PlusMe: Transitional Wearable Companions for the therapy with children with Autism Spectrum Disorders

a European funded project

Deliverable 1.3

PlusMe product demonstrator

Work Package 1 *Engineering*
due at month 15 (30th November 2021).

Lead beneficiary: CNR
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Institute of Cognitive Sciences and Technologies, ISTC-CNR.

1. Overview of the deliverable

This deliverable reports the main features of the new *PlusMe* prototypes. More specifically two new devices, both based on the original *PlusMe* toy, have been developed to deal with several project needs.

The first one is the prototype developed by IMM-CNR (from now on *PlusMe-IMM*). It presents many hardware improvements, and represents the main technological output of the project. This device was developed from scratch according to industrial criteria (i.e., engineering of development process; use of standard schematics and electronic diagrams; production of standard blueprints, etc.), in order to obtain a “product” ready for a potential scale production, to be done by a professional high-tech company. This new device was then developed keeping in mind all the potential issues concerning a possible market exploitation, such as: safety of power supply; readiness of certifications for bluetooth and radio emissions; safety of materials, etc. It is important to note that this engineered prototype will be already produced in small scale (25 samples) within the related European project *IM-TWIN*[1], which uses the *PlusMe* toy within a wider technological system composed of several interacting components (more info on the dedicated website www.im-twin.eu).

The second one is the prototype developed by ISTC-CNR (from now on *PlusMe-ISTC*). This device has been developed in parallel to *PlusMe-IMM*, with the purpose to develop the new software (firmware of the device and software for the control App). This is possible as the core of both prototypes is the same: the ESP32 microcontroller. *PlusMe-ISTC* is then a sort of “bridge” between the original *PlusMe* (based on Arduino boards), and *PlusMe-IMM* (based on the more powerful ESP32 microcontroller).

PlusMe-ISTC has been developed also for a second important purpose, due to a project necessity. This prototype is easily replicable for a small hand-made production, carried out directly by the researchers, without the need to involve a professional company. The small scale hand made production (estimated in 6 devices), is necessary to disseminate *PlusMe* toys to other institutes involved in the treatment of neurodevelopmental disorders, with particular reference to Autism Spectrum Disorders (ASD).

The deliverable is structured in the following main sections:

[1] M-TWIN: from Intrinsic Motivations to Transitional Wearable INtelligent companions for autism spectrum disorder, Grant Agreement No. 952095, https://im-twin.eu/eu-legal-information/

- ***2. PlusMe* device, by IMM-CNR**: this section describes the new prototype developed by IMM-CNR;
- ***3. PlusMe* device, by ISTC-CNR**: this section describes the new prototype developed by ISTC-CNR and the new control App;
- ***4. X-8* device, by ISTC-CNR**: this final section briefly describes a new experimental interactive toy, based on the same hardware and software of the previous devices. The device is presented here as it shows how both the hardware and software work carried out on *PlusMe*, is adaptable and improvable in new interactive devices.
- ***5. Future development:*** this brief section present the last deliverable, due at the end of the project.

2. PlusMe device, by IMM-CNR

The prototype developed by IMM-CNR takes the concepts described in the confidential deliverable D1.2 *Engineering process of PlusMe*. The following subsections present a broad overview of the developed components and their assembly. Please note that some components are not described as confidential.

2.1 Architecture and hardware design

The main board architecture is shown in figure 1. The principal modules are:

- The Battery Management System (BMS) for power supply;
- The USB interface for system programming and debugging;
- The microcontroller module using the ESP32 module;
- The audio board;
- The SAM system interfaces for all Sensors and Actuators Modules present in the system.

The displacement of the various SAM-A and SAM-B modules, where sensors and actuators are placed, are shown in figure 2.

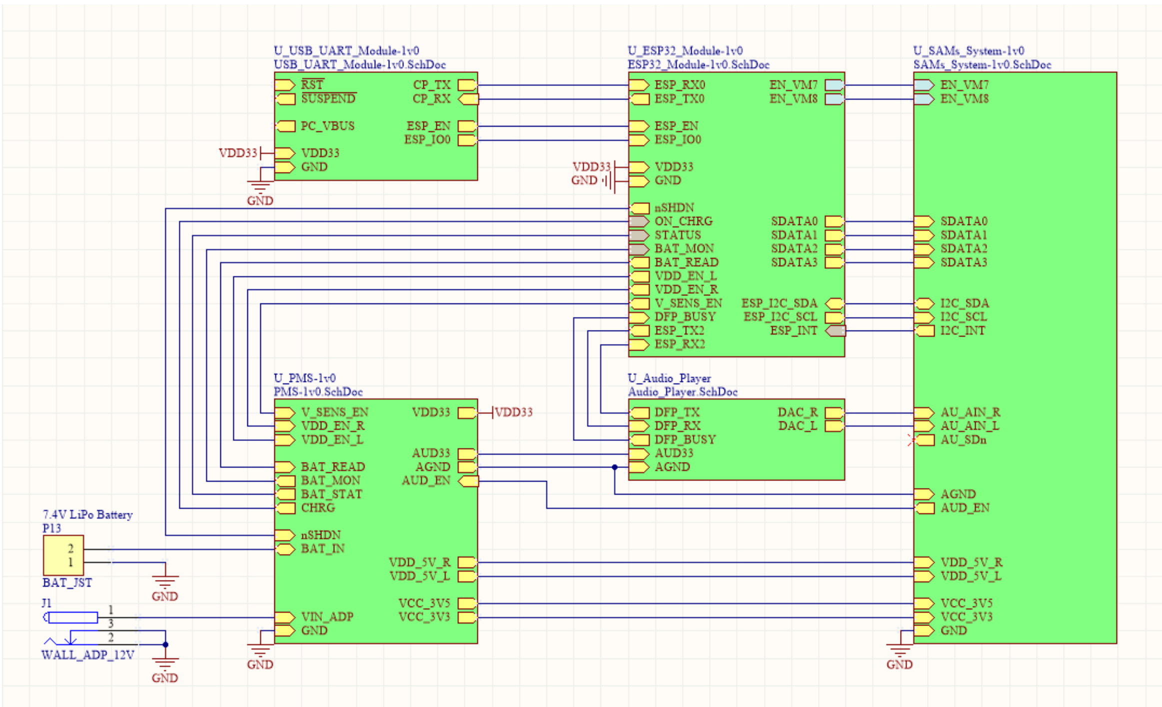

Figure 1. Main Board electronic architecture.

