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# A computer vision algorithm for the estimation of the human hair diameter

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***Abstract*—The problem of the state of health of human hair is often underestimated because the consequences are in most cases only aesthetic, but a damaged and unhealthy hair can also have social repercussions and worsen the quality of life of the affected individuals. So, in recent years the market demand for greater attention to the health of the hair has grown. Furthermore, the development of IoT and smart devices is opening up new frontiers in all fields where technology can support the needs of individuals. The beauty industry is trying to meet the needs of this market requests in light of these recent technological developments. This paper presents the project "Internet of Beauty", whose final goal is to develop a IoT network based on an intelligent hairdryer able to modify its configurations in terms of air flow rate and temperature on the basis of the specific health features of the user hair, in order to preserve its health. The state of health of the hair will be evaluated through the acquisition and processing of images taken by the user's smartphone, estimating parameters that closely affect the health of the hair subject to drying such as the size of the diameter of the user's hair.**

## I. INTRODUCTION

Today we live in a world that is increasingly connected: systems that a few years ago were normal household tools, they have now become real smart objects.

Thanks to the introduction of the Internet of Things [1] and to the propagation of the domotic systems, the demand for small and smart household devices has become fundamental. This is particularly true for one of the most common objects: the hairdryer. With its daily usage, it is a very simple tool to use. Yet, an improper utilization can lead to some serious damages.

In fact, it is known that hot air directed at the skin can cause burns, especially in delicate areas such as the scalp. Moreover, too much heat from hooded hair dryers or overheated hand-held hairdryers can cause several other problems such as hair loss [2] or bubble hair [3], a phenomenon named after the presence of gas bubbles within the hair shafts.

Thus, one way to avoid hair and scalp damage is to adjust the hairdryer temperature and flow rate of hot air. The optimal temperature to avoid the aforementioned lesions, among the various factors that determine the general state of health of a human hair, depends strictly on the size and typology of the hair. For example, very fine hair is much more sensitive to high temperatures than a thicker type of hair. In fact this means that the dimension of the hair could provide a very useful information for setting the right configuration of the hairdryer. Hence, the problem is that almost all the hair dryers on the market do not permit to regulate the own temperature and the thickness of the hair is unknown for most people.

This paper presents a description of the project "Internet of Beauty", a project funded by the "Regione Lombardia" whose goal is to create a new smart hairdryer, which is able to interact with the home automation infrastructure and with normal personal communication devices (i.e. smartphones and tablets), in this way creating an IoT network. They will also be able to collect data from sensors and share them in the cloud with other systems also. The information will be processed with algorithms suitably developed to modify the device's configuration according to the information of the user's hair. The final goal of the project is to respond to the market demand of an intelligent device able to modify its configuration in terms of temperature and flow rate of hot air, based on information on the current health status and typology of the hair. In this phase of the project we focused our efforts on estimating the size and typology of the hair.

The best way to know the hair health's is a trichological visit [4], but it requires time and it is not considered by the majority of the people. So, to meet people's necessities and habits, it has been chosen to develop a solution which takes advantage of the smartphone cameras, which are increasingly powerful even in a medium-range device and capable of detecting small objects. In the choice of phone cameras, instead of sophisticated microscopes, lies the innovation of the present paper which aims at verify the possibility of estimating the measurement with reasonable accuracy and assessing the limits of using a non-professional device.

A first analysis of the literature suggested the use of algorithms for finding the lines in an image, since a human hair can be approximated by a line. This problem has already been faced and solved with the development to the Hough Transformation algorithms [5], [6], [7]. These algorithms are widely available and work well, but there is no information about the line thickness.

For this reason, in the present paper, we propose a novel algorithm to estimate the thickness of a hair from a picture and provide a classification of its typology (thin, medium and thick). Then, we present a description of the IoT system architecture, the hardware and software architectures, emphasizing the main functionalities of the system and describing the roles of each component in the system architecture.

