Smart Mirror E-health Assistant – Posture Analyze Algorithm

Proposed Model for Upright Posture

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***Abstract* — Today there exist many different types of smart assistants and devices, such as virtual assistants, smartphones and wearables, which have a purpose to coordinate and optimize the daily activities of the people worldwide. The smart assistants' focus is mainly on basic human needs, e.g. browsing, scheduling, navigating and other similar activities. However, not many smart assistants are concerned with the human health overall. In this paper, we focus on the possibility of using a smart mirror to detect health issues. A new Smart eHealth Mirror model is proposed, that consists of a smart mirror which works on its own algorithm and behaves as smart assistant. This proposed model uses face recognition authentication, posture problem detection, and proper posture guidance, followed with suggestions for preventive healthcare. The algorithm identifies the person's posture and carefully analyses the posture and body changes over time. The obtained results from the analysis satisfied our expectations by improving the upright posture of the tested individual by considerable rate. The benefit of the proposed smart algorithm is proven by the evaluation results, which improved with each new individual analysis. (*Abstract*)**

Keywords — Smart mirrors; smart assitants; eHealth; health issues

I. Introduction

There has been a steady and significant growth of use of smart devices in the past decade. This is as a result of the growth of the industry of Internet of Things (IoT). Each day there are more and more smart devices, vehicles, buildings and other objects, which consist of software and electronics, that are interconnected either by some network or to the Internet. These smart things have the main purpose of collecting and exchanging data.

The constantly increasing usage of smart interconnected devices on a global level, led to a growth of smart homes as smart technology ecosystems, whose purpose is to coordinate and optimize our daily activities. Recently there has been a new development of smart mirrors which became part of the smart homes. This is mainly used for controlling energy usage, organizing daily human routines, navigating, monitoring of buildings, entertainment etc. One of the most important applications of the proposed smart mirror is the ability to track health status over time. The aggregated data can be further used to detect health issues patterns, i.e. repetition of health problems during specific periods, and make lifestyle recommendations.

Early detection of health issues is essential for on-time prevention on further medical complications. A smart mirror can be used as a device to monitor and observe the physical health of the people and provide reliable healthcare experiences tailored to each individual. Detecting early signs of possible disease will help reduce the burden of healthcare costs.

In this paper we propose a smart mirror model whose main feature is early health issues detection in order to assist the people's wellbeing. Additionally the model provides face recognition authentication for better user experience and data corrections and updates with user interactions at minimal levels. The mirror includes some of the daily used applications, such as current time, alarm, to-do list, news feed, current weather display, and e-mail reader.

The smart mirror Posture Analyzing Model, as we name it, has the capability to detect people's health problems or body changes by in-depth analysis and comparison of the images of the individual. One of the essential steps in the general workflow model is the Posture Analyze Algorithm (PAA), a new proposed algorithm used to analyze the posture and visually guide the person about how to be positioned properly in order to have accurate results. The sections that follow will introduce the proposed model and the new algorithm in details.

II. Related Work Studies

The concept of smart mirrors has been exploited in both, commercial development and production, and theoretical research and model prototyping. Some projects and models in the area of smart mirrors, will be briefly described and discussed.

A. Commercial development and production

Smart mirrors classified in this group have entertainment purposes, including scheduling and browsing tools.

Some products in this area, work more like smart TVs, such as Waterproof Mirror TV, Luxury Waterproof TV, and Smart Mirror with Music Center [1].

There are other Smart Mirror projects whose contributors are engineers from technology leading companies. For instance, Google engineer Max Braun has developed a Smart Mirror with current weather display, news feed and open-ended voice search features [2]. Another project is available on the Microsoft Edge's GitHub repository. This project enables user recognition for personalizing the user experience accordingly by matching faces to profiles [3].

The Naked smart mirror [8] detects the physical body changes of the whole human body. They scan the undressed body and create a 3D representation of it on the smartphone. The data from the smart mirror to the smartphone is transferred using

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wireless networking, making the entire process prone to data leakage and violation of privacy.