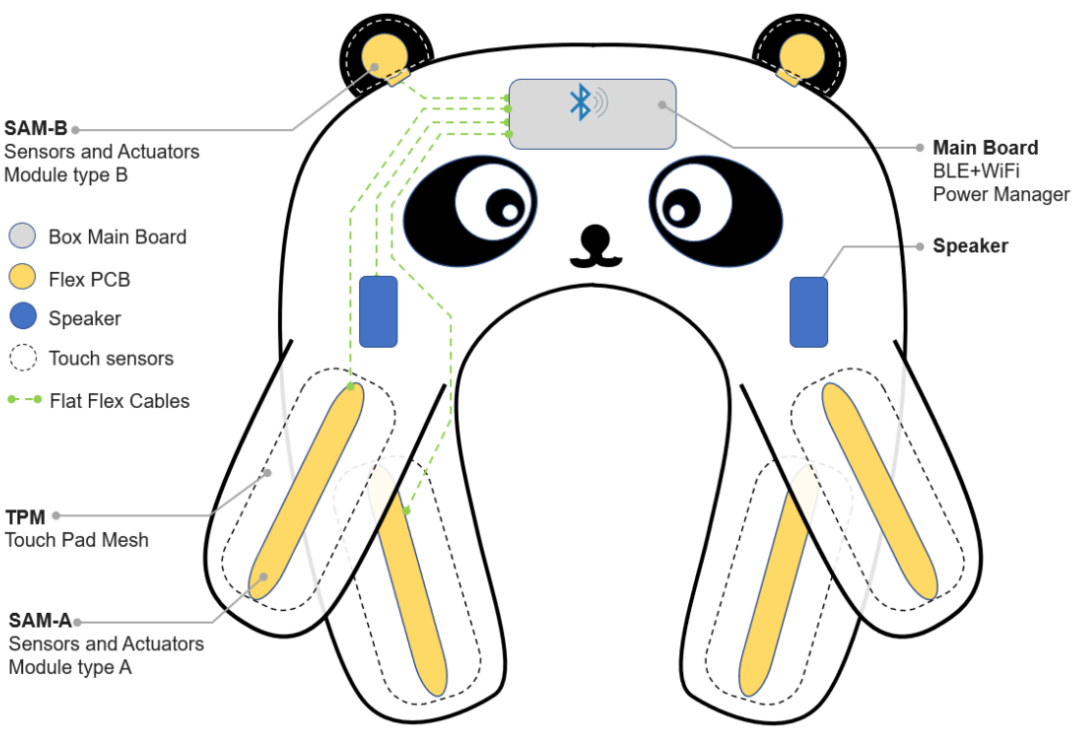

Figure 2. Concept of the system modules.

2.2 Main board layout design

This section illustrates the layout design of the main board controlling the PlusMe device. Figures 3, 4, and 5 show a preview of the final PCB.

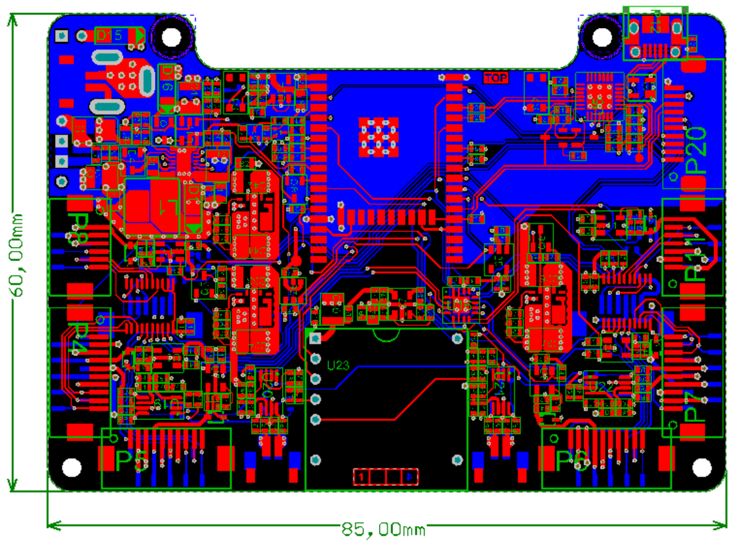

Figure 3. Layout and Dimension of Main Board.

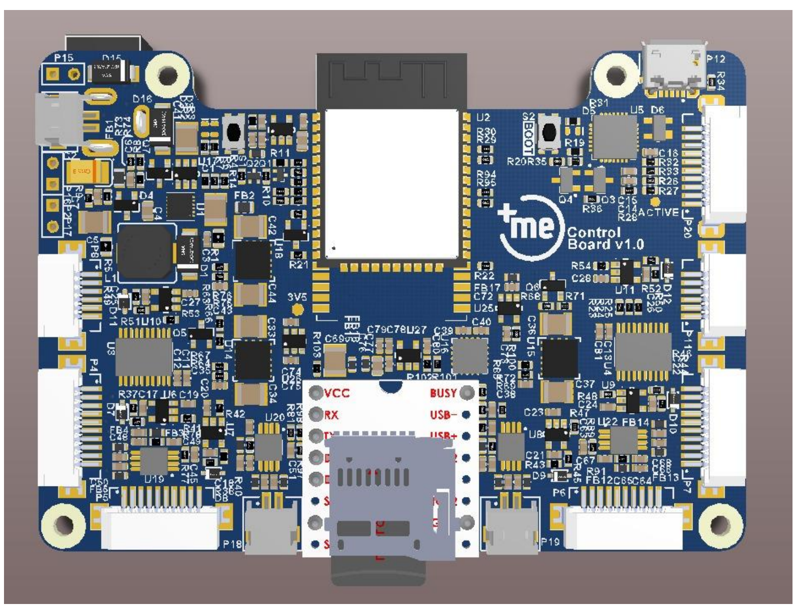

Figure 4. Preview of Main board Top Assembly.

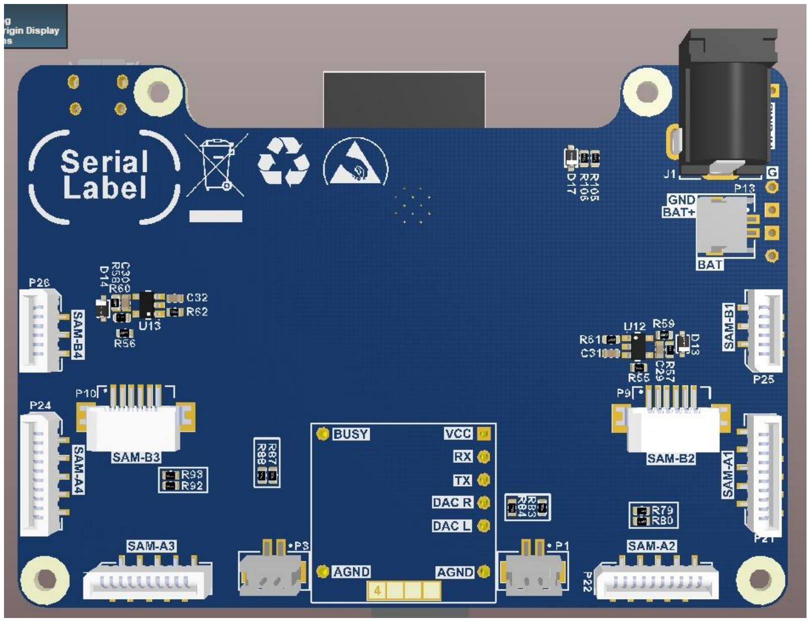

Figure 5. Preview of Main board Bottom Assembly.

2.3 Main board assembly

This section provides several images (figures 6, 7, 8, 9) of the final PCB.

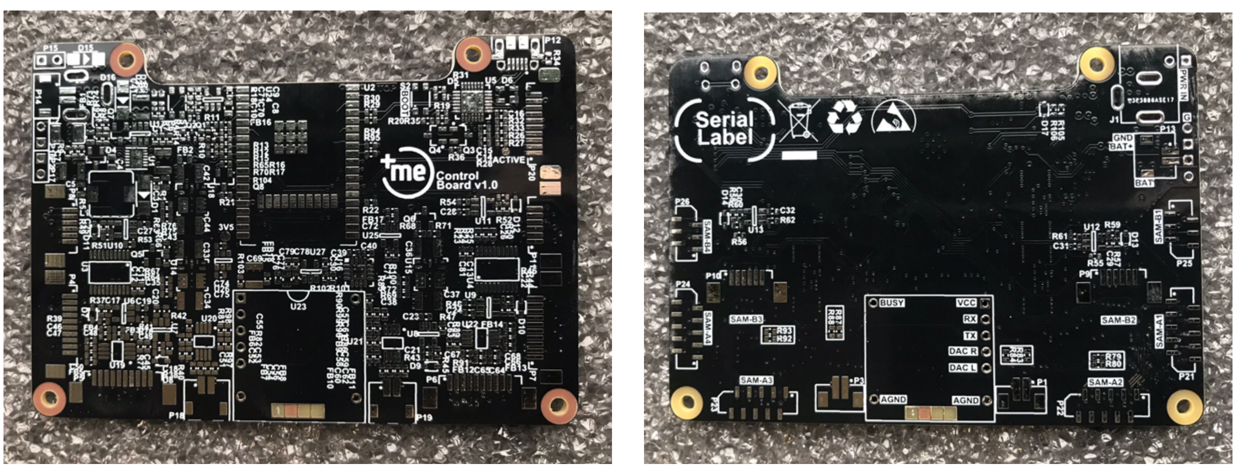

Figure 6. Top and Bottom PCB (not assembled).

