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DEVELOPMENT OVERVIEW OF A SMART CUSTOMIZABLE PRODUCT

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Abstract: *This paper presents the development phases of a smart product that can be manufactured on a cyber physical production system. The intelligent product's requirements are defined from the manufacturing perspective and then converted into technical product characteristics. Finally, we refined the technical characteristics to create a functional tablet with customizable hardware functionalities as a customizable product.*

Key words: Smart Product, Cyber Physical System

1. Introduction

In the future digitized or super smart societies (e.g. Society 5.0), all things surrounding us will have a degree of intelligence and customization which will allow unprecedented human-machine/computer interaction and collaboration in all sectors (e.g. education, healthcare, manufacturing etc.).

Every day products embed more and more communication and computational capabilities, allowing them to exchange data with each other or interact with their human users. At the forefront of development are compact devices such as mobile devices (i.e. tablets, smartphones). Challenges, on one side, are to offer an overall meaningful experience when using them. On the other side, a big challenge is to enable cost-effective lot size one production [1]. To meet requirements for both cases, the current trend in automation and data exchange as described in Industry 4.0, the product will play an active role in its manufacturing (e.g. active in terms of manufacturing process selection, information storage of production parameters etc.) [2] and its adaptation to offer a meaningful overall experience to a broad spectrum of users that enables.

In this paper we present the first development phase of a smart product in form of a customizable tablet that allows games to be played on a single or on several similar devices. Its design allows manufacturing of each order that is not restricted to a single manufacturing recipe. The tablet can be customized by choosing from different combinations of both functional and chromatic modules. Active implication in the manufacturing process, is not focused in this paper.

Using the personalization and easy-to-use interface developed within the DiFiCIL research project [3], the user has the ability to select 6 combinations using 3 types of peripheral modules: Bluetooth speaker, portable flashlight and power-bank. Thus, the user has a large spectrum of customization and is indirectly engaged in the production planning being involved in the product's configuration process, having to select its desired product formation (e.g. modules variation, chromatic choices, engravings or preinstalled software applications). The term easy-to-use is also available for the tablet's software interface, meaning that the entertainment applications installed on it can be used even by small children.

The customization will be done through a production system that contains a decentralized decision-making architecture. This architecture will contain multi-agent transporters named AGVs (Autonomous Guided Vehicles), collaborative robotic arms for manipulation, multi-axis CNC for personalization (e.g. engraving and milling, etc.), all integrated in multiple so-called "plug & produce" production system modules [4]. These production system modules will be manually combined (by the production system planner) in many matches possible depending on the client's requirements. Once assembled, the production system will adapt to the client's

needs by constantly calculating and processing its production stages and confronting possible hazards (e.g. the collaborative robot tries to detect if it manipulates a defective tablet display).
The tablet and its external modules will be pre-manufactured with all the electronics and software required for them to work once assembled and will be separately stored in a buffer cabinet located in a buffer-carrying production system module. A collaborative robot will pick the required components chosen by the client and will place them on the AGV, then in a predefined or calculated way, the transporter will find its own way to the next required production process.

2. Methodology

The product's idea came from the need to develop a smart product that is suited to be fabricated on a cyber physical system. In order to achieve this, we had to develop a product that permits its end user to customize it thus, implying that the manufacturing system has to self-adapt to the customer's preferences. From those requirements we came up with a product capable of offering entertainment applications to people aged between childhood and adulthood. Interactive games usually use the possibility of joining the tablets together in a way that the integrated NFC antennas can communicate with each other. An example of an application consists in an interactive Pong game in which 2 people can couple 2 tablets together and move the ball from a player's tablet to the other. Another example is a Ticktacktoe game that requires 9 tablets connected in a 3x3 matrix. A characteristic of the product is its case material colour setting that the user can choose. This feature grants an attractive designing tool that appeals more for small children or even adults.

Based on the general requirements the product must respect (an interactive way for the user to be entertained by the product and a systematic correlation between the product and the production stages) the whole design process has been separated into two main levels: mechatronic development (mechanical, hardware and software) and the planification of the fabrication process so that it can be produced on an intelligent manufacturing system.

The mechanical and electronical development phase implies studies on the physical aspect of the system and the laws of physics that it must respect in order to function in the required way. For example, the electronics of the tablet must maintain certain levels of electric voltages on specific functional blocks, or the whole electronic main-board must respect certain dimensional gauges to tightly fit inside the tablet's plastic case.