The paper is organized as follows: Section II describes the "Internet of Beauty" project and the system architecture; Section III is focused on the algorithm used for the hair diameter estimation; Section IV presents the experimental results and Section V is devoted to conclusions and future developments.

## II. THE INTERNET OF BEAUTY PROJECT

This section describes the hardware and software architecture of the IoT system.

### *A. Hardware architecture*

The hardware architecture of the project is depicted in Fig. 1. This system has three main components.

The first one is the IoT Platform $(B)$, whose core component is a RushUp Kitra 710c. This is a Single Board Computer (SBC) based on Samsung Artik processor that collects and processes all the signals from the sensors. Inside the platform there is also a differential switch to prevent dangerous situations related to the electrocution.

The second component ($(A)$ in Fig. 1) is the smart hairdryer. The dryer contains three sensors: an inertial sensor, a temperature sensors and an infrared sensor. The first one will be used to detect hairdryer falls and to switch off the device if no movement is detected. The second one measures the air flow temperature and the third one the temperature of the scalp.

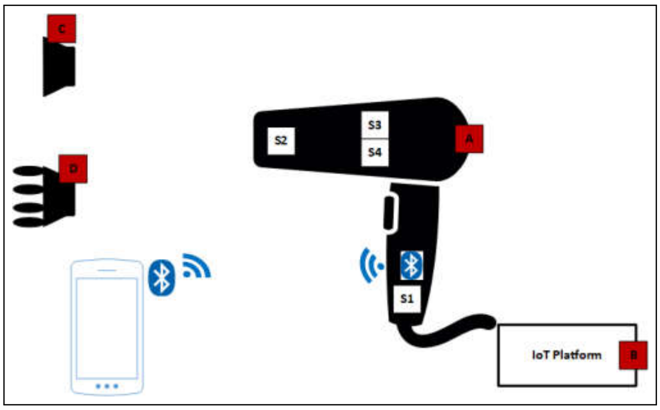



Fig. 1. System architecture

Finally, the hairdryer is endowed with a BLE Module for communication of the operating data with the personal device.

All these components create an IoT network that can be connected with the domotics system of the house. The domotic connection system is an important characteristic of the smart hairdryer, as it is used to understand also the power consumption of the device and the user profiles. In fact, the connection to the domotic system is completely safe and the system does not activate the hairdryer if the user does not power the system on.

### *B. Software architecture*

The communication with the hairdryer is provided by the user smartphone, in which there will be installed the proprietary application (the current prototypes have been designed using Android technology). This application communicates via Bluetooth and will be used for taking the pictures for the estimation algorithms and setting the hairdryer functions. Fig. 2 shows the software architecture.

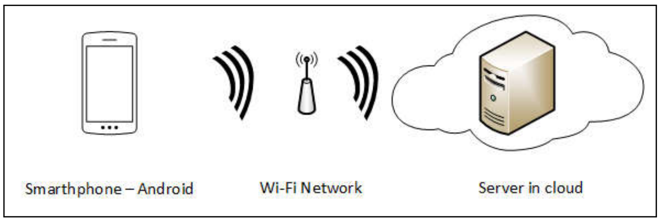



Fig. 2. Software architecture

When the user initially opens the application, a login page is shown. Once logged in, the user can choose different functionalities (Fig. 3). Therefore, the user can decide whether he is willing to take a picture of his hair by tapping the relative button. Thereafter, in order to take the photo, the smartphone must be equipped with a macro lens on the camera. As soon as the snap button is pressed, the app will send the image to the cloud server, which elaborates it and, if it is not correct, it will send a message to the user asking for a new one. Whereas, if the photo is valid, the server will send the result to the application. Finally, the user can see the results on his own device. At this point, if the user pushes the button "Send", the application will submit the parameters to the hairdryer via Bluetooth.