B. Theoretical research and model prototyping

The smart mirrors in this classification have been developed in model prototypes based on their corresponding theoretical studies.

The authors in [4] introduce an interactive mirror for smart home whose main features include emotion recognition, human height identification, garment identification, and suitable garment selection based on skin color. Another paper [5] introduces a mirror for positive affect in everyday user morning routines as a part of a smart home. The main purpose of the mirror in this paper is to increase the motivation, happiness and fitness of the user after getting up in the morning.

The eHealth Wize Mirror project [6], [7] has purpose to detect cardio-metabolic diseases, measure cholesterol level, oxygen level, emotions and mood, followed with suggestions about different lifestyles in order to avoid such diseases. The analysis is done by scanning the face and the geometric features of the arcus of the eye and detecting missing wavelengths. They used different methods to acquire the data: face scan to detect cholesterol, green light to measure oxygen level on skin, mirror sensors for 3D head pose tracking, and 3D scanner for 3D face reconstruction. The individual is scanned while being in a seated and fixed position, which is not optimal for smart mirrors that are placed in home environment, such as halls and bathrooms. Additionally, they mainly scan the individual's face and eyes.

In June 2014, researchers from Oxford reported that they had developed a software that uses face recognition techniques which correctly predicted genetic disorder, on average, ninety-three percent of the time [22], [23], [24] and [25]. Additional health problems, such as spine stress, injuries and movement, and posture problems have been previously investigated in [9], [10], [11], and [12]. However, these methods are focused on detecting the position of one body part, require additional sensors or wearables to be placed on the body, third party devices to be attached on existing systems in order to analyze the posture, and require wireless data transfer which consumes much more energy than local processing. The method in [9] focuses on risk reduction of spine related injuries occurring in certain work and recreational activities by developing a wearable device which tracks the position and movement of the spine. Disadvantages of wearable devices are that some users forget or refuse to put the wearable on, they can be intrusive and can produce false alarms caused by momentarily actions.

Considering the negative points of the addressed models in the previous approaches, such as, seated and fixed scan position, static mirror placement, additional sensors, third party devices, wearable requirement, wireless data transfer etc. we propose an algorithm that detects the posture of the person and decides whether it is a proper upright posture. Unlike [9], [11] and [12] which require sensors and wearables placed on different body parts or third party devices attached to the current system, our method relies on image analysis of a correct body placement. The silhouette of the person is detected by implementing a variation of the method explained in [16]. Contrary to the implementation in [10], which transfers the data wirelessly, our method analyses the data locally.

Our Smart Mirror eHealth Assistant is scanning the person's upper body half since the ideal placement of the mirror is above the bathroom sink. Additionally, the scan process does not require a fully undressed body in order to process information. Another advantage is that we are detecting body shape changes and pigmentation, i.e. color changes of the person's skin to conclude if there exists any type of skin illness.

III. NOVEL SMART MIRROR

Our proposed smart mirror will include some of the general everyday use features, such as, current time, alarm, to-do list, news feed, current weather, and voice e-mail reader. Another characteristic would be smart electricity management in the bathroom, or even the entire smart home. However, the main feature is analysis of the upper body in order to detect health issues. We greatly reduce human interaction with the mirror, by implementing face recognition authentication in order to automatically identify the user facing the mirror and personalize the experience accordingly.

The model workflow starts with photo shoot of the user, followed by the authentication process. The authentication step is essential for tailoring the user experience at highest levels, and personalizing the displayed information and analysis. Once the authentication is finished, the proposed algorithm begins the analysis and the results are evaluated, i.e. the new results are compared with the old results, and health progress timeline is displayed.

