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Abstract—The paper describes the original mechatronic device, which with the help of the developed control software reproduces virtual images on a material plane. Device mechanics allows various tools and materials for drawing. High-level user programming interface is written in Smalltalk with an idea to be user- and education-friendly. Low level control is carried out by an eight-bit Atmega microcontroller. The paper presents general ideas, describes prototype device developed and underlying problems and solutions occurred during the design process.

Keywords—Mechatronics, robotics, smalltalk, drawing device, user interface.

I. INTRODUCTION

This work is devoted to the description of the device, which connects the virtual and material.

The authors’ idea is to show potential of virtual computing, the aim of which is the creation of material structures and devices in the real world. The use of capabilities of the modern computer technology is not always linked to the physical world and developers often forget about the true purpose of the computer and do not go beyond the imaginary virtual spaces, inventing alternative “physics” and thus giving rise to an alternate universe at the end, with its laws and rules.

Two examples of approaches for use of the computer technology that could show the difference are: virtual reality and automation of production. Originally similar to each other (both simulate reality by copying the known laws of nature), these examples differ in the application of their results: computer games and the production of material objects, respectively.

Of course, the authors do not question the approaches, but rather pay attention to the productive and unproductive use of their results. In this regard, it should be emphasized that within the engineering sciences we are primarily interested in the creation of real objects, which would have the needed functionality and would allow people to integrate organically into their surroundings.

Therefore, the simulation result should always be correlated with real natural process. Simply put, any modeling must end with real world application of its results and thus withstand or not withstand a test of the reliability of used approaches.

The purpose of this work is the description of a device capable of mechanically reproducing an image, set by a user in a virtual two-dimensional canvas, on a material flat canvas.

II. THE DEVICE

The mechatronic device we propose is described below in four subsections: Block Diagram, Servo Control Circuit and Applicability Analysis, State Machine And Algorithm and The Hardware Part.

A. Block Diagram

In order to understand what kind of the device this article is about, it is important to consider the block diagram shown in Fig.1 - elements presented are:

1) Arduino board
2) Servo (expansion) shield
3) Servo

Fig. 1. Exploded view drawing of the device
The device is operated with a computer, which will send data to the Arduino [1]. The microcontroller processes it and sends signals to the servos through the expansion shield. As power obtained through the USB-port of the computer may be insufficient to manage several servos at once, it was decided to carry on the delivery of energy via an expansion shield. Guides are attached to servos and the fastener (intersect) element is able to move along each of them freely. It performs several functions: connecting guides in one point, holding and interchanging of drawing tools.

### B. Servo Control Circuit and Applicability Analysis

Since it is possible to control only the angles of rotation of the servos, it is necessary to derive a formula that will set the appropriate angle for each of the 2 servos for given coordinates. We represent them in the coordinate plane (see Fig.2) and taking position of one of them (servo C) as the origin, so that the second (servo D) is on the X-axis in the positive direction. Then the position of a given point B will be determined by the angles BCA and BDA. It is easy to calculate the angle of the guide line CB by the given coordinates of the point, and thus the angle of rotation of the servo C. To calculate the angle of the guide line DB, it is necessary to set the distance between the points C and D (CD segment - constant, AC and AB - variables) defined from experiments and accuracy calculations of the servos.

Servos used in this project have mediocre accuracy, which requires separate analysis of areas in which the painting is stable and those in which errors achieve too much importance. According to preliminary calculations, for a servo having a $\theta = 2^\circ$ step (nominal error of servos used in this unit), an area with reasonable accuracy (region I in Fig.3) will be a circle of radius $R = 80$ mm, since the further away from the servo (region II in Fig.3), the error

$$\delta = 2R \times \sin(\theta/2)$$

becomes more than 3 mm (excluding servo assembly defects), which in practice will lower the image quality strongly enough.

For a more accurate assessment of the quality of the joint work of the two servos a mathematical model of the created device was implemented in the Squeak development environment [2] [3] (Fig.4), which allows to judge about the region with reasonable accuracy, formed by simultaneous work of two servos.

Analyzing the results obtained using a mathematical model and calculation of accuracy zones for each of the servos, together with the experimental results, we can conclude that the area of quality usage of the developed device (at the given parameters of components) is a semi-circle of 70 mm radius centered between servos (green area in Fig.5).

### C. State Machine And Algorithm

The developed device has 6 main states shown in Fig.6. States 7-9 are complementary and describe the moving process of the tool.

Software part of the device comprises two interconnected parts.
The first - the user interface on a computer (Fig. 7), developed in Squeak dialect [4] of Smalltalk programming language. It was chosen because the code written in it has a graphical interpretation. It made possible to create a user interface without using additional software.

In its current state the user interface is an area of adjustable size, within which the user, using computer mouse, can create or load the preferred virtual image, and the action tool-bar. With its help, you can select one of the modes: pencil tool for drawing lines, marker - for points, sprayer - for bulk materials, eraser - to correct the image. Also the tool-bar has two buttons: Print to start the device to plot (print) the created image and Clear, to erase the entire virtual canvas.

When operating in the airbrush mode the software has to track the velocity of the fastening element to which instruments are attached, since the picture quality depends on the constant velocity of the tool. Which is tricky because of changing distance from the servos (local centers of rotation) in movement. To address this problem, in the shaded area in Fig. 7 dosing bulk material per time unit is proposed to be increased.

The second part serves to interpret the data received from the computer and to control the servos. It is implemented on a software platform Arduino - one of the most common and easy to program (Fig. 8).

The general algorithm of the system is shown in Fig. 9.
The algorithm allows to control the hardware by forming complex control actions [5] in a chain: computer-microcontroller-mechanism.

**D. The Hardware Part**

Rapid prototyping was used to build the current version of the device. Its electronics is represented by a common Arduino Uno board. This board is a standalone programmable electronic device consisting of 6 analog and 14 digital outputs, 5 power outputs, power connector and a USB-port, through which the connection to the computer is performed (Fig.10).

Arduino programming is carried in a C programming language dialect.

Two standard servos were used to ensure movement of the fastening (intersect) element (Fig.11).

A general view of the device is shown in Fig.12.

Arduino shields and servos for convenience were placed on one platform (backbone), which was cut with a laser cutting machine from a sheet of plywood.

**III. Conclusion**

The implemented mechatronic device satisfies the goal indicated in the introduction, which consists in connecting virtual and material worlds.

It should be noted that the developed device is a working prototype and this work reflects the current state of the project, which is still far from completion.

The device is rather large and has mediocre accuracy, which still is not a dead end, because it can be overcome using higher quality materials and components together with programming techniques. The results confirm the practical realization possibility of the authors’ ideas and validate further work to complete the project.
Born as educational the described project can also be used for educational goals: as an example of using and applying an Arduino microcontroller or solving different program tasks with Smalltalk language. The required skills for this design are very close to those in robotics in general. Detailed educational appliance of the proposed project could be a subject to describe and publish in the next paper.

The authors plan to continue the work towards improving the quality, accuracy and ergonomics of the device, and add the ability to remotely control it from a smartphone. Interesting direction considered for further research is usage of augmented reality, ensuring connection between virtual reality devices and the real world.

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REFERENCES


