CONFERENCE IN MEMORY OF PROFESSOR JERZY WRÓBEL

CAD in Machinery Design

Implementation and Educational Issues

XXXI International Conference

COLLECTIVE MONOGRAPH

EDITORS

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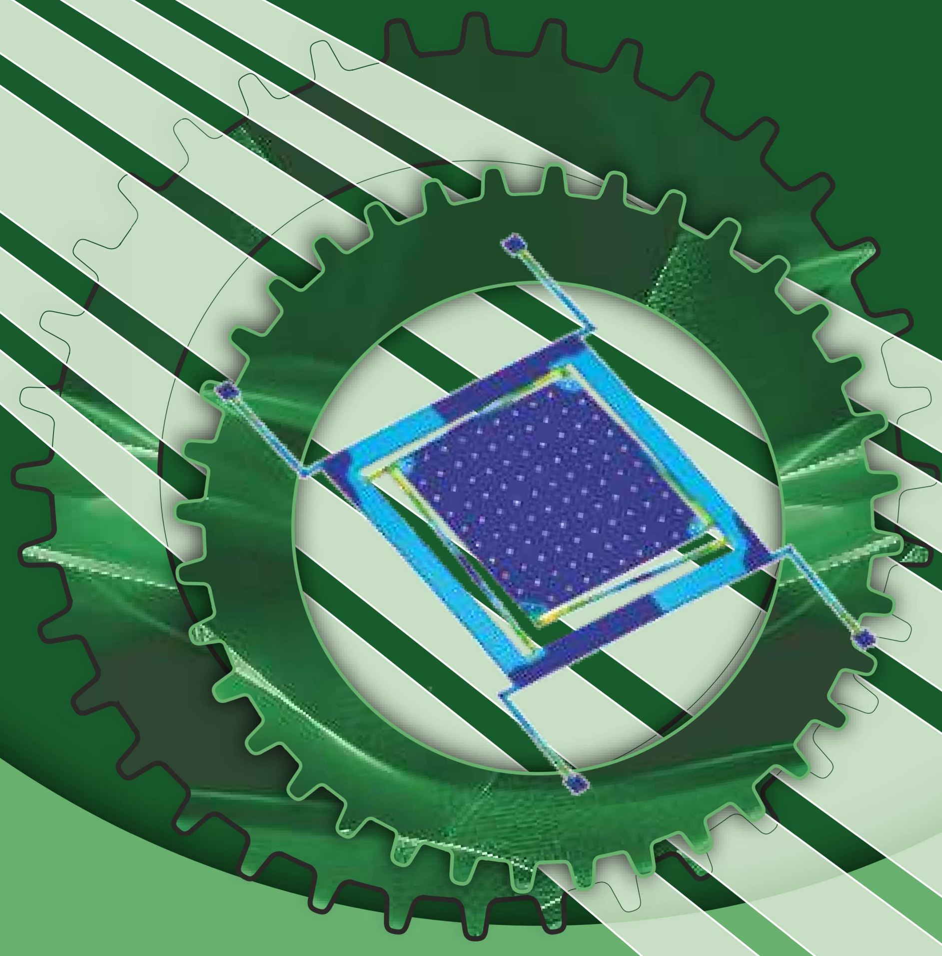

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Preface

The CADMD conference series started in Warsaw in 1994 and has been organized annually since then in Poland and Ukraine.

In 2023 the XXXI CADMD conference took place in Supraśl and has been dedicated to the memory of Professor Jerzy Wróbel.

A short history of the conference can be found on its website (http://cadmd.lpnu.ua/).

The organizers are as follows:

- Faculty of Mechanical Engineering, Białystok University of Technology, Białystok, Poland;
- Department of Automated Design Systems, Lviv Polytechnic National University, Lviv, Ukraine;
- Faculty of Mechanical Engineering and Robotics, AGH University of Science and Technology, Krakow, Poland;
- Institute of Fundamentals of Mechanical Engineering, Warsaw University of Technology, Warsaw, Poland.

The aim of the conference is to exchange experiences between scientists in modern information technology, the development of CAx systems, teaching methods and the implementation of automated systems in the educational process, and establishing closer ties between researchers.

The conference papers are presented on problems in the field of MCAD and ECAD techniques and CAx tools in automation of machine and mechanism design, identification, modelling of processes and systems, UAV, UGV, robotics, automation, electromechanical systems, application of information technologies in engineering, software, programming and algorithms, additive technologies, reverse engineering, databases, CAx engineering education, educational methods and Internet technologies in education.