As for the software part, the project is focused around the idea that the tablet has a certain user behaviour which is offered, for example via the visual feedback display, or on any of the modules that is connected to the tablet. We also kept in mind that the product must be assembled on an industry 4.0 compliant manufacturing system.

2.1. Mechanical design

The smart product that we intend to produce is comprised from a 7-inch tablet (Figures 1 and 2), an inter-connection hub which offers the possibility of adding 6 different modules (Figures 4, 5 and 6) that can alter the product's applications.

After the electronical requirements were defined the product's design was completed and 3D modelled in CATIA CAD software [5]. With this resulting 3D model, we could verify if all the components can be properly assembled and simulate the manufacturing process in order to identify if there are any components that cannot be obtained with traditional fabrication technologies (e.g. CNC milling). The first step of the mechanical development process was to create a 3D prototype using additive manufacturing. This prototype is only a "dummy" version of the product, used to test the mechanical conformity.

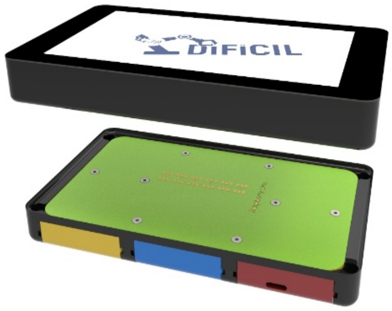

Figure 1.Tablet CAD model

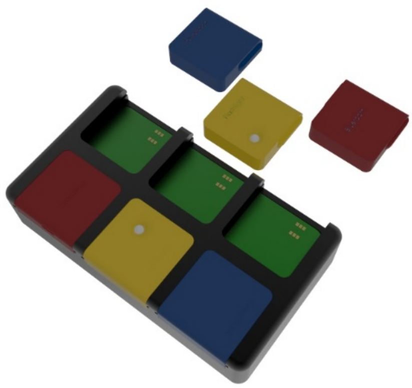

Figure 2. Modules and hub CAD model

Beside its functionality, the purpose of this product is to test demonstrate the advantages of a cyber-physical production system. In order to achieve this, the main characteristic that our product has to fulfil is that it must be highly by the end-user. The product's customizable feature comes from the possibility of varying through three types of modules that can be inserted into the hub's slots (Figure 6): a power-bank, a flashlight with incorporated battery and a Bluetooth speaker with incorporated battery. Each module can be inserted in any of the 6 slots from the hub and can communicate with the main tablet. In this way, the end user can control different states of each module, independent of the slot position. Additionally, each module has a stand-alone function and each one is chromatically customizable, and it can also be personalized with engravings.

2.2. Electronic design

The main implementation idea orbits around the adaptation of an existing powerful logic processing unit to use extra features that offer physical feedback to the user. In this case, those extra features are represented by the six modules that can be inserted into the hub and the near field communication (NFC) ability that enables the interaction with other identical tablets. Constituting the main component of the product, the tablet is comprised of different components: the case, the 7" capacitive display, a Raspberry Pi module, a main-board and the NFC antennas. All the communication between the main processing unit and the peripherals except the display is done using the main-board as a gateway. The tablet's display has a capacitive touch and 4 Near-Field-Communication (NFC) antennas on each of the side walls of the case. The bottom face of the tablet contains connectors that make electrical connection to the inter-connection hub and finally to each of the 6 modules. The main schematic block (Figure 3) will describes the electronical design from a functional point of view. The power supply consists of 2-series Li-Po batteries that can be recharged trough a charging circuit from an external charger that usually has a 12V supply voltage. The supply distribution from those batteries to the rest of the circuits is divided into 2 voltage levels: 5V and 3.3V. In turn, 5V is divided into 2 categories: one 5V supply for the CPU and display and one 5V for the modules supply (through the SIM connectors). Each of those voltage levels has a step-down converter that drops the battery voltage of 8.4V to its respective voltage.