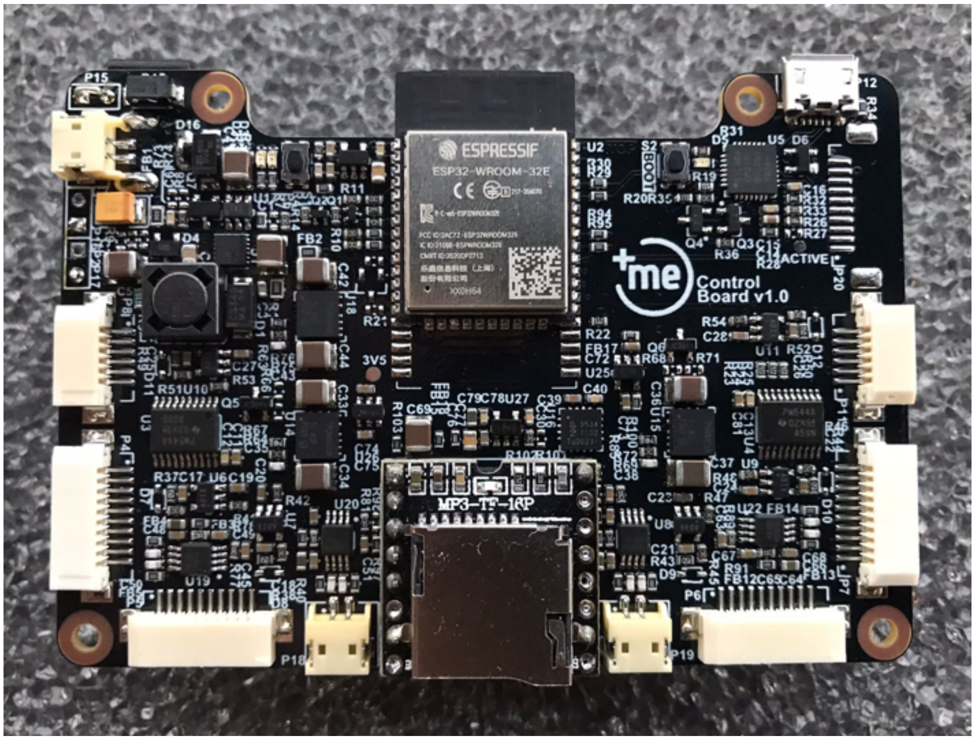

Figure 7. Main board Top Assembly.

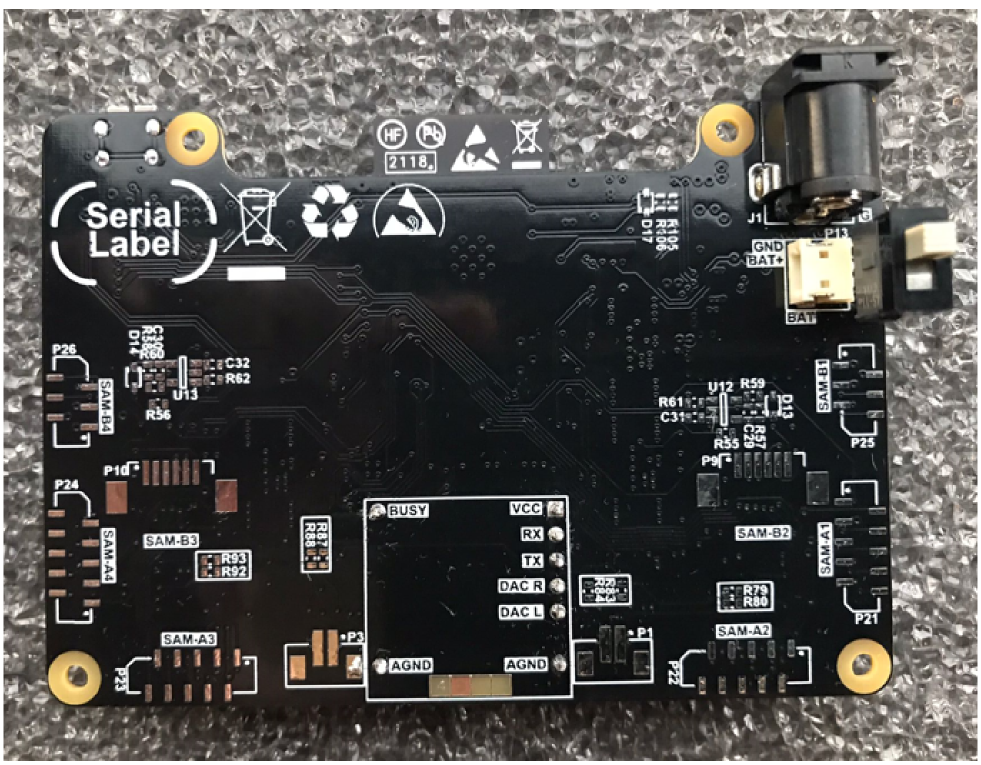

Figure 8. Main board Bottom Assembly.

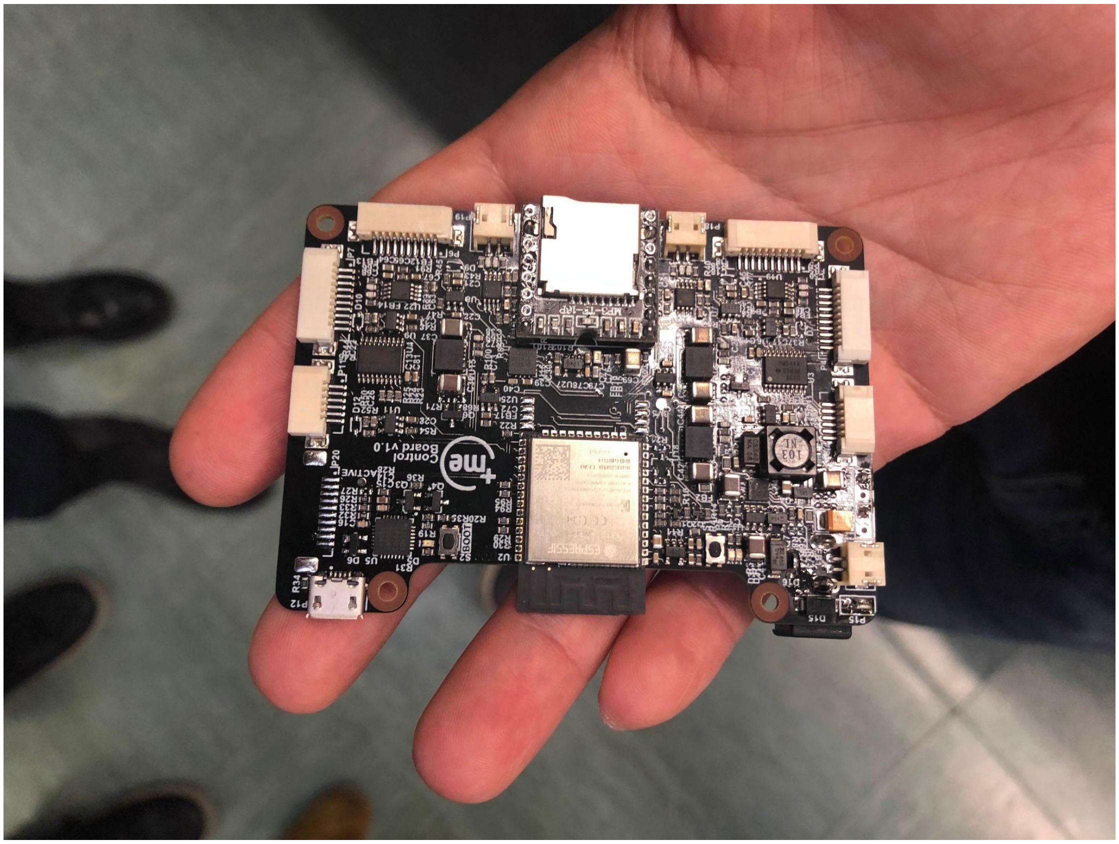

Figure 9. Real dimension of Main board. As shown, the engineering process allowed the miniaturisation of all components.

