Automation of the Conductive Ink Synthesis from Recycled Parts from Metallurgical and Chemical Residues Joined to Polymer Resin and Solvent

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Abstract. Conductive ink is a modern method for making printed circuit boards (PCB’s), with new and somewhat different properties such as electrical conductivity, adhesion on non-conventional surfaces (glass, wood and paper) and the printability it possesses. However, such technology is cost and limited access given the machinery needed for the synthesis of ink and the tax on our currency. This situation leads to an increase in the technological gap between developed and developing countries. Therefore, the objective and motivation of this work is to present InkCo, a machine that automates the process of synthesis of conductive ink from metallurgical and chemical waste of the region. Understanding that through automation, virtual CAD modeling and materials science it is possible to develop the objectives of sustainable development (ODS) 4, 9 and 12, which seek innovation in industry and responsible consumption. Based on these ideas, InkCo is a mechatronic technology product that seeks to reduce this technological gap, through the implementation of rapid prototyping technologies (3D printing, laser cutting and prototyping of controlled circuits), for its structural construction, and thus generate an input (conductive ink) that can be used for the creation of more unconventional technology (3D printing of amorphous circuits on dielectric surfaces).

1. Introduction

In the context of the construction of electronic and some electrical devices, different types of physical arrangements have been developed for their connection and subsequent fastening. The product of this development has been called PCB (Printed Circuit Board). The development process of these boards is very complex. This complexity lies in the need for very specific knowledge, for example, mechanics, in cases where the process is by removal of chips, or chemistry, if lithographic methods are used for burning and developing circuits. On the other hand, the inputs required to produce a PCB are geometrically formal elements of a material similar to copper sheets on a normally thermostable polymeric layer such as Bakelite. Therefore, the new ways of creating electronic or electrical devices are of little variety in their geometric arrangement due to the options that exist. Currently, in order to design and produce an innovative electronic device, we are looking for elements that help to achieve physical arrangements for much more flexible connections and in shorter times. In addition, bearing in
mind that in order to make each of these so-called PCB’s, resources are needed, such as copper as a conductive element, polymers, or other inputs according to the manufacturing method, such as, for example, machinery or chemicals in the case of the developing method. It is imperative to seek new ways to manufacture PCB’s with a low cost in raw materials and meeting what the current environment demands.

However, there are alternative processes that allow the production of PCB’s with better characteristics than traditional processes, one of them is conductive ink. This process allows the realization of rapid prototypes [1] on any type of surface, as long as it is possible to permeate with this ink, giving solution to the needs of flexibility and time. The knowledge required for the use of this good is little, and for this reason it is a good ally. On the other hand, this ink opens a door to innovation in the environmental field, given that the elements for the creation of this ink are a waste of the metallurgical industry and these can be taken from different sources such as steelworks or metal-mechanic workshops [2, 3].

Bearing this in mind, it is proposed to create a machine designed to obtain a product that emulates the conductive environment of electrical signals, which is no more than the emulation of the copper layer in conventional PCB’s. For the emulation of the polymer we can use any surface that allows it to be permeated by the ink and create a bond as does the Bakelite (thermostable) with the copper layer.

Therefore, we will present the parameters under which InkCo must work in order to obtain a conductive ink synthesis, the general requirements of InkCo for its operation where its materials and work inputs will be explained, the design that was made in computational design [4] according to the defined parameters required for operation will be presented, and finally the results obtained from InkCo with its conductive ink synthesis process.

2. Parameters for InkCo’s Work

InkCo is a machine that automates the process of conductive ink Synthesis from recycled parts from metallurgical and chemical waste, together with a polymeric resin and a solvent. Therefore, it is necessary to keep a check on the parameters, depending on these needs, the variables that affect said synthesis are presented, taking into account that later these variables will become parameters that can be varied from the software (app development) that has InkCo. Therefore, the variables that affect the automated process will be defined by, Amount of material [gr], mixing time [s], hierarchy in the mixture [list], Temperature [°C] and relative humidity [%]. Taking these variables into account, the reasons for the importance of each one will be explicitly explained, taking into account that some items have already been dealt with in other InkCo publications.