The XXXI International Conference CAD in Machinery Design – Implementation and Educational Issues occurred under the patronage of:

- Rector of Białystok University of Technology
- Rector of L'viv Polytechnic National University
- Rector of AGH University of Science and Technology
- Rector of Warsaw University of Technology
- Main Board of SIMP (Polish Society of Mechanical Engineers and Technicians)
- President of ProCAx Association

The conference took place in Supraśl, Poland, on October 26–28, 2023.

Conference CADMD_2023 was co-financed from the state budget under the programme of the Ministry of Education and Science of Poland called “Doskonała Nauka” project no. DNK/SP/548614/2022.

2.4. Automated design of fire detection devices body components

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Summary: The master model of fire detector body components was designed and produced using CAx. The 3D model of the fire detector enclosure components was developed and improved by adding fasteners for the Arduino mini board, simulation modeling was carried out, and the lower cover of the fire detector was produced using a 3D printer. This will allow the carrying out of full-scale experiments of the fire detector and system.

Keywords: heat detector, computer added design, microcontroller, 3D-model, 3-D print

Introduction

Application of CAx systems for modeling, research and manufacturing of new body parts of a technical device allows for improvements of its structure and ensures functionality [1]. This approach allows you to develop a master model of the device in 3D and make a 3D print of its body parts [2]. They allow for 3D design of a technical device. However, it is advisable to prepare the model for 3D printing in the systems Ultimaker Cura, PrusaSlicer, Simplify3D, etc., whose software is free and oriented to most modern 3D printers that are in wide use. It is expedient to conduct simulation modeling of the functioning of technical devices in the MATLAB Simulink system, which allows you to develop a structural model and analyze the technical object at the functional-logical level.

Technical devices of intelligent systems in need of improvement include fire detectors (FD), which are part of the fire alarm system (FAS) [3]. One of the most effective methods of fire protection systems is the fire alarm system (FAS).The FAS consists of many components: fire detectors, monitoring and signaling devices, a control panel, an alert system, automatic control devices, backup power, and a monitoring and control system [3]. FD generally consists of body parts, electronic control board and sensors.[4]. There are list of the FD body examples of optical-electronic smoke FD (Fig. 1).

To improve the functional capabilities of the fire alarm system, it is advisable to use modern algorithms for the hardware component operation of the fire detector [5–8]. Such algorithms of the hardware components operation improve the FD speed operation. Namely, it reduces the time of detection of ignition by thermal fire detectors. In [6], a fuzzy logic block for a multi-sensor fire detector with smoke and heat sensors is proposed and synthesized based on the theory of fuzzy logic with the Mamdani algorithm.

This makes it possible to detect ignition at an early stage and make the right decision on its elimination. In [7], a flame detector with IR and UV sensors was developed using fuzzy logic. A model of this multi-channel flame FD was developed in the MATLAB software.

a) b) c)

FIG. 1. Fire detectors body examples, a) DETECTO SMK110 – address detector Of the LLC "Tiras-12", b) SPD2-Tiras is a non-addressable detector of the LLC "Tiras-12", c) SPD-3 Elite – detector of the "Arton" PE company

The results of simulation studies showed that the fuzzy correction unit recognizes different stages of changes in the wavelength and the frequency of flickering and forms the necessary output signal based on the compiled rule base.

In [8], an improved self-organized radial-basis neural network integrating the fuzzy Takagi-Sugeno model was used to develop a three-channel infrared flame detector. The implementation of the FD algorithms is provided with the help of microprocessor technology. In particular, on the basis of the Arduino microprocessor technology using the C programming language, the hardware implementation of the fuzzy logic of the Sugeno thermal substation was carried out in [9]. For this purpose, a microcontroller based on the Arduino Mega 2560 hardware and computing platform using the C programming language was used.

In [10–13], the authors use an Arduino Uno board with various types of sensors to build intelligent fire detection systems. In [10], the system sends a message about a fire or a malfunction via a GSM modem, turns on the fire extinguishing pumps, gives alarm signals and turns off the electricity supply to the house. In [11], the proposed system, after exceeding the threshold values of the controlled features, the microcontroller turns on the fan to remove smoke. At the same time, the Arduino sends information about the fire via the ESP8266 Wi-Fi module. In [12, 13], Mamdani's fuzzy logic is implemented on the Arduino Uno board. In work [14], the Arduino Nano board (Italy) was used only to collect information from various sensors and transmit them through the ESP8266 Wi-Fi module to the fuzzy logic controller module implemented on Android.

