Design of Low-Cost Three-Axis Actuation System

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Abstract. Low-cost is an increasingly inflected theme in the mechanical engineering world. A cost reducing leads to the development of new solutions, that could not be used in non-commercional sector before. One of this solution is the free hardware programmable platform called Arduino. This platform is very popular in engineering education sector, as well as in common use. The popularity of this platform lies in low price, intuitive interface and universality. Result of this article is to achieve a low-cost, readily modifiable, students friendly three-axis actuation system for the movement of three-axis facilities, like is a co-ordinate measuring machine (CMM). For this reason was used Arudino AtMega board and three stepper motors con-trolled by the pair of joysticks.

Keywords: Arduino · three-axis · actuation system · low-cost · steeper motors · CMM

1 Introduction

The new and high professional external three-axes actuation devices used in mechanical engineering industry have very high acquisition cost and they are not usable like appropriate example as a learning and teaching tool. For this reason was considered about the assembly of the low-cost three-axes actuation system controlled by Arduino At-Mega platform (Fig. 1).

The Arduino At-Mega is a very popular open plat-form in the public sector and especially in the student's sector as well. At the beginning of this project the Arduino component was connected and code was written. Afterwards were all Arduino and other mechanical components implemented to the originally fully human power moveable co-ordinate measuring machine [1]. The aim of this article was assembling and programming of the low-cost actuation system and implement this system to the real CMM Somet Berox, in compliance with today's required standards of accuracy.

2 Materials and Methods

2.1 Arduino System Assembling and Programming

The actuation system was assembled and programmed with the aim of been used as a teaching and learning tool to increase the students mechanical engineering knowledge's and interest in engineering areas. [2] Platform Arduino was chosen as a most appropriate

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variant. The Arduino hardware consists from Microcontroller board Arduino AtMega 2560, 3D CNC Shield V3, Arduino motor driver DRV8825 for each motor, two PS2 joysticks for control of the axes XYZ, power supply and other electronics components like wires, breadboard, resistors, led diodes and emergency stop button. The whole assamble of the commercially purchased Arduino components see on the Fig. 2.

Control Code. Arduino platform operate on the own developmental environment, using programming Arduino language and software IDE. The Arudino software is compatible