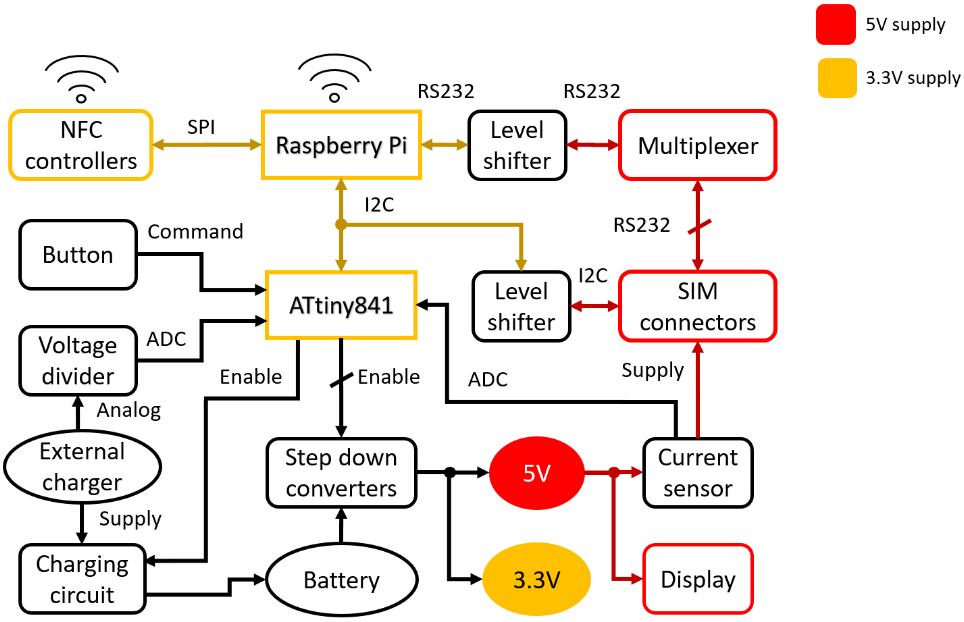

Figure 3. Electronic schematic block

The chosen central processing unit is a Raspberry Pi 3 model B module that has a processing clock of 1.4GHz with quad-core processor. It contains an integrated 1GB of RAM and various peripheral connections like USB, SPI, I2C, HDMI, Wi-Fi etc. It communicates with the modules through the integrated microcontroller called ATtiny841 (we shall call it Power Management IC – short: PMIC) and the 4 NFC controllers. It constantly makes a data transfer between the PMIC in order to find important information about the tablet's state like battery capacity, charging voltage, modules current consumption and commands received by the user via the push-buttons.

The PMIC controls and reads multiple peripherals inside the tablet. It constantly maintains a safe state for the tablet and avoids any hazards that the tablet might encounter. The user can turn on or off the tablet CPU and display and the modules supply by pressing a certain amount of time on the push-button. For an amount of less than 3s, the PMIC tells the CPU to turn off or on its display; for in-between 3-7s the PMIC toggles the modules' supply; for more than 7s the PMIC turns on the CPU and display or tells the CPU that it must turn off itself, so that the Raspberry can set its memory and registers right for the shutdown.

Various communication protocols are used between the CPU and peripherals, for example: SPI for the 4 NFC controllers, I2C for the PMIC and modules and RS232 for some of the modules.

2.2.1. *Power-bank module*

Depicted in fig. 4, the power bank module can be recharged trough a micro-USB connector mounted on the side of its case. It contains a battery charging IC and a boost converter that step up the battery voltage to a constant 5V supply to the tablet or the other modules. This module has a stand-alone functionality as a remote charger for electronic devices and incorporated into the product it offers extra battery life to the tablet.

