICATION RIG

### Summary

Assessment of viability of oak seeds is mainly performed by mechanical scarification followed by visual assessment by trained employees. This procedure is slow and prone to human errors, thus automation of this process is desirable. Shortening the design of complex automation systems requires the use of modern methods, allowing for modeling and simulation of systems containing elements of mechanical, electrical and digital components. The article presents selected aspects of the design of control algorithms for the acorn scarification prototype. A virtual prototyping and Model-Based Design (MBD) approach have been used.

**Key words:** scarification of acorns, Model-Based Design, control

## ZASTOSOWANIE METODYKI PROJEKTOWANIA OPARTEJ NA MODELU W PROTOTYPOWANIU ALGORYTMÓW DLA BADAWCZEGO STANOWISKA SKARYFIKACJI ŻOŁĘDZI

### Streszczenie

Jedną ze stosowanych metod badania zmian mumifikacyjnych nasion jest skaryfikacja mechaniczna, połączona ze wzrokową oceną żywotności nasion przez człowieka. Ręcznie wykonywana procedura jest powolna i podatna na błędy, dlatego też automatyzacja tego procesu jest pożądana. Skrócenie czasu projektowania złożonych systemów automatyki wymaga stosowania nowoczesnych metod, pozwalających na modelowanie i symulację systemów zawierających elementy zarówno mechaniczne, elektryczne, jak i podzespoły cyfrowe. W artykule zaprezentowano wybrane aspekty projektowania algorytmów sterujących stanowiska badawczego do skaryfikacji żołądki. Do rozwoju stanowiska badawczego wykorzystano wirtualne prototypowanie oraz metodykę projektowania opartą na modelu (MBD – ang. Model-Based Design).

**Słowa kluczowe:** skaryfikacja żołądki, projektowanie z wykorzystaniem modeli, sterowanie

### 1. Introduction

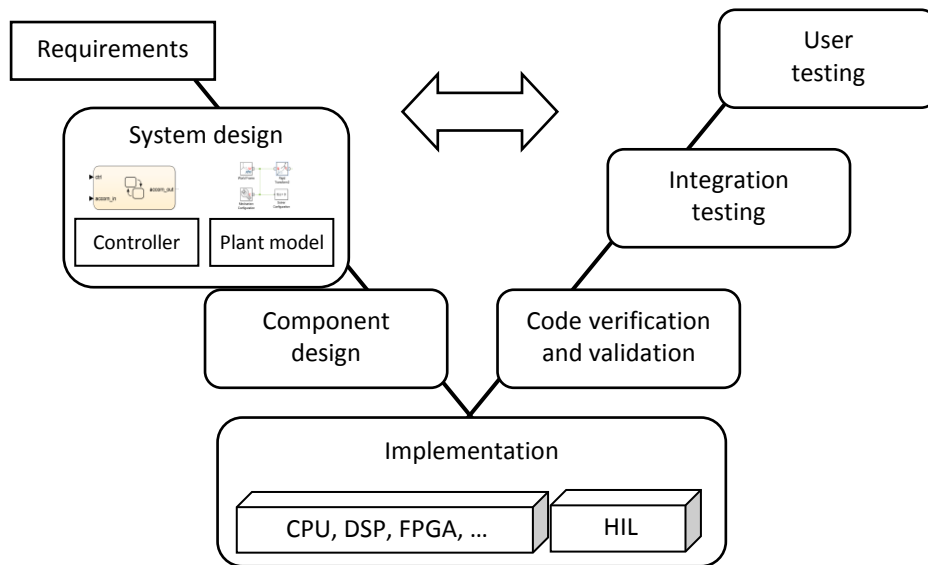
Virtual prototyping is a known technique in development of various devices application areas. Dedicated CAD software tools (e.g. SolidWorks™) are used for verification and analysis of agricultural machinery [8, 12, 13]. In control applications MATLAB/Simulink or LabView software is often used for modeling, simulation, identification and verification [1, 3, 5, 6, 7, 10]. In this paper we propose to use MATLAB environment for simulation of behavior of mechanical components along with control algorithm. Simplified functional models of mechanical components are used for simulation of acorn trajectories and collisions. Delays and values of signals vital for control are evaluated during the same simulation run. This approach demands integration of multiple domains (physical, electrical, discrete control logic) and using various numerical solvers (fixed step size, variable step size, stiff or non-stiff). Similar approach including simulation of vision-based motion detector has been presented in paper [9].