2.4 Main board box design

This section provides images of the protection box, which holds the PCB (figures 10, 11, 12). The box was printed in PLA with a 3D printer at ISTC-CNR.

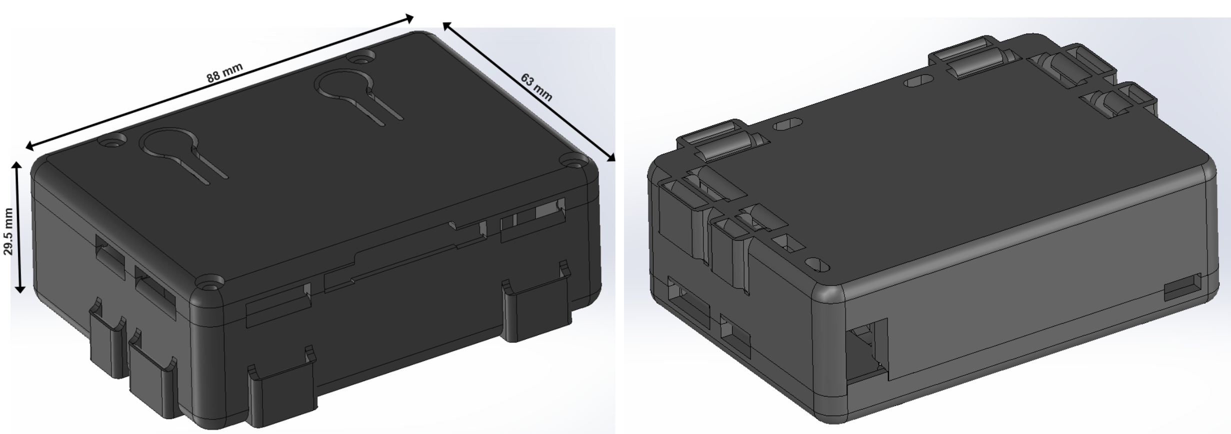

Figure 10. Design of the box for the Main board electronics.

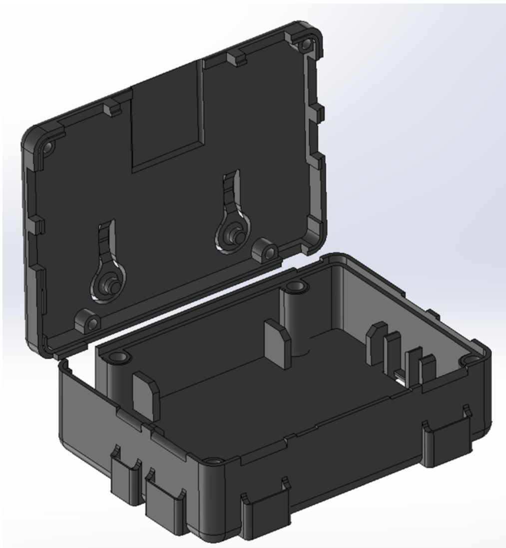
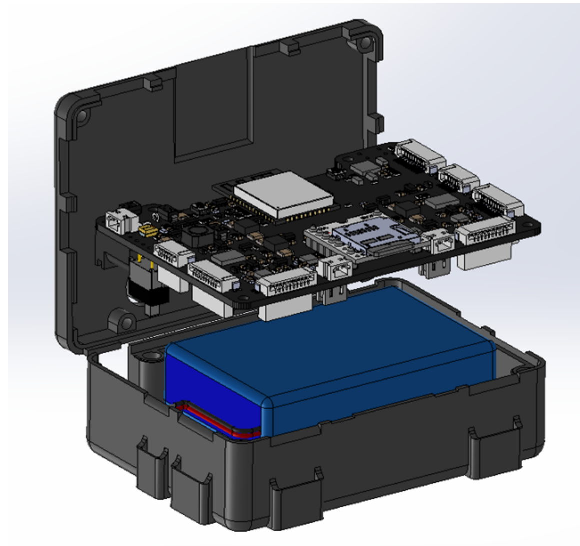

Figure 11. Inside view of the box for the Main board electronics, and exploded view of the Main Board assembly.

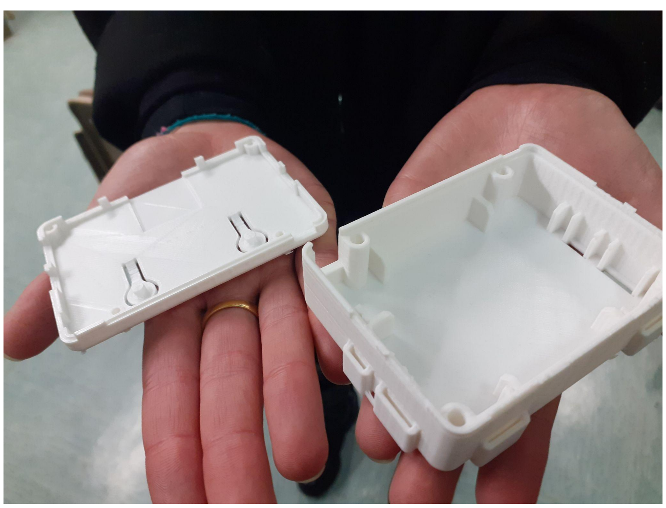
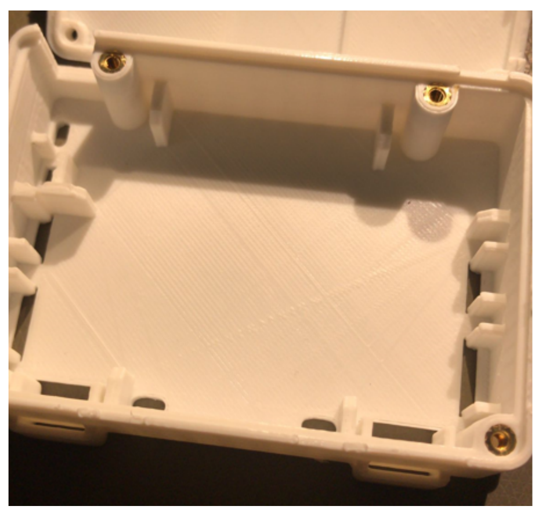

Figure 12. Realization of the box on left; on right screw inserts added in the plastic box.

2.5 Design of the SAM-A unit

This content is confidential.

2.6 Design of the SAM-B unit

SAM-B unit has been designed and created using a flexible printed circuit board. Figure 13 shows the layout of the SAM-B unit, and figures 14 and 15 show the realization.

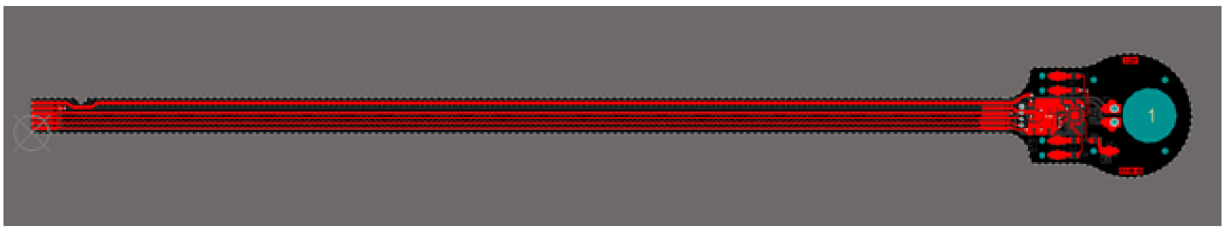

Figure 13. SAM-B Layout.