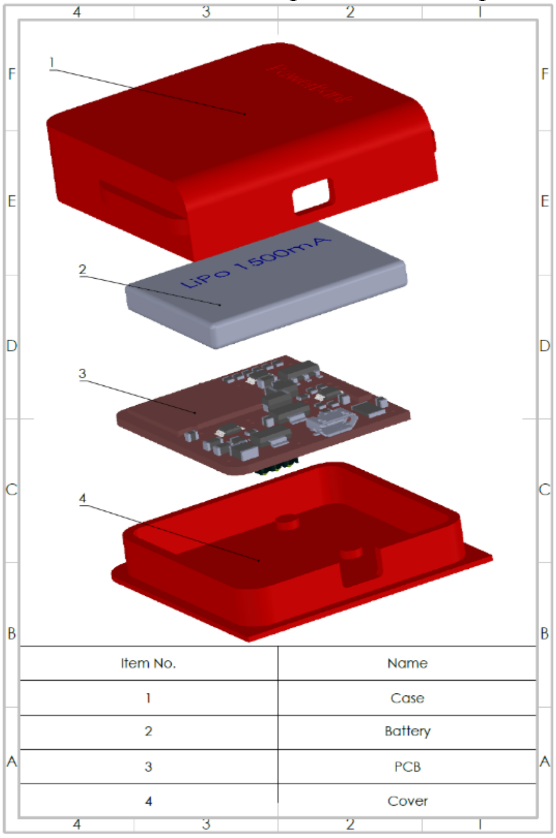

Figure 4. Power-bank module assembly

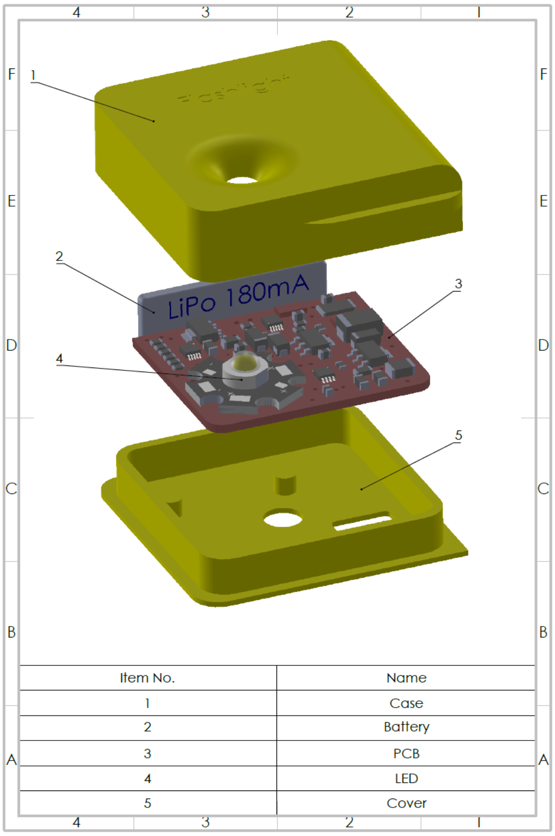

Figure 5. Flashlight module assembly

2.2.2. *Flashlight module*

Depicted in fig. 5, it contains an LED driver IC that controls the supply of the integrated power LED and communicates with the tablet via I2C protocol and a battery recharge IC. This module illuminates at an approximate 120m on a white color. It can be used as a flashlight or in the whole product assembly it can give various feedback to the user. (e.g. intermittent flashes when a notification appears).

2.2.3. *Bluetooth speaker module*

This module (fig. 6) can pair with the tablet either by Bluetooth, or by AT commands done by the RS232 protocol and can offer audio signal through its 12-bit DAC and amplifier. The module contains an internal battery so that it can be used separately from the tablet. Its battery can be recharged when inserted into the hub.

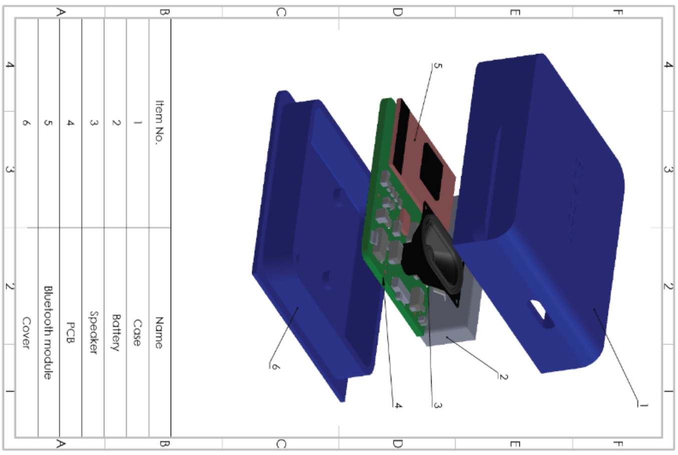

Figure 6. Bluetooth speaker module assembly

2.3. Software development

This unit has an operating system based on Linux environment with slight modifications (Raspbian) with which a programmer (user) can develop various scripts and programs using most common programming languages (Python, C Sharp, C++ etc.).
A functional source code is needed for the PMIC to manage the tablet's hardware state. This source code is developed, compiled and uploaded to the ATtiny841 through the AVR Studio 7 IDE. The algorithm that it follows is based on a state machine with many interrupts and flags as possible for it to eliminate eventual hazards that may appear during functioning. The algorithm can be interpreted using a flow-chart design (fig. 7). The scripts for the Raspberry Pi are developed using Python language in simple script command lines.