A simplified model of an automaton has been build for the purpose of acquisition of data parameter identification, and eventually verification of algorithms (Hardware-In-the-Loop simulation – HIL). It includes mechanical components (produced using 3D printing technique), actuators

(servos, and stepper motors) and a CPLD-based control interface (Complex Programmable Logic Device) connected to the MATLAB software PC via USB2.0 interface. The experimental setup comprises two high speed digital cameras for analysis of the acorn in subsequent stages of processing.

### 2. Materials and Methods

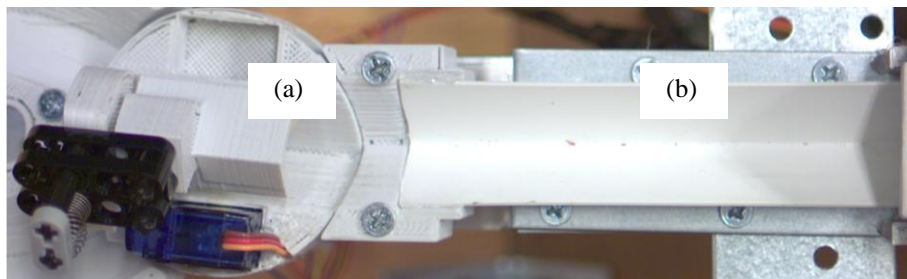
In order to design and verify initial design of the scarification automaton, a well-known Model-Based Design approach (MBD) [2, 4] has been used. MBD is the methodology where an engineer creates a high-level system model (executable specification) at the beginning of product development, based on a set of requirements. This model can be simulated and verified in respect of requirements at any stage of the development cycle – system level design, component design and implementation. By using automatic code generation and continuous verification, the design errors can be quickly identified and addressed. This can speed up development of the product. A system model usually consist of two parts – a model of the plant (in this case scarification automaton experimental setup under development) and a controller (Fig. 1).



Source: own work / Źródło: opracowanie własne

Fig. 1. Principles of Model-Based Design

Rys. 1. Idea metodyki Model-Based Design (projektowanie w oparciu o modele)



Source: own work / Źródło: opracowanie własne

Fig. 2. Hardware used for initial stages of processing: (a) rotator, (b) feeder

Rys. 2. Mechanizm wykorzystany w początkowych fazach przetwarzania: (a) rotator, (b) podajnik

The goal was to design scarification automaton, which consist of an input container for the seeds, connected to an input of a seed transportation path that comprises the following elements arranged in the following sequence: a feeder, a length and orientation detector, a rotator, a positioner, a gripper, a scarifier, vision-based sorter of seeds and seed containers. Fig. 2 shows the hardware performing initial stages of acorn processing sequence: from the feeder to the rotator.

The essential part of the automaton is a controller, which is responsible for reading out signals from sensors and driving actuators of particular subsystems. The required sequence of actions is following:

- the acorn is released from an input container by a latch and falls down to the feeder,
- in the feeder, acorn moves across the field of view of the camera subsystem that detects its orientation and length,
- then, the acorn falls down to the rotator which rotates the seed if necessary and forwards it to the scarification module,
- the seed is positioned and a scarifier cuts the end of the seed,
- vision-based detector performs visual assessment of the viability of the seed on the basis of the image of the cross-section,
- finally, acorns are separated into healthy and spoiled

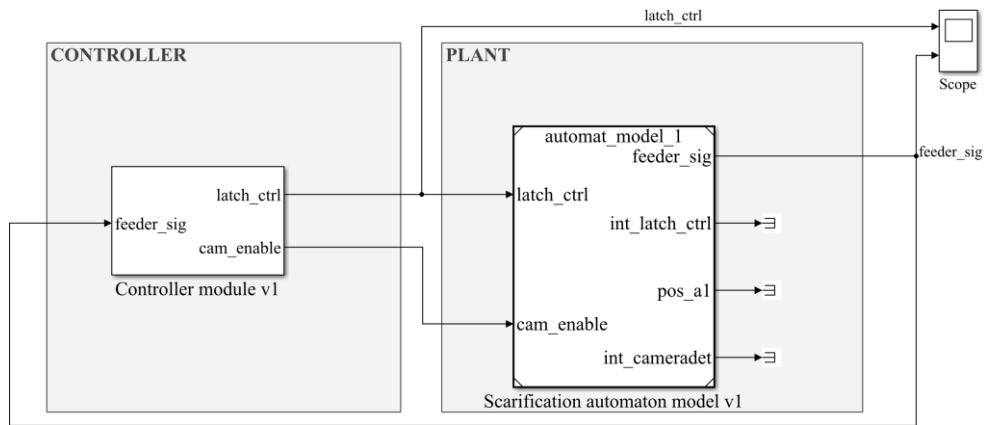
and placed into output containers.