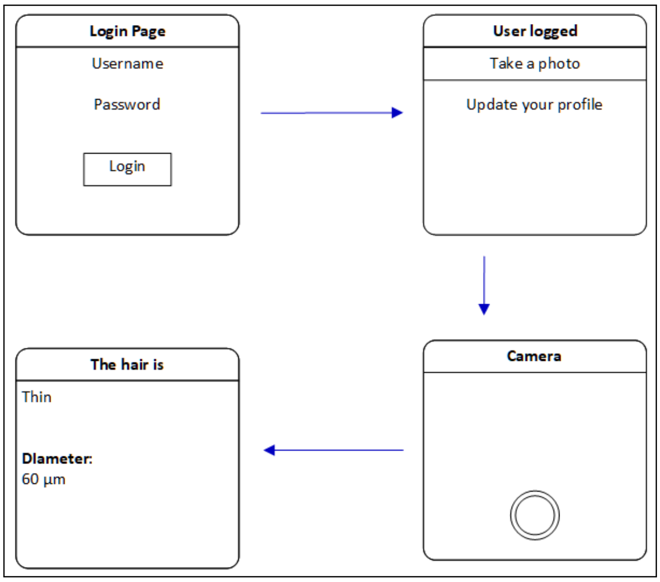



Fig. 3. Application usage steps

Hence, the algorithm in the server will be able to fulfil its goal, that is to estimate the hair thickness, given the aforementioned information. In the next section, the methods used to estimate the hair diameter $d$ will be presented. In fact, the ultimate aim is to classify the hair as belonging to one of three categories:

1) thin: $d < 60\mu m$;
2) medium: $60 \leq d \leq 80\mu m$;
3) thick: $d > 80\mu m$.

## III. HAIR DIAMETER ESTIMATION ALGORITHM

This section describes the process of estimation of the diameter on a human hair. In the first part, the experimental protocol will be discussed, i.e. the proposed setup for the experiments, the specific hardware that has been selected and the software that has been used. In the second part, the algorithm that has been developed will be described in detail. Finally, the results of the proposed algorithm will also be presented and discussed in detail.

### A. Experimental settings

*1) Experimental setup:* a human hair, externally, can be roughly divided into three parts: root, shaft and tip [8]. Instead, internally, a human hair can be divided into three sections: marrow, cortex and cuticle. In particular, the outermost, the cuticle, acts as a cladding of the hair. Over time, the cuticle layer may deteriorate so that the tip of the hair is more thinner than the root area. From this, it follows that the diameter of the hair is not uniform along its entire length but that it can vary from one point to another of the hair also by $5-10\%$ [8]. To make the diameter estimate more reliable, three different photographs for each hair were taken, one of the root, one of the shaft and one of the tip region. In such a way, three different measurements are obtained at the end of the diameter estimation procedure. This would be possible only in case of sufficiently long hairs. The decision process regarding the final evaluation of the hair size will be described in the section that reports the experimental results.

In order to photograph the hair in such a way that it is visible and distinguishable from the background, it has been designed a non-reflective cardboard support of a white tone. This support has been integrated with a black square marker of a known size $(1cmx1cm)$ positioned at the left end of the support, and it is assumed that the user will place the hair to the right of the reference. This will serve as a reference mark that simplifies the research of the hair in the image and allows the calculation the *pixel per metric* of the photo. This procedure will be explained in major detail in the next subsection that describes the algorithm. Several experimental images were collected with hair of different typology, size, belonging to individuals having different sex and ethnicity to cover different use cases and design an algorithm that is as much robust as possible. An example of experimental image is depicted in Fig. 4.

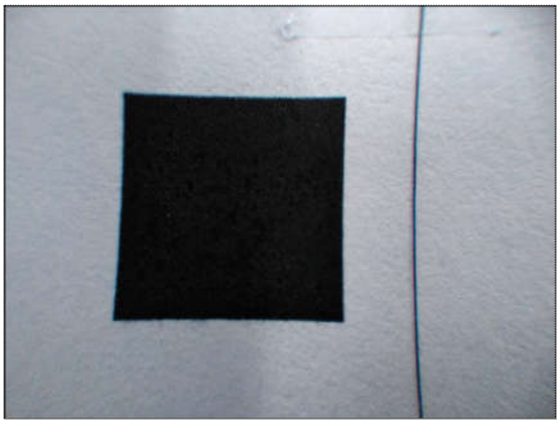


Fig. 4. Example of experimental image.