All these works demonstrate the relevance of improving algorithms for controlling the microprocessor FD component and the need to improve the design of the FD body parts. Therefore, improving the FD efficiency is possible due to the improvement of the algorithm of the FD hardware part and its implementation on the Ardoinomini board. For this, it is necessary to improve the design of the FD body parts for the possibility of attaching Ardoinomini-type microprocessor boards [9]. The process of modifying the design of the fire detector involves the development of a 3D model of the FD body parts, improvement of the model by adding Arduino board fasteners, simulation modeling and the production of a master model for further full-scale experiments of both the FD body parts and the FD as a whole. The purpose of the research is the 3D design of the FD body parts with the Arduino board and production of these parts using 3D printing technology and master model creation, engineering analysis and optimization of the fire detector design.

Section 1. fuzzy logic algorithm for microcontroller application.

To improve the functionality of the fire detector, it is advisable to use modern algorithms for the fire detector's hardware. For example, algorithm based on a controller with fuzzy logic.

A module based on the Arduino Uno platform was chosen for the study, it has compact dimensions and a low profile. Its basis is the Atmega328 microcontroller, which has the following characteristics: 32 KB of flash memory, 2 KB of RAM, 14 digital inputs/outputs (6 of them can be used as PWM channels), 8 analog inputs and support for popular interfaces and communication connection [9]. Such a hardware control algorithm will improve the fire detector's performance, namely reduce the time it takes to detect ignition by thermal fire detectors.

The mathematical basis of fuzzy logic follow [9]. To explore diverse fuzzy systems within the MATLAB/Simulink software suite, there exists a dedicated toolbox known as the Fuzzy Logic Toolbox. Utilizing this toolbox, fuzzy systems can be effectively represented and simulated through Simulink. This article explores the Sugeno fuzzy inference technique, often referred to as the Sugeno-Kang method, which is a shortened form derived from Takagi-Sugeno-Kang. An illustrative rule in the Sugeno fuzzy model of the first order, specifically when the membership functions of the output data are linear dependencies on two input signals:

IF Input1 = xandInput2 = y, THEN (output will be)

$$z = ax + by + c. \tag{1}$$

where 'a' and 'b' represent the coefficients of linear dependence on input signals, and 'c' is a constant.

In the context of the software implementation of a fuzzy block in the Arduino software environment, optimal outcomes are achieved when utilizing triangular and trapezoidal-shaped membership functions. The triangular curve serves as a membership function and relies on three scalar parameters: *a*, *m*, and *b*, denoted as:

$$\mu_A(x;a,m,b) = max(min(\frac{x-a}{m-a}, \frac{b-x}{b-m}), 0). \tag{2}$$

Parameters *a* and *c* establish the "legs" of the triangle, and the parameter *m* denotes the peak.

The trapezoidal curve functions as a membership function and relies on four scalar parameters: *a*, *b*, *c*, and d, as illustrated

$$\mu_A(x;a,b,c,d) = max(min(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}), 0). \tag{3}$$

Parameters *a* and *d* establish the location of the "feet" of the trapezoid, while parameters b and *c* define the "shoulders".

In [9] our team created a fuzzy Sugeno controller model with two inputs and the determined specifications. The parameters for the membership functions are specified in [9] also.

Based on the previously formulated and tested fuzzy block model in MATLAB/Simulink, it was implemented using the C programming language on the Arduino Mega 2560 board. Arduino software has many advantages, the most important of which is the ability to connect a wide range of modules and sensors to Arduino; the ability to work on different operating systems. The Arduino Mega 2560 board is powered by the Atmel ATMega 2560 microcontroller, operating at a quartz frequency of 16 MHz. In the Arduino software suite, leveraging the established mathematical foundations (1)–(3), we executed the hardware implementation of the proposed zero-order fuzzy Sugeno block with two inputs. Post-Arduino board programming, experimental investigations were conducted by altering the potentiometer voltage input on the board from 0 to 5 V, with the fuzzy block generating a signal.

The Arduino's calculations yielded an error margin of less than 2.5%. This discrepancy stems from the Arduino's data bit size, where float variables are utilized alongside an 8-bit digital-to-analog converter. One could augment the bit size by employing a variable of type double float, albeit at the expense of reduced microcontroller speed. The fuzzy block's complete cycle execution time is 0.004 s, yet operational velocity can be marginally enhanced through software optimization. Consequently, the implementation of the maximum heat detector's fuzzy logic block with the Arduino board's fuzzy Sugeno block is achieved.

Section 2. Design and Engineering analysis of FD body.

The following software for automated design was used to solve the problem of 3D modeling [15] of FD body parts with an Arduino board. Fusion 360 is a free platform for 3D CAD, modeling, industrial design and mechanical engineering. Blender is a software package for creating 3D computer graphics. Cura is an open source slicing application for 3D printers and 3D printing.