Mummification changes that appear in cross-sections after scarification allow to predict viability of each seed by means of computing vision-based features. These features can be used in a similar way like mass and density [11] for estimating quality of seeds.

Time of the acorn processing is an important factor – we aim to minimize it (assumed performance of the seed system is about 1 acorn per second). Therefore, identification of delays introduced by individual automaton components is essential. Above description of the automaton defines our requirements: (I) individual components and connections between them, (II) methods of controlling transportation of seeds from the input container, through transportation path, into a one of the output containers based on mummification detector results, (III) overall automaton performance.

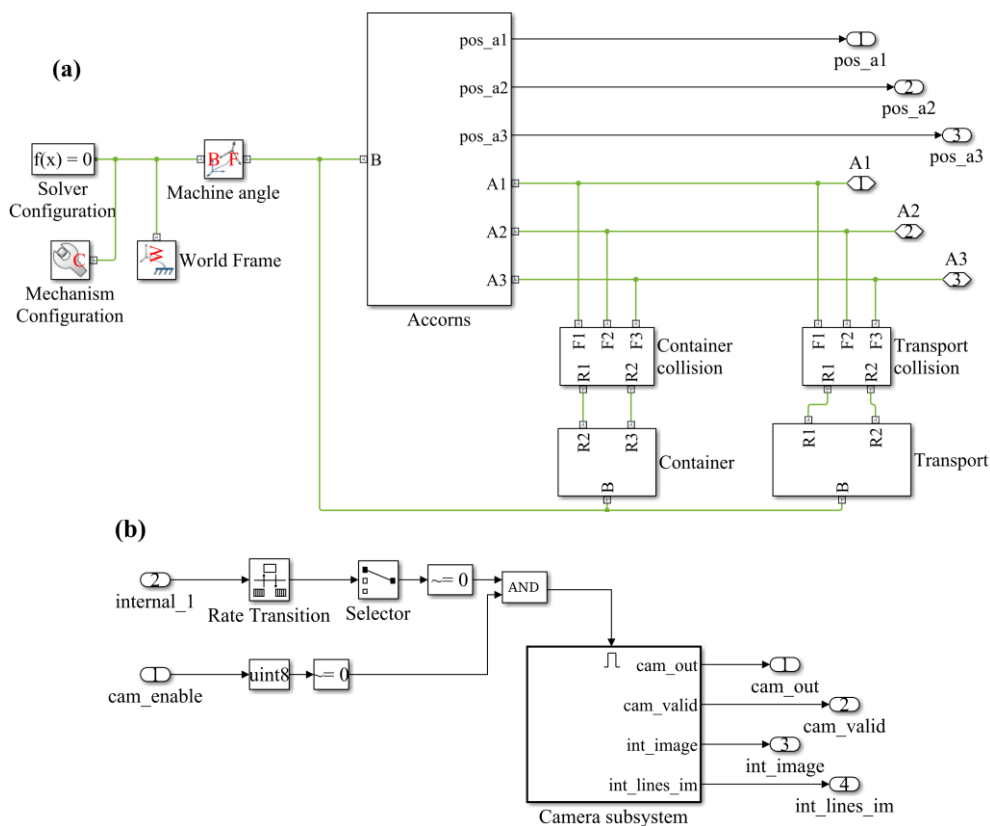
### 3. Results and future work

Based on the requirements, the modeling of the entire system and its individual components was made using MATLAB® environment (MathWorks®) and its modules (Simulink®, Stateflow™ and Simscape Multibody™). A model of the scarification automaton and the controller (Fig. 3) acts as a reference specification of the whole system, allowing us for simulation and testing both plant and its controller together at different stages of design.