*2) Hardware:* the main characterizing point of this project is the use of the mobile phone to take pictures of the hair. The resolution of the camera has been chosen in such a way that it is sufficiently high, so that the thickness of a hair can be captured by one or more pixels. Moreover, the diffusion of this type of cameras on the market has been considered, so that this procedure can be used by the vast majority of individuals who own a medium-quality mobile phone. For this reason, a currently widely used standard camera with a resolution of 12 Mpx has been selected. Furthermore, to improve the resolution of the image, it was decided to equip the camera with a low-cost macro lens capable of zooming up to 5x.

*3) Software:* the software used for the experiments was coded from scratch using Python as programming language. Furthermore, openCV and scikit-image packages were used, as open source software packages for image processing.

### B. Algorithm

The algorithm consists of the following steps: marker detection; *pixel per metric* estimation; hair detection and diameter estimation.

*1) Marker detection:* after the image has been acquired and read by the openCV software, it is immediately converted to the gray scale colour space. The first objective of the procedure is to locate the marker inside the image, this is important for two reasons: the first is that thanks to the fact that the size of the marker is known, through simple mathematical proportions it is possible to determine how much each single pixel covers in terms of size. Moreover, given the positioning of the marker on the extreme left of the support, it will also be possible to limit the area where to go to look for the hair as we know it will be found to the right of the marker.

To locate the marker efficiently, the second step is thresholding the gray scaled image in such a way to create a mask which will be applied to the image for isolate the reference and help its localization. The threshold value used was determined by stacking all the images in a single matrix and plotting the histogram of the gray intensity values, as shown in the figure 5, and choosing the value that best discriminates between the black colour of the reference and the background of white colour. The value of 60 was chosen from the experimental images.

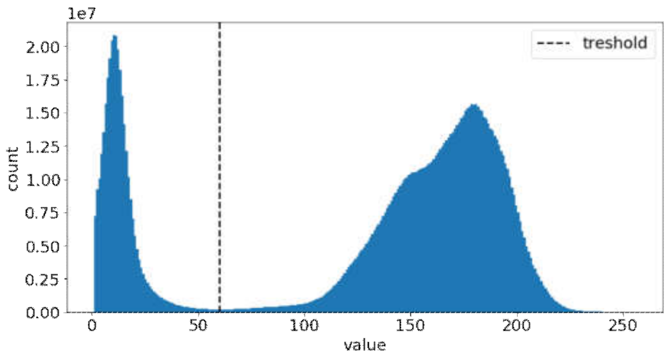



Fig. 5. Histogram of gray scale values of the experimental images.

Clearly, since a hair can have a very dark colour similar to the black of the reference, it is possible that even part of the hair is not removed by the threshold. The mask obtained after thresholding is depicted in Fig. 6, where it is possible to observe that part of the hair has not been remove.

For the reason above, the thresholding is followed by the localization of the contour through the openCV function `findContours` which implements the algorithm described in [9]. A following control keeps only the contour found with the larger area to preserve only the square reference and discard any other contours detected.

*2) Pixel dimension estimation:* as can be seen from the example image from Fig. 4, in all the photos used in the experimental phase the reference is very distorted by the lens mounted on the camera, this pincushion distortion could introduce a high error when the resolution of each pixel is evaluated. It is observed from Fig. 4 that the right side of the reference is the less distorted one, for this reason it was thought a way of isolating this right side from the rest of the previously found contour to evaluate the resolution of the pixels. To find the contour's right side, it was simply taken the rightmost point and all those on his left within a certain empirical limit of 80 pixels, found during the experimental phase.

At this point, among all the pixels selected by this procedure, it was taken that the one with the larger ordinate ($y_{max}$) and the one with the smaller ordinate ($y_{min}$). The vertical distance of these two points ($l = y_{max} - y_{min}$) represents the dimension of the side of the square reference in terms of the number of pixels. At this point, to evaluate the resolution of every single pixel of the image we simply divided the number of pixels $l$ by the dimension of $10^4 \mu m$ of the side of the square.