Stages of the design of fire detector body parts, which were performed in this work.

1. 3D modeling of the device in the BLENDER system software and obtaining.stl models for 3D printing in the Cura system.
2. 3D printing of FD body parts using the Cura software and obtaining a master model of the device.
3. Engineering analysis and optimization of FD body parts in the Fusion 360 software system.

In the BLENDER environment, the upper cover and the FD base body were created (Fig. 2). Also, special legs for mounting an Arduino Mini board measuring 33x18 mm were designed and placed on the base. To implement the next stage (obtaining a master model of the device) creation of a master model of the FD body parts using the Cura software environment. The production of the FD body part master model took place on the basis of the equipment of the Department of Automated Design Systems of the "Lviv Polytechnic" National University. In particular, the Ender 3 Max 3D printer was used.

a) b)

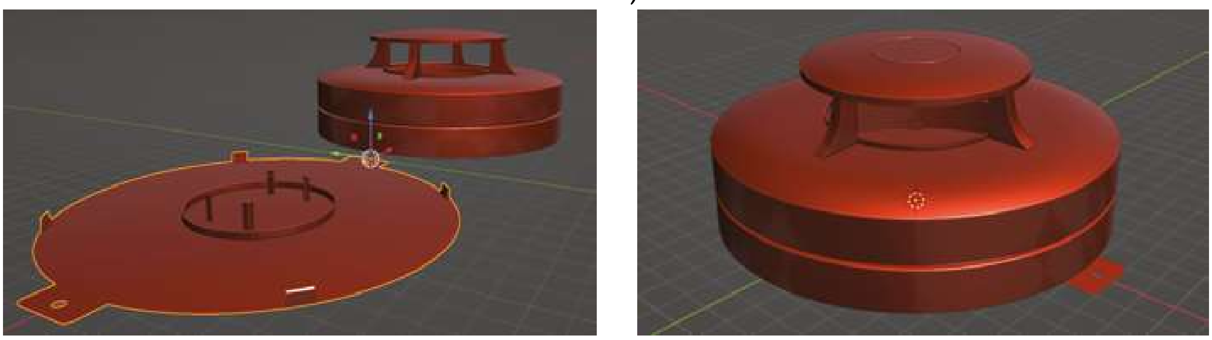

FIG. 2. The body created using the Cura software, a) the body in the disassembled state, b) the case in the assembled state

For the printing process, the CuraSlicer software 'Cura' [15] was successfully applied, which made it possible to prepare and adjust the printing parameters of body part models on a 3D printer, such as speed, layer thickness, filling, etc. After studying the 3D model of the Fire Alarm, the following modifications were made to the settings of the basic profile of the Ender 3 max printer for PLA plastic. It was the production of the master model of the FD body. In particular, a master model of the F D base with new mounting elements for the Arduino board was 3D printed (fig 3).

FIG. 3. The result of 3D printing of the FD lower cover body with new fastening elements

Post-treatment was carried out using dichloromethane (DCM) solvent for products printed with certain types of plastics such as Acrylonitrile Butadiene Styrene (ABS) or Polycarbonate (PC).

Engineering analysis and optimization of fire detector body parts were carried out in the Fusion 360 software [4] system during these researches. The process included the following stages: 3D construction of Fire Detector parts based on a printed master model (fig 4, a, b, c). Assembly parts of the FD in the Fusion 360. (fig 4, d). Thermal calculation of the fire detector in the temperature range of its operation based on the developed 3D model. Analysis and optimization of the design of the seat pleace for the Arduino board in the Fire Detector.

The dimensions of 3D models built in Fusion 360 correspond to the actual dimensions of the printed master model. The obtained 3D models allow the carrying out of research of various influences, in particular temperature. This is a significant advantage, as it does not require full-scale tests of a real sample and eliminates the risk of damage to finished master models. The results of modeling before the influence of temperature are taken into account for the correction of production of serial products.

For FD body parts, one of the main parameters of its functioning is the temperature class. Therefore, a study of the body part on the influence of temperature fluctuations of the external environment was carried out. Thermal calculation of the body parts of the fire detector in the temperature range of its operation (50–80°C). The results showed a satisfactory temperature distribution. The fixing elements and the details of the fire detector have been optimized as a result of engineering simulation of the seating position for the Arduino board in the fire detector.