Source: own work / Źródło: opracowanie własne

Fig. 3. A Simulink model of the scarification automaton along with the controller at one of the early stages of development  
Rys. 3. Model Simulinka automatu do skaryfikacji wraz z kontrolerem (początkowy etap modelowania)



Source: own work / Źródło: opracowanie własne

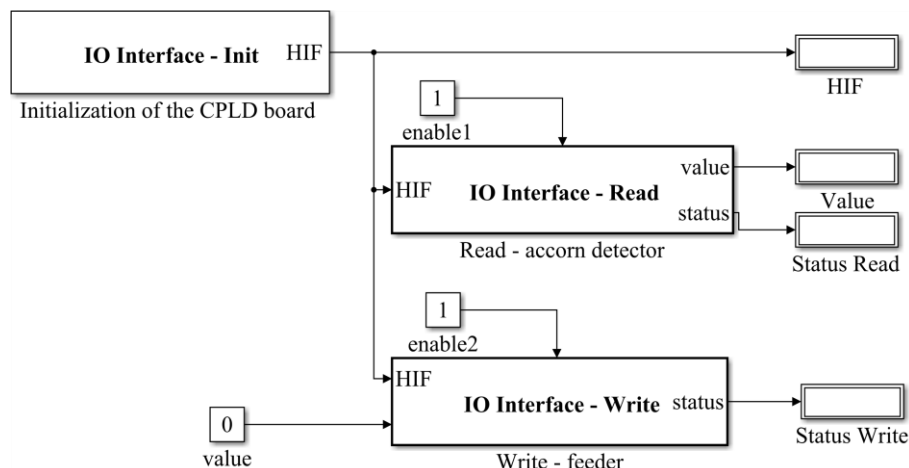
Fig. 4. A part of the automaton model: (a) mechanical part of the feeder and transport, (b) discrete part of a machine vision subsystem

Rys. 4. Część modelu automatu: (a) elementy mechaniczne podajnika i systemu transportowego, (b) elementy cyfrowe pod-systemu przetwarzania obrazów

The individual components can be simulated separately, allowing more detailed focus on various aspects of the automaton. For example we've modeled and simulated behavior of the transportation of seeds from the input container, through transportation path and field of view of the orientation detector (camera), into a rotator (Fig. 4). The realized model uses Simscape Multibody Toolbox. The model functionality allows to test the operation of acorn's feeder in the continuous or stepping simulation mode. The feeder output allows to trigger the subsequent component of the automaton. The preparation of testing scenarios allows to simulate the behavior of the virtual prototype and further operation

of the real device.

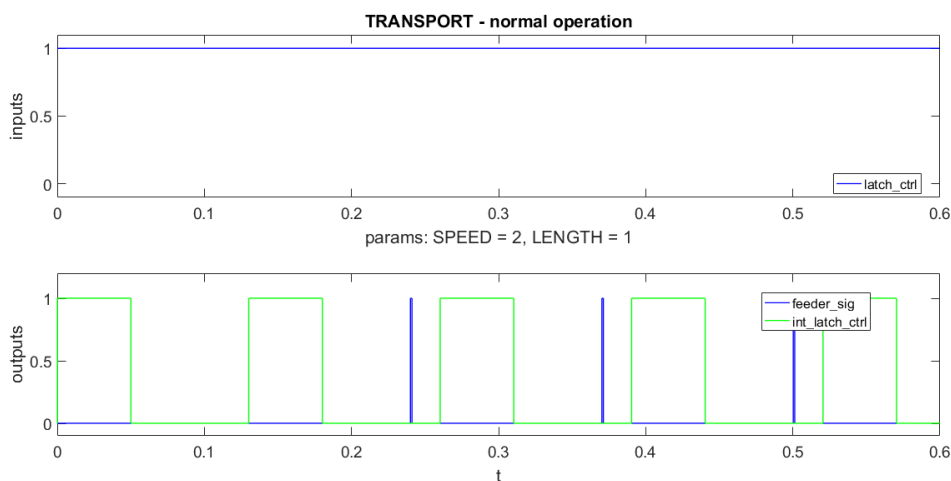
Based on mixed design (simplified mechanical model, discrete time camera system), we designed the controller for that part of the system. Using Model-Based Design, optimization of the control system and automated code generation for HIL (Hardware-In-the-Loop) testing was also possible. By implementing a set of drivers (in a form of Simulink s-functions) to a real prototype (Fig. 5), we were able to test functionality of another part of the automaton and identify its parameters (i.e. rotator rotation angles corresponding to the respective outputs, delays).