*3) Hair detection and diameter estimation:* once the right side of the reference is identified, the entire image area that resides on its right is cropped. For the setting hypotheses we know that the hair will surely be in this area that we have extracted. The previous passage is useful both to limit the area of the image needed to look for the hair, and to reduce the area of image to work on, which leads to an advantage in terms of computational load of the algorithm. After cropping the image it is possible to identify where the hair is located, looking at the average gray values along the columns. In fact, in correspondence of the pixels where the hair is located we expect that the gray values are lower than those belonging to the white background. This fact is appreciable in Fig. 7.

At this point taking the minimun value of the average gray values and using it as a threshold it is possible to obtain a mask that isolate the hair from the background, Fig. 8a.

The final step of the algorithm consists in the actual calculation of the hair diameter. This is done by applying the hair mask to the cropped image of the hair. To obtain an estimate that is as robust as possible, the number of non-zero pixels on each row is counted and the mean value of the latter is taken as the final value as shown in Fig. 8b.

## IV. Experimental Results

A hair fiber has a typical diameter $d$ of $50 - 100\mu m$ [8] and based on it, it can be classified into three different categories: thin ($d < 60\mu m$), medium ($60 \leq d \leq 80\mu m$) and thick ($d > 80\mu m$).

This preliminary algorithm has been tested on a small dataset which includes hairs of different lengths and types, provided by people of different ethnic backgrounds. To provide some simple statistics that could give an idea of the accuracy and consistency of the algorithm it was decided to make 5 different photographs for each part of each hair. In this way it

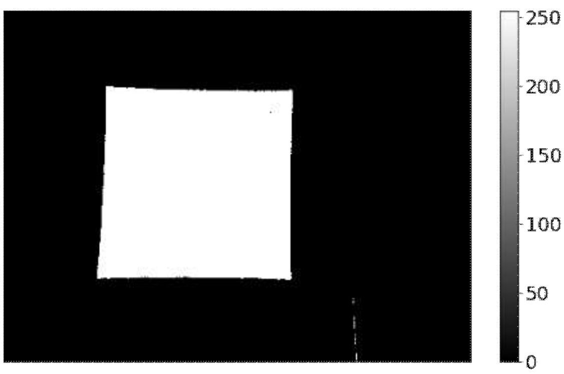



Fig. 6. Mask obtained after thresholding.

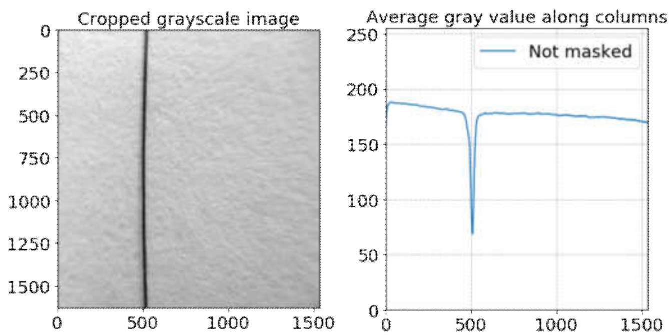
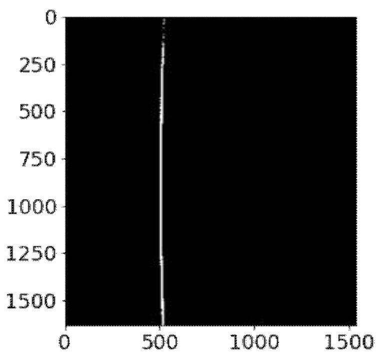
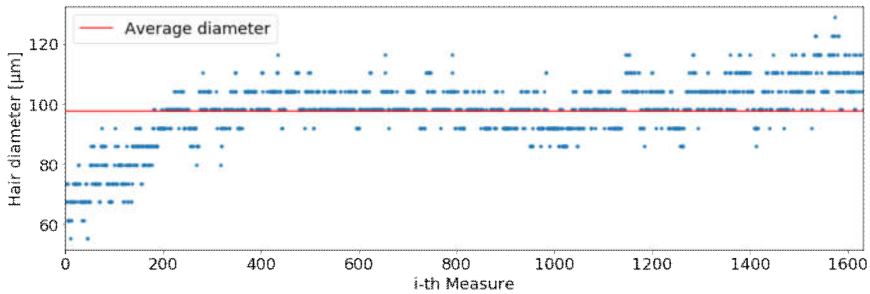