It is important for the smart mirror to be waterproof, since it is intended to be placed in bathrooms. The environment for the smart mirror needs to be without steam. That is why we are adding a sensor system that would detect steam on the mirror glass and activate air conditioning. A steam sensor such as Gravity's Steam Sensor [13] can be used. This sensor can be connected to Arduino IO Expansion shield directly. The output voltage will increase when the humidity of the sensor surface increases. Once steam is detected in the bathroom, a special fan can be activated to clear the steam on the mirror.

IV. WHY SMART MIRROR

Nowadays there is a relatively easy access to integrated circuits, also known as chips. With the introduction of System on Chip (SOC), such as the Raspberry Pi, the idea of developing smart devices for smart home is rapidly increasing its popularity. With smart mirror being increasingly popular project [2], [3], [17], [18], [19], [20] and [21], we wanted to integrate our proposed algorithm within similar project.

V. MODEL WORKFLOW

The fundamental purpose of the smart mirror Posture Analyzing Model concept which is elaborated within this paper, is to detect health problems or body changes by in-depth analysis and comparison of the individual's images. Once health issues are detected, the user will be able to schedule an appointment with a health specialist directly using the mirror features.

The algorithm that we proposed, requires that the user reflection is within the marked area on the mirror, and that the posture points match with the position of the balance points. The algorithm is smart, because it keeps track of the health progress and constantly updates the health advices. Ideally, after each analysis, the newly evaluated results are better than the old results. The general workflow model, follow the concept represented below:

1. Start
2. Photo shoot// Take Picture
3. Authentication ( )// Perform Facial Recognition Authentication
4. Check if the user has been analyzed before
   - IF recognized
     - Load personalized data// display relevant news, health advices, personal interests, and timeline of posture improvement progress
   - ELSE
     - Initialize the person in data storage
5. Run PAA// Launch Posture Analyze Algorithm (PAA)
6. Analysis//Evaluate Results
7. End

The mirror's algorithm can be launched by voice control, hand gestures, or by pressing a button on the side of the mirror. After the start of the algorithm, the user is given a visual notification of balance points and correct upright posture. After a short period of time, the integrated camera takes a picture and identifies the user using Robust Sparse Coding (RSC) algorithm with modifications, explained in [14].

The outcome of the modified RSC algorithm, dictates the further workflow of the model. If the person is recognized, information which is relevant to the user is displayed. Otherwise, the user is initialized in the storage system, optionally followed by introductory questions from variety of topics. The user profile is shaped based on the answers, as in the following example:

1. What was your age when you first encountered back problems? (Selection of age intervals to determine the age when the first signs of back pain occurred); what is your occupation? (Selection of multiple work activities); how often do you perform heavy physical activities? (Selection of time intervals).

The algorithm uses the provided information and the results after each analysis to improve its accuracy and adapt to the daily habits of every member in the household. On each iteration, the information is updated and more relevant health advices are shown. We recommend two optimal time periods for the analysis. In the morning, when the person is well rested and relaxed, and in the evening, when the person is getting ready to sleep. Every image is compared with the rest of the images on a daily basis in the same time period.

Besides the health advices and the topics of interests, the Smart Mirror keeps track of the analysis results over time. Every analyzed blueprint stores a hash combination of the date, time and the unique user specific value in order to distinct results by the time when the analysis was performed and the user who was analyzed. The storage of the timestamp-user hash combination is required in order to represent a visual timeline of the entire analysis history.

The most important step in the general workflow model is the algorithm proposed in the paper, the PAA. The algorithm is necessary because it visually guides the person on how to be positioned properly in order to perform accurate analysis. The result depends on the positioning of the key points on the individual's body according to the balance points on the mirror. The balance points (gravitational points) are centered vertically on the top and bottom edge of the mirror. The posture points are initialized by the algorithm after detailed scan of the silhouette on the picture. We have agreed on the following 7 posture points: the forehead, left ear, and right ear, left shoulder, right shoulder, breastbone (sternum), and the stomach. The posture points are then connected, constructing a total of 3+1 links: left ear and right ear, left shoulder and right shoulder, forehead point and neck point, neck and stomach and the overlapped forehead and stomach link. The mutual connection of the posture points is processed by measuring point distances and measuring intersection angles.