Source: own work / Źródło: opracowanie własne

Fig. 5. A set of Simulink s-functions for interfacing sensors and actuators for the scarification experimental setup

Rys. 5. Zestaw s-funkcji Simulinka opracowanych do połączenia sensorów i elementów wykonawczych ze stanowiska eksperymentalnego



Source: own work / Źródło: opracowanie własne

Fig. 6. Exemplary results of the simulation of acorns passing by across the feeder

Rys. 6. Przykładowe rezultaty symulacji nasion przesuujących się wzdłuż podajnika

These parameters can be used to fine tuning mechanical model of the automaton, and thus enable modeling and concurrent functional simulation of the whole system, including simplified models of mechanical components, actuators and sensory part. Fig. 6 shows an exemplary output of the simulation comprising open control signal of the feeder and estimated sensor readout. The article shows current state of our work-in-progress. In further stages it is planned to perform Hardware-In-the-Loop simulation of the system comprising real plant and virtual model of the control algorithm according to Fig. 1. The next step includes the integration of image processing and recognition algorithms into the proposed complex model of the automaton.

#### 4. References

[1] Abdellatif T., Combaz J., Sifakis J. Model-based implementation of real-time applications. In Proc. of the tenth ACM international conference on embedded software (EMSOFT '10). ACM, USA, 2010, 229-238.  
 [2] Balogh R., László M. Model-Based Design of a Competition Car. Robotics in Education, Advances in Intelligent Systems and Computing, 2016, Vol. 457, pp. 219-229, 2016.

[3] Du Y., Dorneich M.C., Steward B.: Virtual operator modeling method for excavator trenching. Automation in construction, 2016, Vol. 70, 14-25.  
 [4] Hopfenzitz M., and Guss C., Improve Complexity Management With Model-Based Design in V-Modell. MathWorks®. Presentation in Polarion User-Conference, 2013.  
 [5] Kurytnik I.P., Lis S., Drózd T., Telega A.: Metoda szybkiego prototypowania w opracowaniu algorytmu sterowania instalacją solarną. Pomiary Automatyka Kontrola, 2014, Vol. 60(5), 325-238.  
 [6] Mancisidor I., Beudaert X., Etxebarria A., Barcena R., Munoa J., Jugo J.: Hardware-in-the-loop simulator for stability study in orthogonal cutting. Control Engineering Practice, 2015, Vol. 44, 31-44.  
 [7] Penczek A., Stala R., Stawiarski Ł., Szarek M.: Hardware-in-the-Loop FPGA-based Simulations of Switchmode Converters for Research and Educational Purposes. Przegląd Elektrotechniczny, 2011, Vol. 87(11), 194-199.  
 [8] Petrů M., Novák O., Herák D., Mašín I., Lepšík P., Hrabě P.: Finite element method model of the mechanical behaviour of *Jatropha curcas* L. bulk seeds under compression loading: Study and 2D modelling of the damage to seeds. Biosystems Engineering, 2014, Vol. 27, 50-66.  
 [9] Serres J., Raharijaona T., VanhoutteE., Ruffier F.: Event-based visual guidance inspired by honeybees in a 3D tapered

- tunnel. Second International Conference on Event-based Control, Communication, and Signal Processing (EBCCSP), Kraków, Poland, 2016, 1-4.
- [10] Tomasiak M.: Stabilization of suction pressure in the conceptual milking unit. *Agricultural Engineering*, 2015, Vol. 19(2), 127-135.
- [11] Tylek, P., Kaliniewicz, Z., Kielbasa, P., Zagrobelny T.: Mass and density as separation properties of the pedunculate oak (*Quercus robur L.*) seeds. *Electronic Journal of Polish Agricultural Universities. Series Forestry*, 2015, Vol. 18(4).
- [12] Wang X., Puri V.M., Demirci A., Graves R.E.: Mathematical modeling and cycle time reduction of deposit removal from stainless steel pipeline during cleaning-in-place of milking system with electrolyzed oxidizing water. *Journal of Food Engineering*, 2016, Vol. 170, 144-159.
- [13] Zembrowski K., Danielak M., Stobnicki P., Rakowicz A., Weymann S.: Virtual models of a new version of a loading transporter unit in a tracked vehicle – kinetostatic and strength analysis. *J. Res. Appl. Agric. Engng*, 2015, Vol. 60(1), 116-121.

***The presented work was supported by National Centre of Research and Development of Republic of Poland (NCBiR) within the project "Functional model of automaton, comprising machine vision system, for scarification and assessment of acorn viability by means of automatic recognition of topography of mummification changes", grant no.: PBS3/A8/134/2015.***