Fig. 7. Localization procedure of the hair in the cropped image.




(a) Mask that isolate the hair from the background




(b) Number of non-zero pixels per row

Fig. 8. Mask and Results

was possible to obtain preliminary information on the variance of the output produced by the algorithm.
The validation dataset was made of 7 hairs, each one divided into three parts (root, shaft and tip) and for each part 5 photos were taken.

### A. *Single part evaluation*

In Fig. 9 the results are shown for the first four hairs of the dataset. Looking at each part of the hair individually, is possible to see that the algorithm output has typically a low variance (less than $10\mu m$), except for the tips measurements of samples two and three. These high measure variances may be due to the incorrect shooting of the photos or to the incorrect positioning of the hair on the card.
To verify the real reasons for this uncertainty in the model

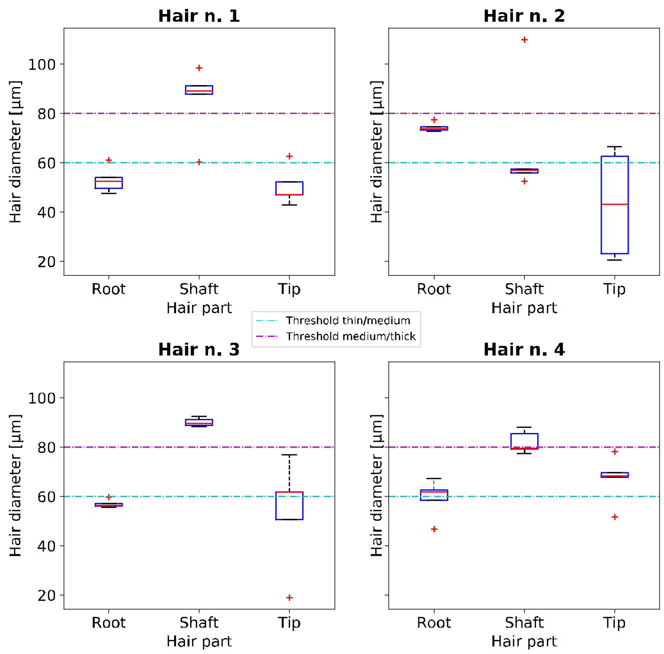



Fig. 9. Algorithm results for the first four samples.

output, it was decided to inspect the samples that generated this result.

In the first case (Hair n.2), it was found that the tip of the sample had a very light colour. When the image is converted into grayscale, there is not enough contrast with the card background and therefore it is harder to separate the hair from the background (Fig. 10b). It was also found that some of the photos were out of focus (Fig. 10b).