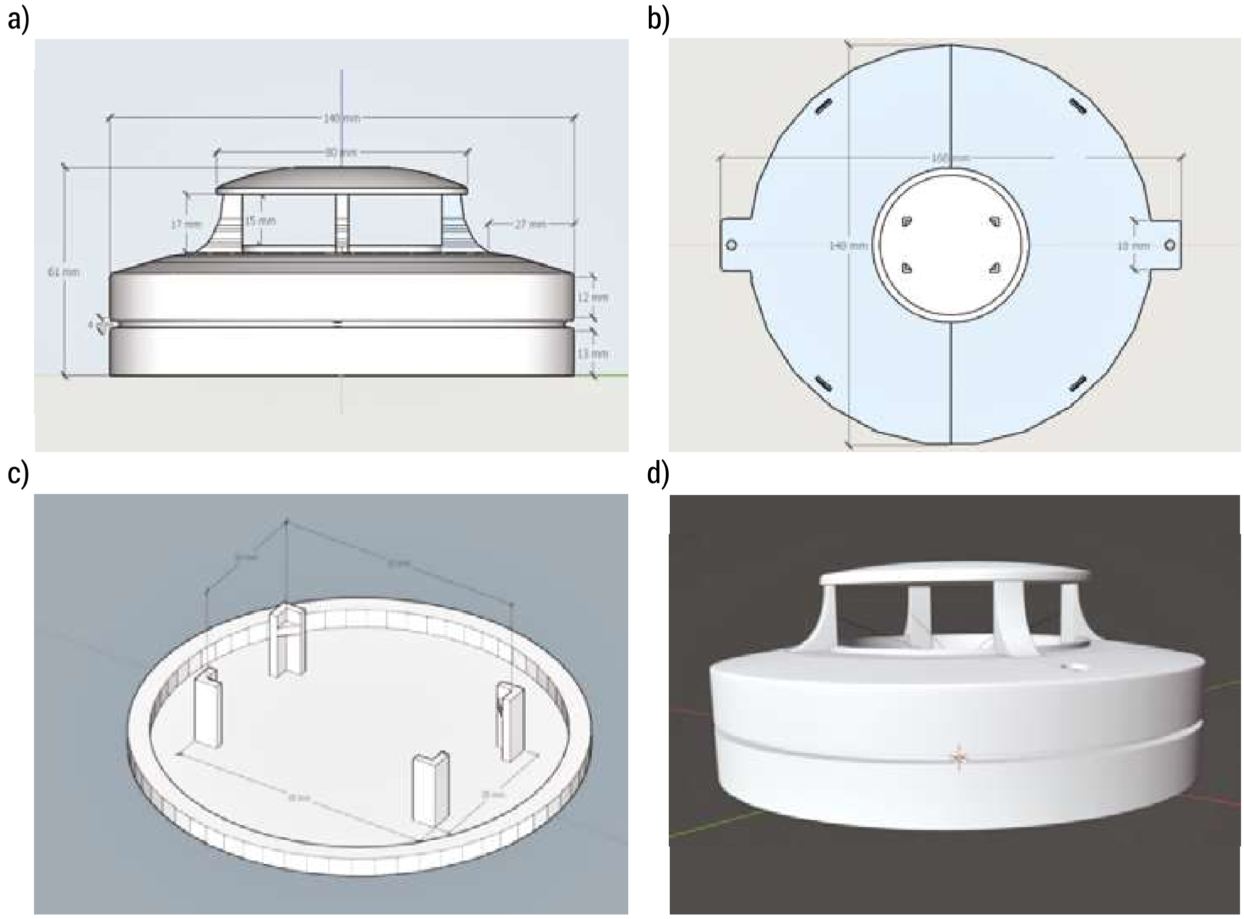

FIG. 4. 3D modeling results in the Fusion 360 system

In general, this paper presents the scientific, applied, and technical-technological results of 3D modeling of body parts of fire detection devices, the selection of modern software for the development and production of the master model. The obtained results will allow to improve the efficiency of the PS and will be useful in the field of 3D modeling and printing.

Conclusions

- The peculiarities of the fire detectors body parts design with the use of microprocessor control based on the Ardoinomini board were analyzed.
- The main regularities of the new algorithm for controlling the FD hardware using a controller with fuzzy logic, implemented with the help of Ardoinomini microcontroller control, are given
- The design of the FD body parts was improved due to the addition of Ardoinomini board fastening elements, and 3D modeling of Fire Detector details was done in Blender software
- 3D printing of Fire Detector details was implemented with the help of Cura software, and its corresponding master model was obtained.

- An engineering analysis and optimization of the fixing elements design in the details of the Fire Detector was carried out with the help of Fusion 360 software.
- The obtained master model will allow for the creation of a Fire Detector with an Arduino board for the implementation of the latest microprocessor control algorithms. It will also improve the performance characteristics of the Fire Detector, in particular the accuracy and speed of operation.

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