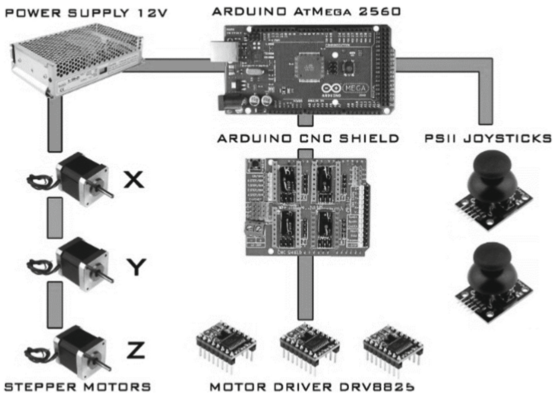

Fig. 1. Schematic assembly of the Arduino actuation system

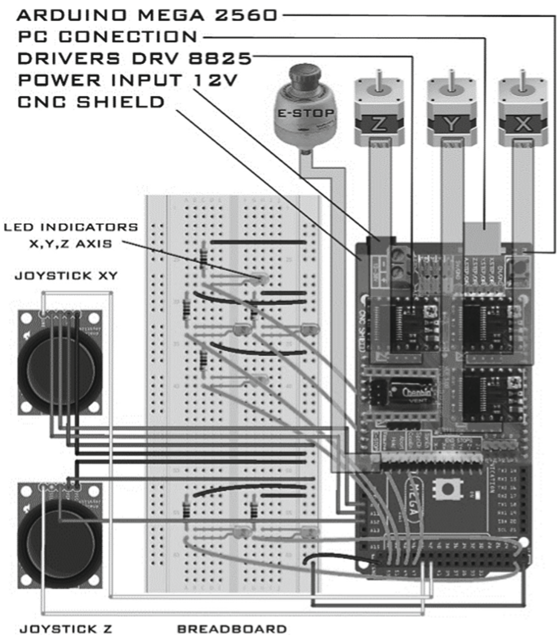

Fig. 2. Complete assembly of the Arduino hardware

with almost all operation systems [3]. The control code containts more than 180 rows was created in this Arduino language, part of the control code for the machine movement in axis X is describe in following script:

```
//X axis
If (aktX > 5) {
   aktX = map (aktX, 0, 1023-KlidX, 0, 100);
   aktX_new = map (aktX, 0, 100, 15000, 1000);
   digitalWrite (dir_pinX, HIGH);
      digitalWrite (step_pinX, HIGH);
      digitalWrite (LED_XP, HIGH);
      delayMicroseconds (aktX_new);
      digitalWrite (step_pinX, LOW);
      delayMicroseconds (aktX_new);
else {
      digitalWrite (LED_XP, LOW);
      }
 If (aktX < -5) {
aktX = map (aktX, 0, -KlidX, 0, -100);
   aktX_new = map (aktX, 0, -100, 15000, 1000);
   digitalWrite (dir_pinX, LOW);
      digitalWrite (step_pinX, HIGH);
      digitalWrite (LED_XL, HIGH);
      delayMicroseconds (aktX_new);
      digitalWrite (step_pinX, LOW);
      delayMicroseconds (aktX_new);
      }
else {
      digitalWrite (LED_XL, LOW);
      }
```

Setting of the sensitivity and the certainty of the smoothness movement were the biggest pitfalls in the programing of the motors. This demands had to be included during the initial phase of the Arduino code writing. Main issue related to low-cost joysticks and their potentiometers incapable to linear movement, was partly solved due to change of the control code. For this reason the primary solution of the motor rotation, depending on the angle of joysticks rotation was rejected and the code control code was changed. Three type of the speed setting was chosen as the most suitable solution. Requested speed is choosen by click of the Arduino joystick and they are available speed 100 - rapid traverse, 1000 - normal speed and 15000 - micro movement. The numbers 100, 1000, 15000 mean delay between two steps of the stepper motor.

Controller Design. Due to the fact, that the hardware of the Arduino remote control consists from bigger amount of the components and they are form into one function whole, the ergonomic cover for safety fits was necessary to create. The low-cost 3D printed

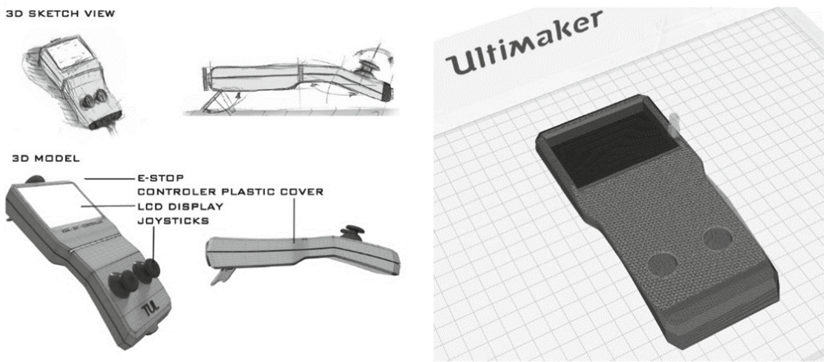

Fig. 3. The controller: Sketch and 3D design, FDM printing mesh

controller was considered with respect to the operator's safety, sensitive components safety, ergonomic and easy manipulation. Affordable controller cover was necessary to design on the ground of these criterions. For the first design sketches was used software Adobe Photoshop and afterwards the 3D design was created in software 3D studio max. Finished 3D model was exported to.OBJ format and afterwards imported to Ultimaker 3D printer software. Software Ultimaker transformed the model in to *.STL format and created special mesh layers necessary for 3D printing. After this operations was the 3D models ready to print. Sketches and 3D design of the controller see on the Fig. 3.

The picture from the interface of the Ultimaker software with the layers is on the Fig. 3. The considered 3D printer works on the base of material extrusion, which is an additive manufacturing process in which material is selectively dispensed through a nozzle. The process is called Fused deposition modeling (FDM). [4].

2.2 Mechanical Components Design and Assembling

The whole actuation system with all necessary mechanical components was implemented on to the CMM. This implementation realized after assembling of the Arduino components, control code writing, stepper motor control code testing and finally special clamping and movement elements designing and manufacturing. All necessary elements were designed considering the current holes and spaces which remained after the disassembly of unnecessary parts and elements from the original CMM. All parts were drafted using CAD software Autodesk Inventor and afterwards were cut on a CNC laser cutting machine. 3D models of the axes XY and Z with implemented clamping elements and other mechanical elements drafted via software Autodesk Inventor see Fig. 4 and Fig. 5. A belt drive was used for the power transfer between the movement devices and the stepper motors [5].

2.3 Final Testing

After the completion of all hardware components and the Arduino code tuning, mensuration's was carried out. The accuracy and repeatability was verified by special lapped gauges block.

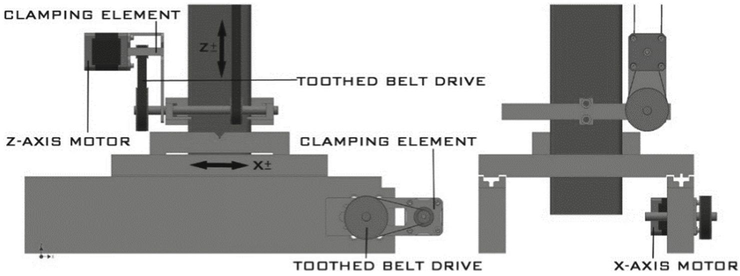

Fig. 4. CAD model of the CMM X axis.