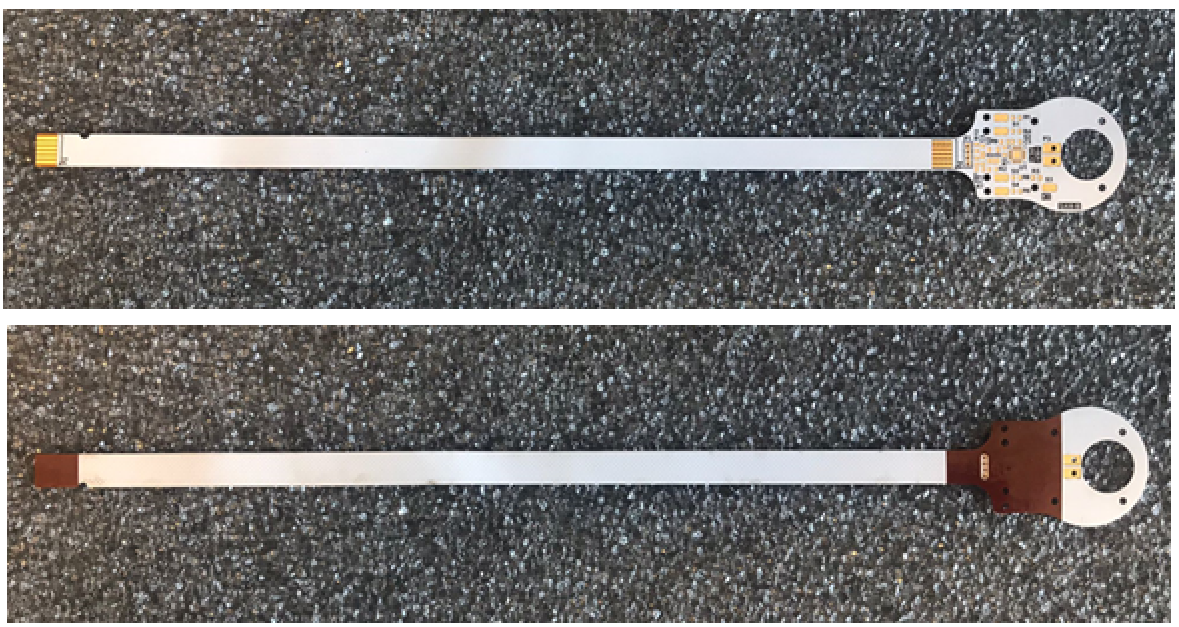

Figure 14. Top and bottom of the SAM-B realization.

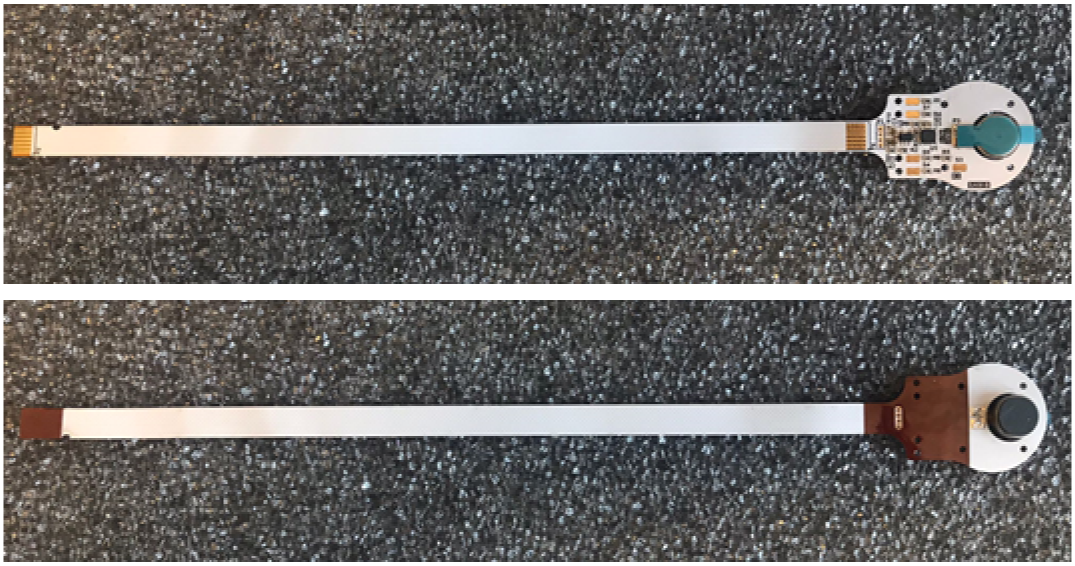

Figure 15. SAM-B assembled.

2.7 Final assembling and test

The following figures show how the various components (Main board, protection box, SAM modules) have been assembled together (figures 16, 17, 18) and inserted into the *PlusMe* pillow (figures 19, 20, 21).

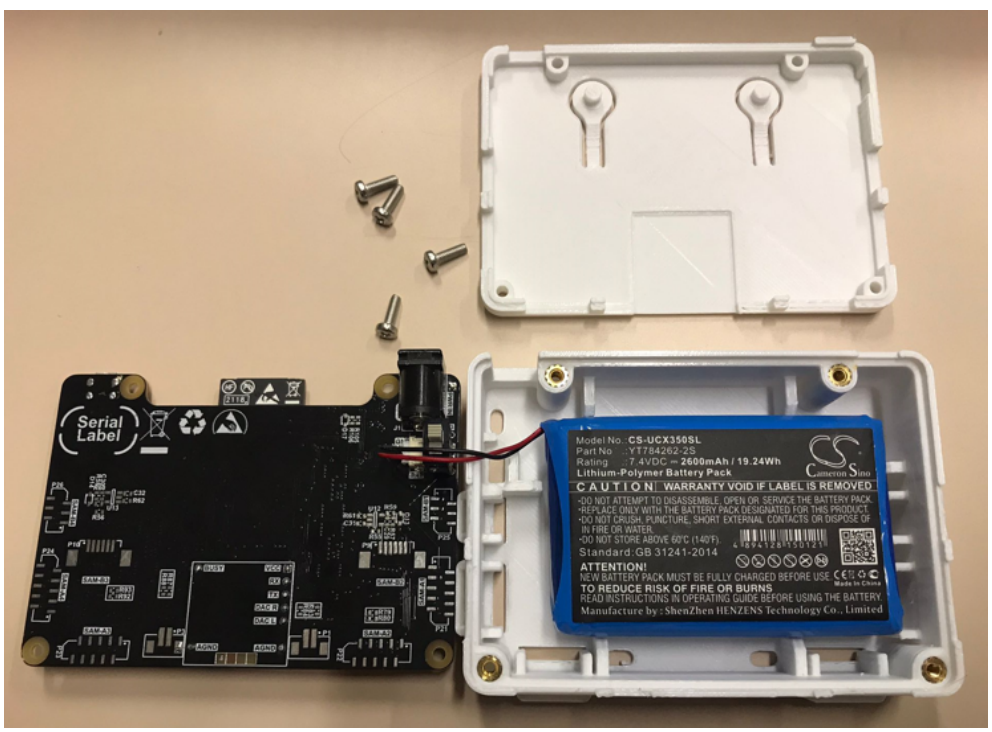

Figure 16. Battery insertion on the bottom of the box.