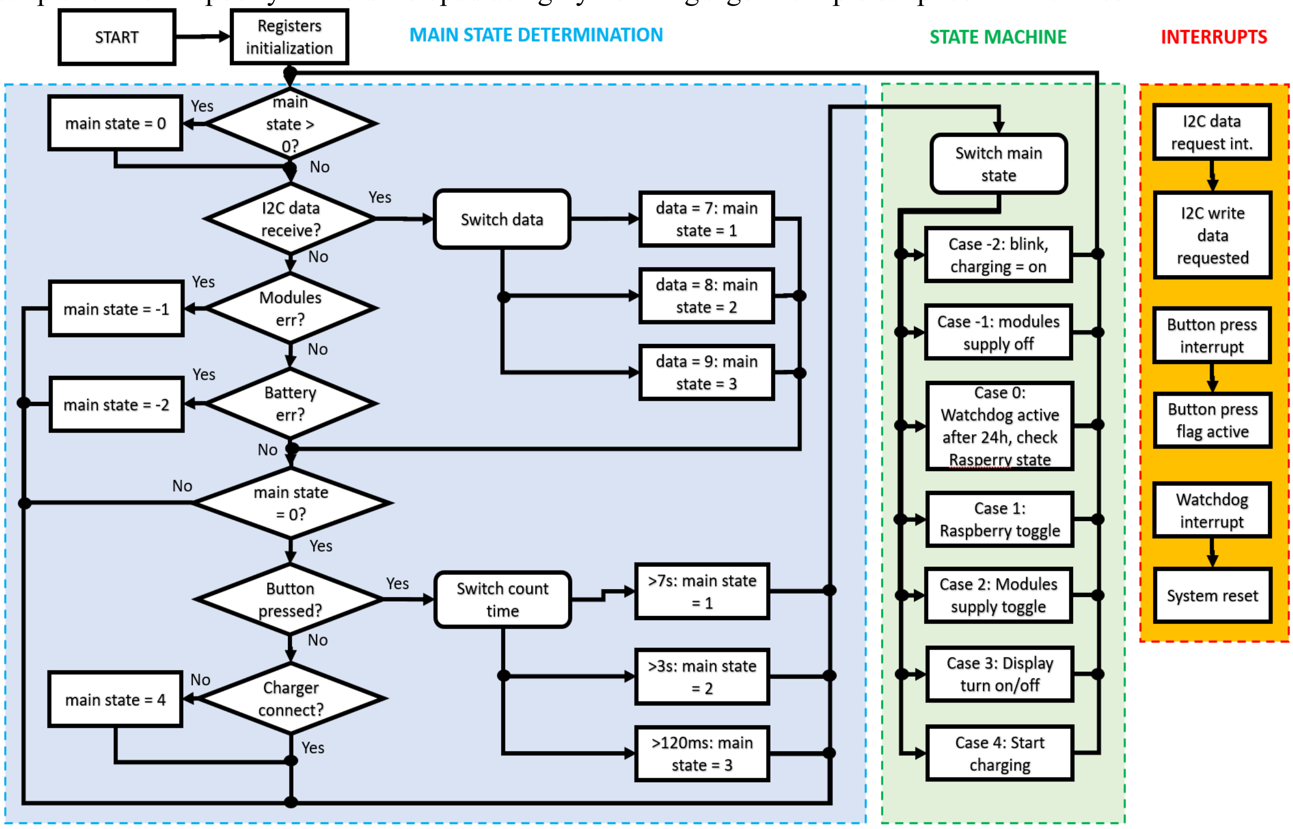

Figure 7. Power management code flow-chart

3. Results and discussion

After the stages of improvement and development, the whole assembly was put to a series of tests that can approve the current version of product. Those tests mainly consisted in: mechanical tests, electrical tests, behaviour tests.
Starting with the mechanical tests, they were mainly based on physical dimensions correspondence and the ease on how the whole product can be assembled. Some of the tests where for e.g. on how the tablet's internal circuitry and display fit inside the case or how easily a module can be inserted into the hub without any case damage. In other words, the user can assemble the modules by gently sliding them into the hub's slots and then mounting the tablet onto the latter one. The tablet and the hub are held together by 8 powerful magnets found on all the corners of the components (Figures 8, 9 and 10).