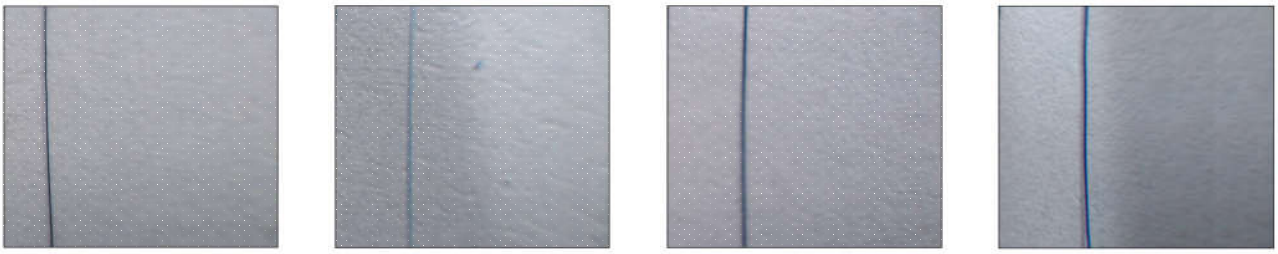
In the second case (Hair n.3), it was found that the hair was positioned incorrectly on the card. As is possible to see in Fig. 10d, in this case the hair produces a shadow that can be much darker than the card's background and, therefore, it have a big influence on the mask used to isolate the hair (see Sect. III-B3). If the hair is not correctly isolated, the output diameter estimate is influenced by the shadow. Finally, it was found that also in this case there were out of focus photos (see Fig. 10c).

In Fig. 11 it is possible to see the results obtained after the removal of the previously described effects. In both cases the results have improved, with a variance reduction. Notice that the measure and the classfication of sample n. 3 has significantly changed, remarking the great importance of a correct photo shooting.

### B. *Output category*

As seen in Fig. 9 and Fig. 11 different parts of a same hair has different diameter and in some cases the difference is very large. This is due to the fact that typically the hair cuticle damage isn't the same from root to tip [8]. So, we chose as the output category the one in which two of the three parts of a hair are set. In the case that all the three hair parts are positioned in different categories, the output is the category of membership of the median of all the fifteen measures.
The results obtained for the entire dataset are:

- $14,3\%$ thin;
- $71,4\%$ medium;
- $14,3\%$ thick.



(a) Correctly taken photo (b) Light hair out of focus (c) Dark hair out of focus (d) Hair positioned incorrectly

Fig. 10. Comparison between hair section of taken photos.

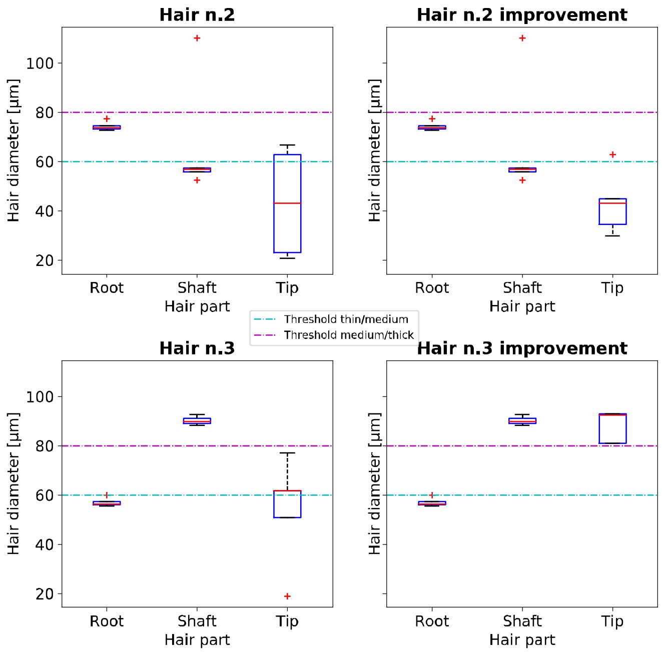



Fig. 11. Improved results for two samples.

## V. Conclusions

This article explains the preliminary results of the development of a research project with the main objective of the creation of an intelligent IoT network where the main element is an hairdryer able to automatically modify its parameters to respect the health of the specific user's hair. This is done estimating the state of health and typology of the user's hair.

One of the most important parameters is the hair diameter. In this first stage of development, the hair size is estimated through an image processing algorithm applied to a picture taken with the smartphone's user through an android application. The results obtained show reasonable performance of accuracy and repeatability if the correct photo acquisition procedures are respected, with an average execution time of 6 seconds (measured on an 3rd gen. i7 processor). The critical parts of this algorithm are the correct positioning of the hair on the cardboard and the correct shooting of the image.

## VI. Acknowledgement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Regione Lombardia


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