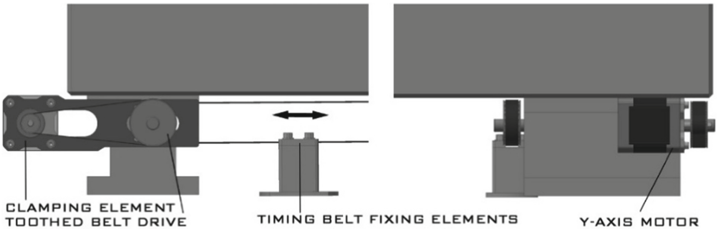

Fig. 5. CAD model of the CMM Y axis.

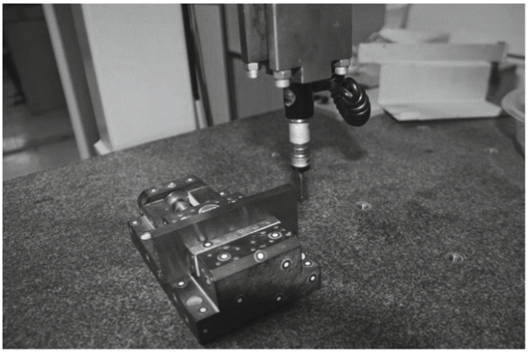

Fig. 6. CMM testing process.

Several measurements of the blocks with length 20, 40, 60, 80 and 100 mm was carried out. The gauge block measuring process on the uprgraded semi-automatic CMM see on the Fig. 6 - The ruby sphere on the touching probe head is touching of the 100 mm lapped gauge block.

3 Results and Discussion

The low-cost three-axis actuation system was developed, the function sample of the CMM using Arguino is on the Fig. 7.

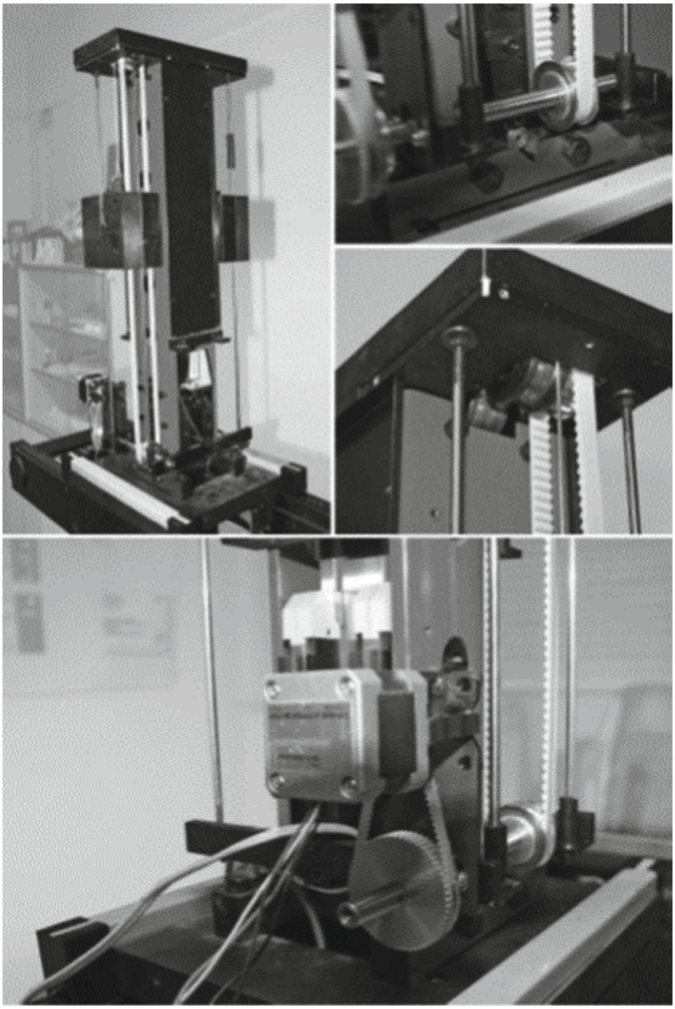

Fig. 7. Function sample of the CMM.

The Results of the Measurement. The results of the measurement lies in the interval+ −0,01 mm from the nominal values (Fig. 8), only two measurements had higher deviation from the nominal values especially because of the operator had not enough experiences with CMM and with evaluation software Tango3D fails which arise from human factor. The fails arise from human factor are inherent in large volume in measurement results very often [6].