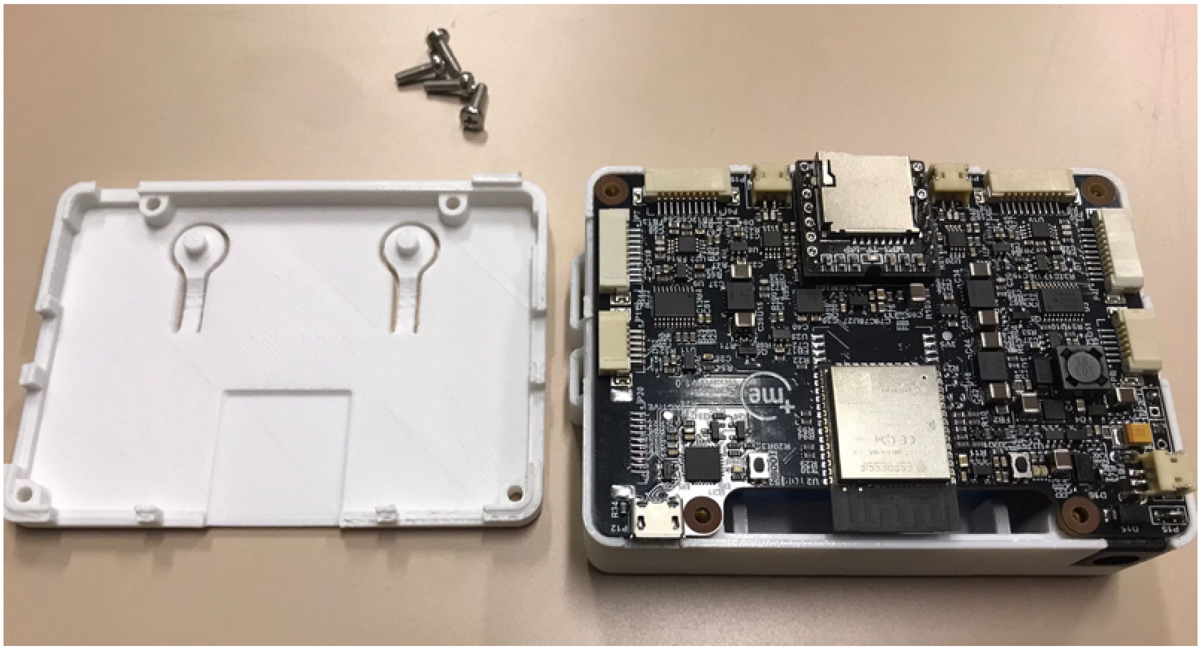

Figure 17. Main Board insertion in the box.

Figure 18. Final Main Board module, ready to be inserted within the *PlusMe* pillow.

Figure 19. Main Board module inside the pillow. The picture shows also the SAMs connections.

Figure 20. Preliminary test of the touch sensors; the device correctly detects the human touch and responds with a green light.

Figure 21. Test of the final, assembled device: the four paws correctly detects the human touch.

2.8 Conclusions

As shown in the previous sections, the final prototype has been concluded; the inner electronics has been successfully tested and is ready to be embedded in a professional fabric envelope (described in detail in the next section 3.6). A short video of the prototype is available on the project website www.plusme-h2020.eu/video/#PlusMe_IMM

The various electronic components, their design, schematics, final assembly and specifications are accompanied by a complete and standard documentation, which can be used by a high-tech company for a potential scale production of the device.

The control software, namely the firmware of the device and the control App, has been developed in parallel by ISTC-CNR, and it is described in the next section 3. The new software will be adapted to the new device and improved through the exploitation of the novel hardware features which are present in the *PlusMe-IMM* prototype.

3. PlusMe device, by ISTC-CNR

Between January and November 2021, the researchers from ISTC-CNR developed a new *PlusMe-ISTC* prototype, which represents a “bridge” between the old device, based on Arduino board, and the new *PlusMe-IMM,* developed in the same period. Both devices share the same core, the ESP32 microcontroller, endowed with wireless and bluetooth low energy connections. This allowed the development of a common shared software on *PlusMe-ISTC*, which can be adapted to the new device by IMM-CNR. The new software is constituted by the firmware running on the device, and by the tablet App controlling the device via the bluetooth connection.

From the hardware point of view, the toy is based on a completely new PCB, which holds the various electronic components and the commercial breakout boards used to manage sensors, actuators, I2C devices, power supply (figure 22). In detail, the ESP32 microcontroller allows an improved management of all sensors and actuators, adding to the final prototype several advancements from the software point of view

The new PCB can be easily reproduced in series, and will be used for a small hand-made production (estimated 6 samples), which will allow the dissemination activities planned in the project.

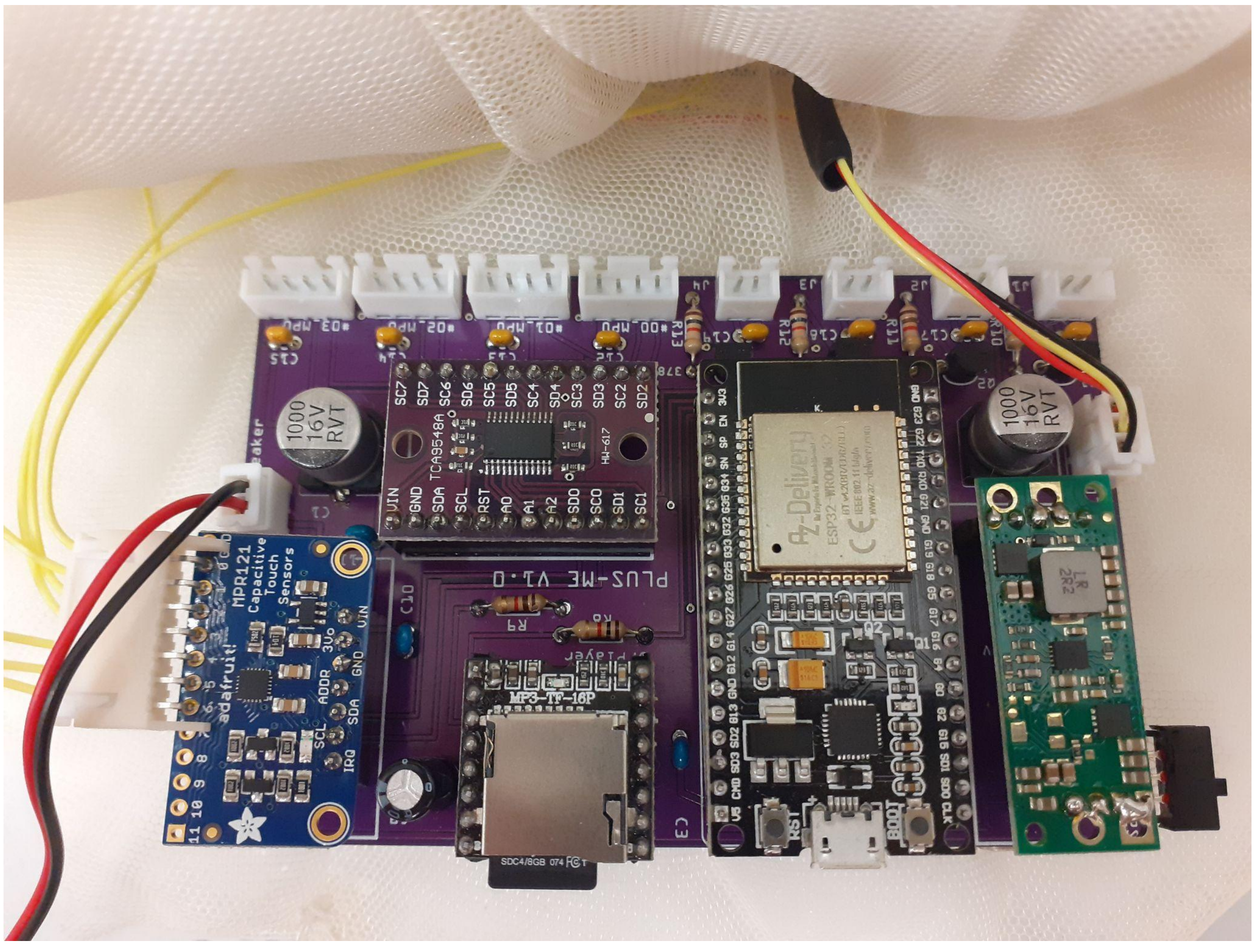

Figure 22. The PCB developed by ISTC-CNR holds commercial breakout boards, such as the ESP32-Wroom-32 developmental board, which is the core of the new *PlusMe* toy.

