Robotic arm controlled by Android app through Bluetooth connection for organic solar cell manipulation

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Abstract. In this paper we present the design of a three joint robotic arm printed out in polyethylene terephthalate glycol material which provide durability and has good chemical resistance. To move the arm, we used four servomotors for a complex orientation in horizontal and vertical plane. At the tip of the robotic arm a 5V vacuum pump was mounted to handle organic solar cells printed out on indium tin oxide treated glass sheets with a dimension of 25/24/1mm. For an easy and precise control of the robotic arm an Android application was developed with an intuitive user-friendly interface. The communication between the robotic arm and the Android App is established through Bluetooth protocol. The control of the robotic arm is executed by a custom program on an ATmega328 microcontroller.

1. Introduction
Organic photovoltaic technology has received increased attention due to its promising qualities, such as the processability of solutions, their adjustable electronic properties, the manufacture of low temperatures and the use of cheap and light materials. While many other photovoltaic technologies are more efficient, organic photovoltaic cells remain advantageous because the toxicity of the materials used, the production costs and their impact on the environment is low. So far, organic photovoltaic cells and maintenance are set in terms of efficiency, which is 13%, reaching almost the efficiency value obtained with low-cost silicon solar cells [1].

The first step towards the mass production of organic solar cells is the choice of the right technique for depositing the organic compound on the desired surface that offers a high yield and low production cost. The main factor that makes photovoltaic technology so attractive is the potential for Roll-to-Roll processing on low-cost substrates, through standard coating and printing processes. Several techniques for printing or coating organic solar cells were established and demonstrated on a laboratory scale. These include inkjet, offset, engraving, mold, rotary coating and more. Each technique has certain advantages and disadvantages, which makes a technique more attractive in certain conditions than others. The next step is to transfer the knowledge developed in the laboratories to an industrial scale of Roll-to-Roll production [2].

The most used deposition technique for manufacturing laboratory scale devices is rotary coating, which is not compatible with the Roll-to-Roll type of production. However, rotating coating is still widely used to study and understand the fundamental principles of organic solar cells [3]. The spin coating process is done by placing ITO treated glass sheets inside a spin-coater device. While the device is rotating the glass sheet at different speeds and time periods, an organic compound is released on top of it which is spread in a very uniform, thin and pattern less manner. After completion
of the rotation process, the cell is extracted from the device and moved to an area where the excess of the organic compound is wiped. Subsequently an aluminum or silver electrode is deposited by PVD (physical vapor deposition) technique onto the organic compound [4].

In all these processes the glass sheets must be handled with extreme care because the organic compound is extremely fragile. Since the organic compound and the electrodes are deposited on their surface, the probes can only be trapped in certain areas so as not to damage the deposited layers. Currently, in the process of manufacturing the organic solar cells, these are manipulated using metal tweezers. Given the level of fragility of cells and any human errors that may occur during their movement, there is a very good chance that mistakes will occur that can lead to premature cell destruction.

To combat this, we proposed for their manipulation a robotic arm [5-9] controlled remotely by a custom developed Android App through a Bluetooth communication [10]. This method avoids the use of tweezers, and thus considerably reduces the risk of cell damage during the manufacturing process.

2. Design and implementation

The block diagram of the proposed robotic arm system is presented in figure 1, which expose its operation. The user can enter the manipulation data in the mobile application, which is transmitted via Bluetooth to the ATmega328 microcontroller. The microcontroller is incorporated on an Arduino Nano development board. The electricity needed to operate the entire system is provided by an external 5V power supply, which connects directly to the Arduino board, the Bluetooth module, the servo motors and the vacuum pump. With the facilities given by the microcontroller, the data transmitted by the user through the application is interpreted and transmitted to the robotic arm.

![Figure 1. Block diagram of the system.](image)

Based on the block diagram we started out the design of the electronics needed to control the robotic arm. The schematic of the entire electronic system was implemented in Eagle CAD and presented in figure 2 (top). To have a complex control on the robotic arm we considered four servo motors: one for the horizontal movement (waist servo) and three for the vertical movements to mimic a human hand (shoulder/elbow/wrist servo). Digital pins 5 to 8 of the Arduino board were used to transmit signals to the four servo motors. For a finger style action of the robotic arm a vacuum pump was considered, that is controlled through digital pin 9 on the Arduino.