Cost Comparison. One of the main aims of this article was the request for the low-cost solution of this three axes actuation system. All costs including material, components and manufacturing were less than 300€, which make from this actuation system (Table 1).

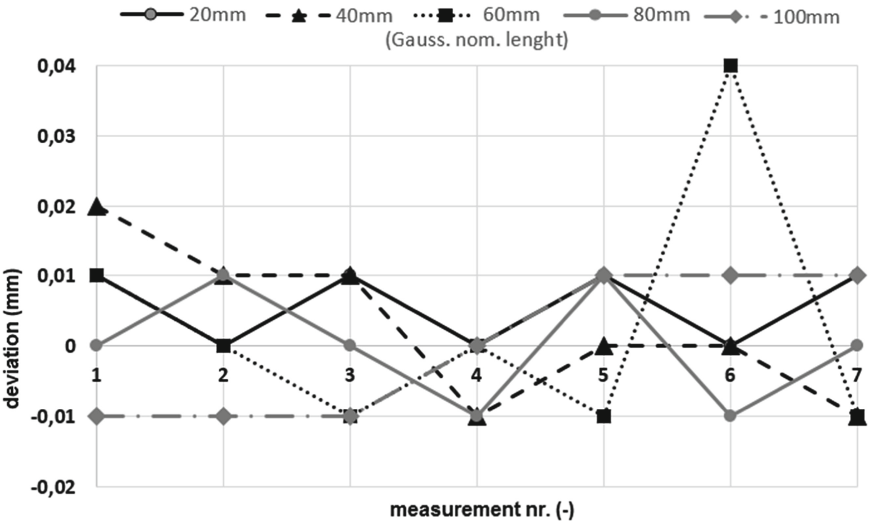

Fig. 8. CMM test of the accuracy and repeatability.

Table 1. Price list of all components

Component	Price
Arduino hardware	102,6€
Stepper motors	41,8€
Mechanical components	95,6€
Other electronics components	45€
Total	**285€**

With regard to the low-cost solution, the comparison with professional actuation solution was provided on the Fig. 9. The acquisition costs for the components purchased are many times lower than the cost for a professional actuation systems. As a result of these price differences is the fact, that Arduino is a very good educational tool as a multidisciplinary field includes programming, design and engineering, for all young students.

The upgraded semi-automatic CMM is not able to equal to modern CMM in accuracy, repeatability, speed or reliability, because whose demands are ever higher. [7] But the Arduino actuation three-axes system is absolutely sufficient for all needs of the students as the educational tool [8]. Some future upgrades are possible recommend on this CMM Somet Berox, which could lead to streamlining of the work processes. A First upgrade concern of the Arduino control code is especially recommended. This upgrade will make it possible to work with CMM in a fully automatic mode. A second upgrade regards the connection between touch probe signals and stepper motor signals by which the safety of CMM components will be ensured [1].

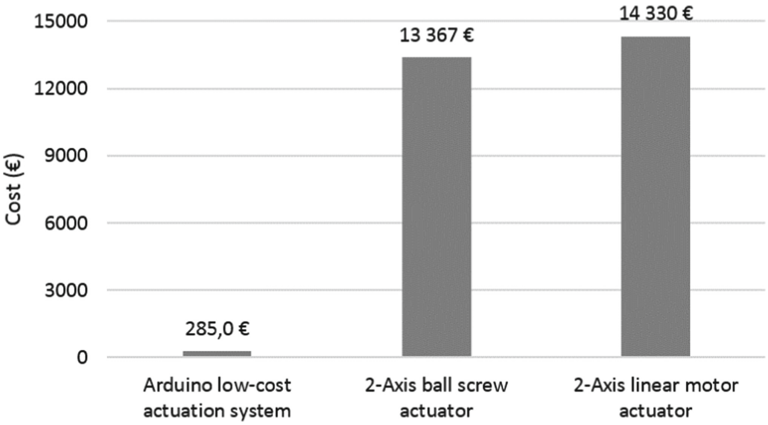

Fig. 9. Aquisition costs.

4 Conclusion

The aim of this article was to reach semi-automatic low cost actuation system applicable to various 3-axes mechanism, like are measuring or machining machines etc. This actuation system was assembled and programmed with Arudino devices and afterward successfully implemented to the manually controlled CMM. Correct accuracy and repeatability was verified by the series of the measurements. This testing guaranteed, that the upgraded CMM works correctly. The biggest advantages of this three-axes actuation solution are low price, up to 50 times lower than professional two or three-axes actuators, educational utilization, and readily modification.

The upgraded semi-automatic CMM, alternatively the Arduino actuation system will be primarily used for educational and learning purpose, this system and components will be readily modifiable.

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