3.1 PlusMe new Tablet App, by ISTC-CNR

The PlusMe App is an Android application that enables the user (e.g., the therapist) to connect with the *PlusMe* device and control it wirelessly via Bluetooth LE. It can be installed on both smartphones and tablets, however it is best experienced on the latter due to the larger screen size. It runs pretty much on any device with Android version 6.0 or above, and does not require high end hardware specifications.

The android app has been developed using the Godot Game Engine which is an open source multiplatform game engine that has gained great success in recent years because of its simple and powerful scripting language which is similar to Python. The most complicated part has been the development of a custom game engine plugin to access android BLE APIs. The plugin has been developed in Java using the Android Studio and built as an android library (AAR); the code will be freely available on the GitHub repository of the project, at the following link: www.plusme-h2020.eu/hardware-and-software/

3.2 Bluetooth Low Energy connection

When opening the PlusMe app the first screen presents a list of PlusMe devices that have been detected in the surroundings of the android device (see figure 23). Each item of the list has a "connect" button that first allows the identification of the corresponding PlusMe device which gets highlighted by turning on all its lights. The user is then asked if the glowing device is the one he/she wants to connect to. After confirmation, the Bluetooth connection is established and the main device control panel is presented. The PlusMe app connects to the PlusMe device through a Bluetooth Low Energy connection. The device is configured as a Peripheral and the Android device as a Central.

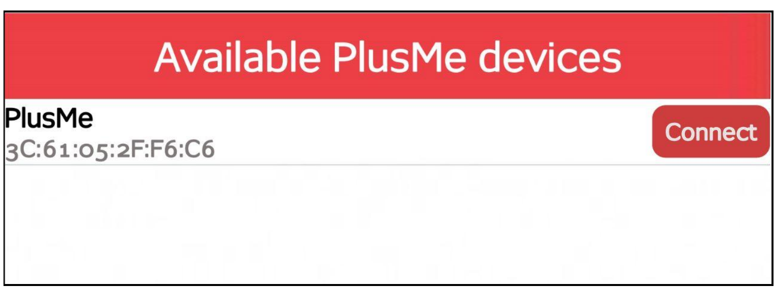

Figure 23. The Bluetooth connection screen shows the available devices.

3.3 PlusMe Tablet App overview

After establishing a bluetooth connection, the App will present a graphical representation of the PlusMe device with the current configuration (functions, colors, sounds etc.) as depicted in figure 24. At the center of the screen there are seven buttons by which the user/therapist can activate seven different functions. When selecting a function a short description of it appears in the text underneath. On the right side there is a vertical slider to control the volume of sound effects. On top of it there is the Bluetooth connection button that can be used to disconnect from the device and go back to the connection screen. On the top right corner there is the debug button that activates the visualization of the raw signals coming from the touch sensors of the toy; this is very useful to spot possible sensor malfunctioning. At the top center of the screen there is a timer indicating how much time has passed since the beginning of the current function (an information very helpful for therapists during the experimental sessions). At the center of the screen, between the PlusMe paws, there is a button with a music note that can be used to activate a specific sound reward chosen from a list in a popup window.

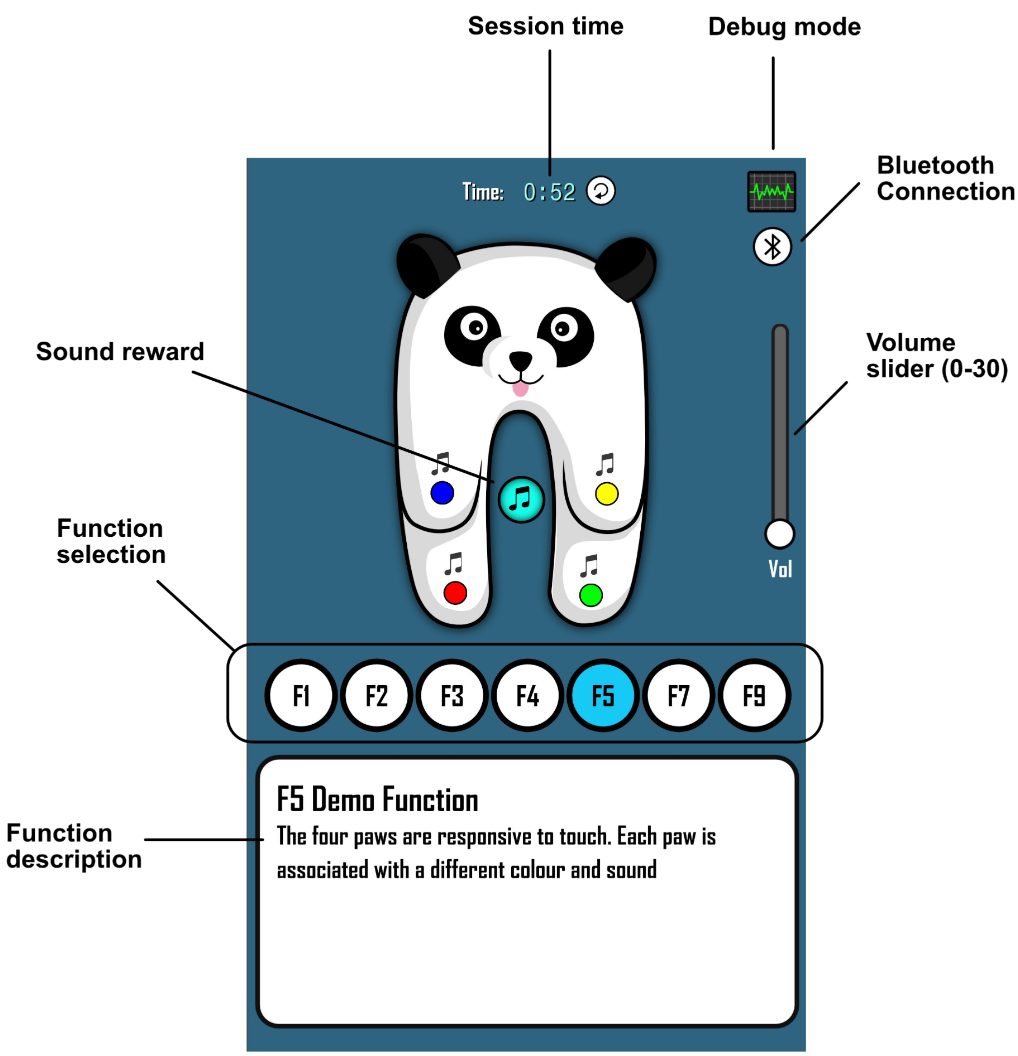

Figure 24. Main control screen of the PlusMe App. Through the GUI the user can customise several features, such as colors, sounds and the current operating mode (function).

3.4 PlusMe response customization

As an example, the GUI of the function number 5 (F5) is described in figure 25. F5 is a sort of demo mode that allows a certain degree of customization of PlusMe responses. When switching to function F5 the bottom part of the screen shows the paw customization panel. This panel shows the configuration of the selected paw; touching one paw activates its configuration and a dashed line appears indicating that it is selected.