Figure 8. Top side of the tablet

Figure 9. Bottom side of the hub + modules

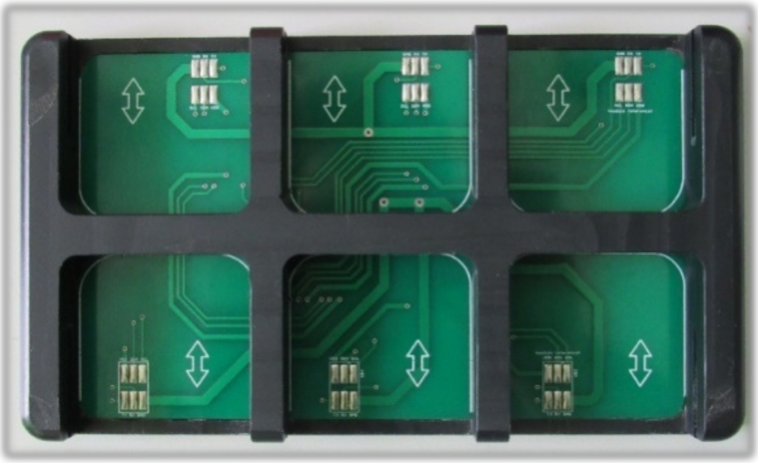

Figure 10. Bottom side of the hub

Following are the electrical checks consisting in electric signals tests done on the main-board and each module. Those tests can be separated into the following categories:

- supply voltage stability

The voltage converters found on the main-board and all the modules maintain a constant voltage in any normal conditions with a voltage noise at a maximum 300mV peak-to-peak.

- logic level adequacy

The Raspberry Pi and the PMIC communicate on a 3.3V TTL logic level, as opposed to the modules that use 5V. This problem is solved using logic level converter ICs mounted on the main-board.

- communication protocols compliances

The tablet communicates with the modules using one of the 2 protocols available (I2C or RS232) or with the PMIC via SPI. Wireless communication can also be in this category. The NFC drivers can communicate with MiFare cards at maximum 5cm (only with the tablet's plastic case as a barrier). If a tablet is to communicate with another tablet, the NFC range will be increased by a certain proportion, depending on the antenna′s alignment.

- sensors readings

The tablet can receive data from the PMIC regarding battery voltage and the electrical current that the modules consume.

- battery autonomy

The tablet's battery usually lasts around 2h if no power-hungry programs are running on the Raspberry Pi. This is affected also by the module′s current consumption. The flashlight module has an autonomy of around 5 minutes at full LED brightness. The Bluetooth speaker can last around 20 minutes at high sound volume. Finally, one power-bank module can improve the autonomy of the other modules by an approximate 70%.

- hazards avoidance

Some of the hazards can include the cases when there is a short-circuit on the bottom connectors of the tablet, or when the battery is almost empty, or the external wall charger has a voltage bigger than the nominal charging voltage etc. Those cases are avoided by this PMIC.

The behavioral tests are done in a more visual way, in a way that the product must offer the user some kind of feedback and read all his/her commands. The user can:

- control the flashlight's and Bluetooth speaker's state. He/she can set the LED brightness and can control the audio playback of the speaker once the modules are inserted in the hub. Those modules can also be used separately from the hub as a stand-alone module. The flashlight's LED can be turned fully on by pressing on a button mounted on the inside face of the case. The Bluetooth speaker module can be used as standard Bluetooth speaker by pairing it with, for example a smartphone.
- offer power commands via the integrated push-button. The user can turn on/off the modules charging state, the tablet and the display lock.
- read tags or cards and communicate with other tablets via the NFC controllers integrated into the main-board.
- play different kinds of interactive games between tablets.

4. Conclusion

From this study we have managed to develop a functional customizable product that can be produced on a cyber physical system assembly line. During this research we designed and validated the mechanical design of the product and also tested its electrical and software functionalities.

5. Acknowledgement

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