The algorithm requires fulfillment of predefined criteria in order to proceed with the evaluation of the results. The criteria is fulfilled if and only if: the forehead-neck-stomach connection link represents a straight vertical line and they overlap the top and bottom balance points on the mirror; the distance from the left ear and left shoulder posture points is equivalent to the right ear and right shoulder distance; the intersection of the lines must represent a perpendicular pair of straight lines.

Based on the discussed parameters, the general workflow implements the proposed PAA that would have the following pseudo format:

1. Start
2. IF posture points and balance points do NOT match
   - Give notifications
3. ELSE
   - Initialize Posture points (connections)
4. WHILE (criterion 1) AND (criterion 2) AND (criterion 3) are not fulfilled
   - IF forehead-neck-stomach link does NOT represent a straight line THEN
     - Give notification and visual representation of correct point placements and posture
   - ELSE
     - Criterion 1 satisfied
   - IF left ear-shoulder distance is NOT equivalent to ear-shoulder distance THEN
     - Give notification and visual representation of correct point placements and posture
   - ELSE
     - Criterion 2 satisfied
   - IF the intersection of lines represent a perpendicular pair of straight lines
     - Criterion 3 satisfied
5. Give visual notification that the posture is upright

As one of the most fundamental segments of the general model workflow, the PAA starts its iteration process after the posture points and balance points have matching positions. Over the original picture, a grid overlay is placed, which is used as a coordinate system template. Each posture point maps to its own coordinate system point. The reason for this is to assign each posture point with its corresponding x, y pair as shown in Fig.1.

The straight line of the forehead-neck-stomach link needs to go vertically through the center of the coordinate system neglecting the posture point position on the y-axis.

The second criterion requires that the distance between the left ear and the left shoulder points is equivalent to the distance between the right ear and the right shoulder points. The distance between the points can be calculated using the distance formula derived from the Pythagorean Theorem in equation 1:

$$PPD = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} + \varepsilon \quad (1)$$

Where PPD – Posture Points Distance; x, y – values of the two corresponding posture points; ε – posture points error threshold. The error threshold is necessary because the human anatomy is not perfectly symmetric. Hence, there is a possibility of a small distance error. Additionally, the ears connection line needs to be parallel to the shoulders connection line. The relation between them is determined with the following equation:

$$y = a \quad (2)$$

Where a - any constant number. These two lines are parallel to the x-axis.

An example of correct posture is shown on the left and an example of incorrect posture is shown on the right on Fig. 1 below:

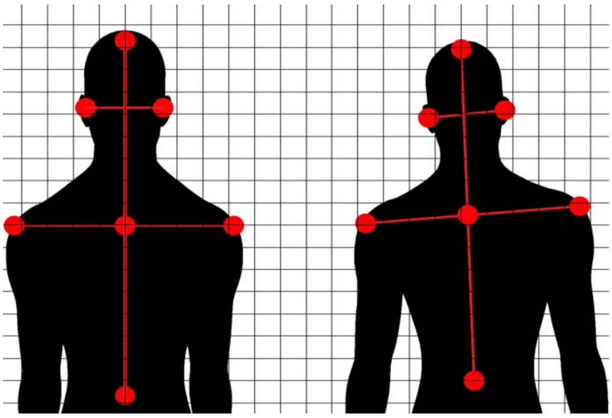

Fig. 1. Example of correct posture according to the predefined criteria (left), and example of incorrect posture (right)

Once the PAA finishes, the workflow continues with the evaluation process. The evaluation process contains the following steps:

1. Evaluate the results from the current analysis
2. Detect body changes (other possible diseases and body issues)
3. Compare current result with previous results

The improvement of the body posture is determined using modified PAA. During the evaluation process, the most recently scanned picture is placed over a series of picture models of abnormal posture and contorted spine. The posture points are compared with the predefined posture points on the abnormal models. These posture points are carefully generated by specific and detailed medical guidance. Based on posture point placement differences, the possible posture/spine disease is selected and appropriate diagnoses and treatments are displayed.