Each paw can be enabled/disabled, the light color can be changed as well as the sound associated with it. Light can be configured to be static or pulsing; If the light is configured as pulsing, the user/therapist can also set the pulse frequency.

A video showing the new App while controlling the new PlusMe-ISTC toy is available at the project website, at the following link: www.plusme-h2020.eu/video/#the New control App

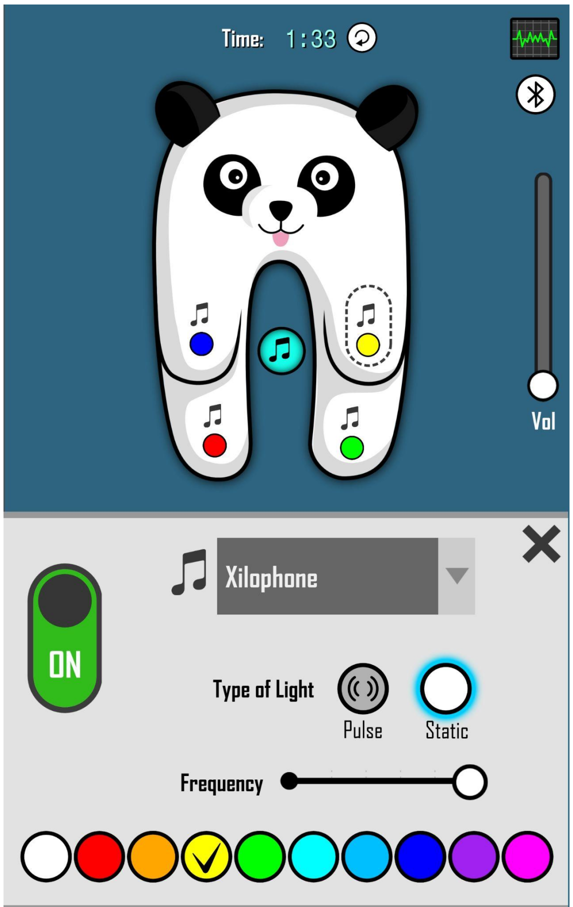

Figure 25. The GUI of the demo function: for each paw the user can set the desired output (color light, sound), triggered when the paw is touched .

3.5 PlusMe new Web App, by ISTC-CNR

As an alternative wireless communication system to control the PlusMe, a Web application accessible from any browser on any device has been implemented, thus also opening the possibility to remotely control the TWC.

The PlusMe Web App is a web page through which one can change the main PlusMe parameters, such as LED Colors, current function, etc. At the current level of prototyping both the PlusMe and the device used to control it must be connected to the same network. The application has been completely developed in the Arduino IDE and runs directly on the ESP32. The ESP32 runs as a WiFi server to which the client connects through the web browser. When the connection is established, through HTTP protocol, the web page is shown. Each time an option on the web page is clicked by the user, the browser sends a GET request to the server and the ESP32 changes its parameters and its behaviour accordingly.

As shown in figures 26, the Web Application is still a prototype and has a very simple graphic user interface. It displays four buttons for each Paw, through which one can decide the LED color, LED mode, soundtrack and also enable/disable its touch sensor. An additional option button has been inserted to choose the function running on the PlusMe.

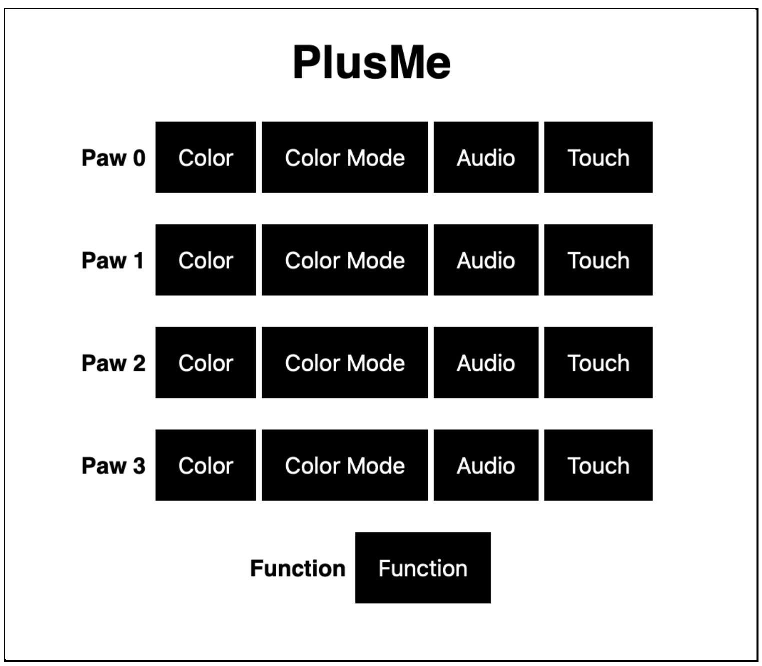

Figure 26. The main graphic user interface of the Web page lets the user to control PlusMe through a Web interface.

In order to see the options for each button and select the preferred one, the user can move the cursor over the relative icon and then a menu window is shown with all the available options (see figure 27). When the user clicks on his/her choice, the request is immediately processed by the PlusMe that changes its behaviour accordingly.

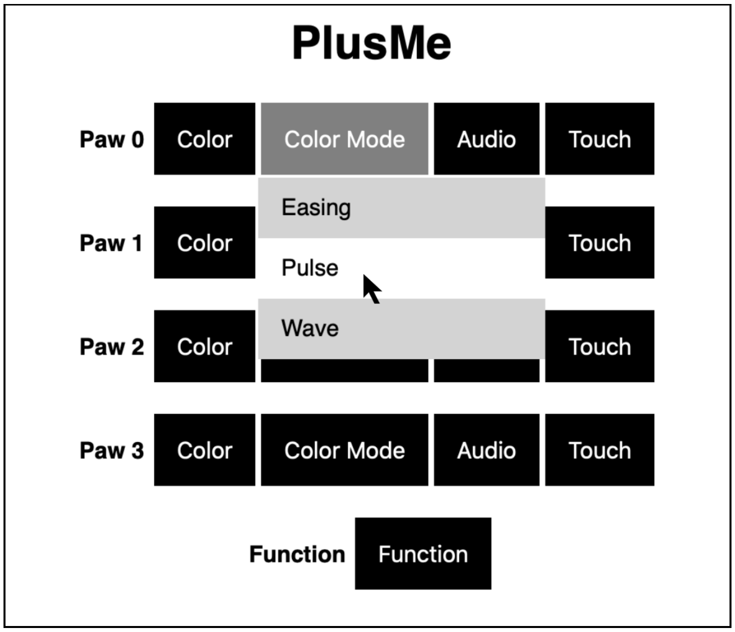

Figure 27. A menu lets the user select between different options.

3.6 New professional design of puppet

A shown in figure 28, the realisation of the external envelope, useful for both prototypes PlusMe-IMM and PlusMe-ISTC, is done in collaboration with professional artists in the field of puppets realisation.

Figure 28. A test of the final, PlusMe puppet, realised by professional artists working in the field of puppets and pelouches.

4. A new Transitional Wearable Companion: the Octopus *X-8*

As a side effect of the entire PlusMe engineering process, the researchers from CNR-ISTC could develop an additional interactive toy which relies on the a modified version of the same hardware and software. Thanks to the connectivity offered by the ESP32, the new toy, called X-8, will be able to connect to PlusMe, and create a more complex system, composed of interacting toys.

A brief video of the octopus X-8 is available on the project website at the following link: www.plusme-h2020.eu/video/#the_octopus_x_8

Figure 29. The Octopus X-8 is a new Transitional Wearable Companion.

5. Future development

At the end of the project, the final results of the technological devices and softwares described above, will be presented in the final deliverable D1.4 *Final report on PlusMe device*, due at month 21 (31 May 2022).