Knowing that the glass probes are weighting a few grams we choose a small vacuum pump, which works with a voltage of 5V. Since it has only two connectors, we decided to control it with a BD243 NPN transistor. The transistor is fed into the collector, the signal is connected to the base of the transistor and the positive terminal of the vacuum pump is connected to the emitter.
The entire circuit is powered using a jack connector and a power supply that is connected to a wall outlet. The power supply provides a voltage of 5V and a current of 4A. The PCB level implementation was conducted as presented in figure 2 (bottom).

![Robotic arm: Eagle schematic (top), final PCB (bottom).](image)

The design of the robotic arm was done in SolidWorks CAD. The robot has been designed to be easy to implement, use and maintain. Inside the base of the robot (figure 3-left), which also acts as an enclosure, there is a place of approximately 11cm x 8.5cm in which all the electronic components will be positioned. Along the two arms of the robot, a channel was created through which the wires from the servo motors and the tube for the suction cup can be pulled. This channel starts from the vacuum pump. The use of this channel reduces the risk of damage of the wires while using the robot. At the same time, it gives a more compact and pleasant appearance. The robot has six main parts (figure 3-middle):

- The electronics enclosure, which will be attached to the work surface, to provide stability and contains a servo motor, the vacuum pump and the PCB;
- The lid, which can be easily removed to access the electronic components inside the enclosure;
• The rotating base, on which the rest of the assembly is attached. This rotating base is mounted on a servo motor that could rotate between 0 and 180 degrees.
• Two almost identical parts that have the role of the arm and the forearm;
• The tip, to attach the suction cup with which the organic solar cells will be manipulated.

All the parts were 3D printed in PETG (polyethylene terephthalate glycol) material which gives robustness to the robot.

Figure 3. Robotic arm: electronics (left), in homing position (middle), mobile app control interface (right).

The logic diagram in figure 4 represents the operation of the Android application developed especially for this project. The application was created using the Android Studio development environment together with the Kotlin programming language.

Figure 4. Logic diagram of operation for the mobile app.
In the first phase, the user reaches a home page, where he sees a brief description of the functionality of the application and has the option to go further. This first page can be seen in figure 5 (left). Subsequently, the application checks whether the Bluetooth is activated on the device that is in use. If it is turned off, the user is asked if he wants to turn it on.

After activating the Bluetooth, the user is presented with a list of all Bluetooth devices that were previously connected to that smartphone. It chooses the desired device, and the application goes to the next step, namely establishing the connection between the smartphone and the robotic arm. When the connection between the two devices is successful, the application reaches the main screen. From here, the robotic arm can be controlled using the buttons on this page (figure 3-right). The buttons are placed next to each robot joint so that the application can be used intuitively. Under each set of buttons there is also a label with the name of the servo motor operated by the respective buttons.

A side menu was implemented on the main screen of the application (figure 5-right), which is accessed using the button next to the page name. Once it is pressed, the user can see additional functions of the application:

- The “Disconnect” button is used when the user of the robotic arm wants to end its activity. Pressing this button will move the robotic arm to a neutral position and the connection will be broken.
- The “About” and “Help” buttons in the “Info” section give the user the opportunity to learn more about the application, either about its role and functionality, or about how to use it.

3. Experimental results

The robotic arm controlled by the Android App was tested in OSC manipulations for proper placing of the probes into the matrix substrate, which was introduced after that in the PVD chamber. A view of the robotic arm operation for this purpose is presented in figure 6.
Figure 6. Robotic arm in action with OSC manipulation.

4. Conclusions
We presented the design and the implementation of a robotic arm for OSC manipulation. The design incorporates three main parts: electronic design, mechanical design and dedicated software application design for mobile devices to control the robot. The robot mimics a human hand movement. The implementation of the robot was a real success, proven by the laboratory testing for OSC handling where the probes were moved from one place to another well-defined spot. The Bluetooth control permits the usage of the robot in different areas where it would be very hard to handle small elements with the human hand, like inside of a glove box. Soon the application will be extended to automatize the artificial solar measurement of the OSCs.

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Acknowledgements
The present work was accomplished by the support of the grant “REGRENPOS” PN-III-P2-2.1-PED-2019-2601, founded by the Romanian Ministry of Education and Research.