![Mixer Tank](image-url)

Figure 1. Mixer Tank.
(i) Quantities of material [5], this variable allows us to govern the final characteristics of the conductive ink, such as the max conductivity, adhesion, and viscosity of the conductive ink, these characteristics can be obtained by mixing the four elements that are part of the conductive ink, since each one can be graded according to the desired quantities [gr] for a defined composition or to be experienced.

(ii) Mixing time, this variable allows us to carry out the homogeneous mixing of the conductive ink since this variable governs the InkCo subsystems that are between (dosing, mixing, grinding and dosing), which are the automated processes in InkCo, this automation makes use of the variable time for mixing.

(iii) Hierarchy in the mixture [6], this variable is of type list since the order at the time of the mixture if it affects the properties that can be obtained in 30%, therefore, it is advised that the order is governed from liquids to the ceramics is (solvent, base, metallic and ceramic powder). However, the user can make an experimental change to obtain new or better mechanical properties [7] that he considers appropriate.

(iv) Temperature and relative humidity, are variables to be taken into account given by the inputs contained in InkCo that are classified from solvents to ceramics, that is, we need a controlled environment to obtain a conductive ink with a high repeatability every time you want to make said mixture. Therefore, sensors are located around the machine that monitors the environment and control it by means of actuators and keeps it within a working range suitable for inputs and for InkCo.

2.1. General Requirements

Within this section, we will analyse the InkCo systems, understanding what are the needs for automation in terms of actuators and sensors, as well as the requirements for controls that allow you to comply with the InkCo operating parameters, so we will start with the subsystems of InkCo, these subsystems are divided in feeding, mixer, grinding and dosing, which has the function of containing and carrying out the process of conductive ink synthesis through actuators, event-controlled mechanisms and signals sent from a micro-controller. These subsystems have the following functions.

(i) Feeding: contain the necessary supplies to carry out the conductive ink in four containers designed for this function.

(ii) Mixer [8]: make the first mixture of the inputs to join the different elements in an aqueous state that contains the four elements.

![Figure 2. Feeding System.](image-url)
(iii) Grinding [9, 10]: it has the function of homogenizing the mixture through the crushing and compaction of the four elements thus obtaining a homogeneous conductive ink.

(iv) Dosing: this subsystem helps us to continue mixing the homogeneous mixture preventing it from drying out and at the same time delivering an amount in [ml] desired by the user.

On the other hand, the conductive ink mixture has infinite form of realization, however InkCo is based on the concept of common ink that is made with a base (resin) and a pigment (colour) that are mixed until obtaining a homogeneous mixture with the desired viscosity. Therefore, it is clear that the actuators and mechanisms are fundamental for this function of conductive ink synthesis, mainly the actuators used are DC motor reducers [11], which are controlled by a relative encoder to control the rotational speed and angular position of the same. Finally, the sensors used are constituted between end of stroke, temperature sensors and finally a time sensor.
2.1.1. Materials This section covers the materials necessary for the construction of InkCo and conductive ink with emphasis on InkCo since there is documentation on the conductive ink of InkCo [12]. InkCo is built mainly on the basis of rapid prototyping technologies such as 3D printing and laser cutting [13]. Therefore, most InkCo parts are made of PETG (a material that possesses the properties of PET and ABS that are considered as engineering polymers), which has mechanical properties suitable for the realization of mechanisms that transmit mechanical energy or that contain liquids such as the nearest similar to water bottles made of PET.

With respect to this the pieces of InkCo are made in 70% of PETG, and in 20% in laser cut with Inputs from MDF to aluminum 6061 sheets that has a hardening given that there are pieces that require a rigid structural element for grinding[14], and the remaining 10% in steel elements such as bearings, screws and motion transfer coupling joints[15].

![Figure 6. Interaction of the different materials in InkCo.](image)

In the case of InkCo, a mixture of four elements defined as follows was used:

(i) **Base**: It is the medium that allows the combination of the elements that make up the ink, as well as the subsequent homogenization of the mixture; for this element was used an input that has the properties of a resin, regardless of whether it is natural or synthetic [13]; for this case, a fast-drying nail varnish was used, since it is a highly commercial and affordable synthetic resin.

(ii) **Powder** [16]: Metallic input that is in a pulverized state, responsible for providing the electrical properties to the mixture, is usually obtained in highly expensive processes such as sintering, however there are more economical and sustainable sources of this input as the waste generated by processes such as the volumetric conformation of iron foundries made in steel mills, waste generated by processes of removal of chips (chips or metallic dust) to this same type of foundries, and the waste generated in the polishing process in metallic materials, the latter 2 sources usually seen in workshops of metal-mechanics, the latter 2 sources usually seen in workshops of metal-mechanics, however there are more economical and sustainable as the waste generated by processes such as the volumetric conformation of iron foundries made in steel, waste generated by processes of removal of chips or metal dust to this same type of foundries, and the waste generated in the polishing process in metallic materials, the latter 2 sources usually seen in workshops of metal-mechanics.

(iii) **Mineral**: Sedimentary rock, preferably ceramic, which provides hydroplasticity to the mixture, as well as the viscosity of an ink itself, given that its mechanical properties such as density and adhesion correspond; in the same way this mineral establishes other properties (mechanical, thermal, electrical and physical) inherent to its constitution, for this reason, the ink has 2 carbon inputs thanks to its good properties for the purpose of the ink, the first obtained from the transformation of CO2 pollution from gasoline vehicles into carbon (KAALINK)[12] and the second obtained from the nucleus of conventional alkaline batteries.

(iv) **Solvent**: It is the substance that allows the union between the base, the powder and the mineral that allows to obtain a “paste” that will be later ground by InkCo’s grinding rollers.
3. **InkCo Automation**

Automation of InkCo is the most important point of development and methodology, given that this point depends on the whole process and therefore developed a scheme that allows us to observe the actions performed by InkCo for the synthesis of conductive ink. In function of this scheme we developed, all the dynamic models and of movement necessary for the temporal control and by variables previously raised for the correct synthesis of the ink, in function of this we will announce a few points.

In this subsystem we have elements that require dosing the four materials therefore, we designed massive division systems such as the ratchet and a bite valve for liquids, so that the volumetric control of the liquid is for the opening time of the valve through a servo motor, and the volume control of the ceramics is through the angular position of the ratchet as shown.

On the other hand, the subsystem of mixture is the main one in receiving the inputs in first instances therefore this system must realize angular displacements to fulfill this task, in function of this idea it is necessary to understand that it is realized by means of a train of gears controlled by the angular positioning of a servo motor, which has very clear events that are governed by final sensors of race. With the objective of indicating which is the rotation limit given that he must execute two movements at the same time one rotating before Z and the other rotating before Y.

![Image of Mixing Subsystem]

**Figure 7. Mixing Subsystem.**

### 3.1. Systems Dynamic Control

Therefore, the design of the state machine that performs the InkCo automation is governed by binary configurations, which usually ask if a process has finished to continue with the other, although there are also tasks in parallel to optimize the processing time.

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On the other hand, the subsystem of zirconium[9] mixture is the main one in receiving the inputs in the first instance therefore this system must perform angular displacement to fulfill this task, depending on this idea is necessary to understand that it is done by a train of gears controlled by the angular positioning of a servo motor, which has very clear events that are governed by final sensors of race, in order to indicate which is the limit of rotation given that the must execute two movements at once one rotating before Z and the other rotating...
4. Results and Discussion
The conductive ink obtained from InkCo, is an ink that meets the basic requirements that are encountered in the market, for example that for 30cm does not have more or less 2Ω, such data and measures are exposed with greater clarity in the documentation related to InkCo ink [6, 7] [11, 12].

![Figure 10. Test of resistance measurement in the application of conductive ink InkCo.](image)

5. Conclusion
The development of Colombian technology that consumes inputs from our region, improve the innovation process that our country must face, through the use of rapid prototyping that helps us convert computer models into physical products that solve needs and in this case, give solution to the objectives of sustainable development since the innovation does not lie in the process but in how we get the same product making an analysis of the materials held in the region, in addition InkCo can help the equal knowledge among equals is a reality given that the commercial value of InkCo is zero because it is an open source development.

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