Another evaluation step is the one that detects other body changes, such as swelling and skin condition. Detection of such changes is done by comparing the current image with images from previous analysis, as shown on Fig. 2. The current image is subtracted from an image from previous analysis. If the result is different than zero, including error coefficient, then a body change is detected. In order to improve detection accuracy and picture model overlapping, the images are appropriately scaled by x and y axis aiming to match the outline of the silhouettes on both images. If the outline differences increase linearly, then a body change is diagnosed.

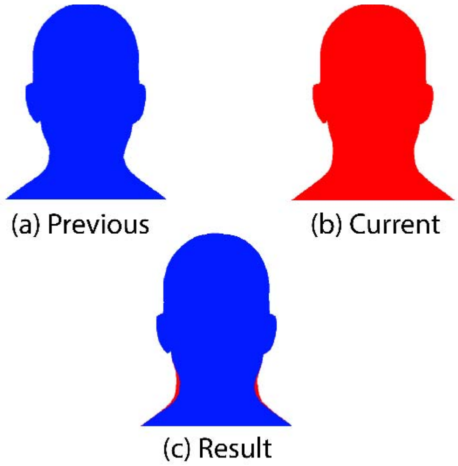

Fig. 2. (a) Previous analysis image; (b) current analysis image; (c) difference of both images where the difference is visible

The skin condition can be evaluated by comparing pigmentation on the skin. The silhouette of the person is analyzed using the method explained in [15], where hue filtering is used to segment the predefined colors, e.g. red shades determine skin irritation. Once the PAA ends, the following step is the evaluation of the results. These results are stored so that we can obtain history of health status of the users.

VI. Posture Analyze Algorithm Results

We applied the algorithm by creating a web application that would work on the smart mirror. The application displays the criteria status in the notification panel as shown on Fig 3:

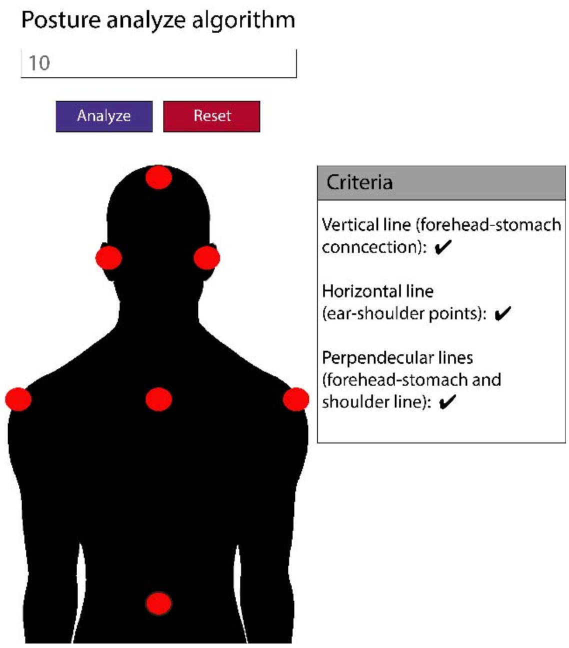

Fig. 3. Example of proper posture displayed the web application with satisfied criteria

The algorithm was applied on pictures of one person, taken over the course of 30 days. The results represented in Fig 4, are evaluated using (2) with error coefficient of 0.2. The analysis started with frequent point distances greater than the error coefficient. In later analysis the point distances between the left pair and right pair were equalizing, resulting with constant distance range between zero and the specified error coefficient.

Distance difference of zero, means perfect posture, while any value greater than zero, but lower than the error coefficient means satisfactory posture.

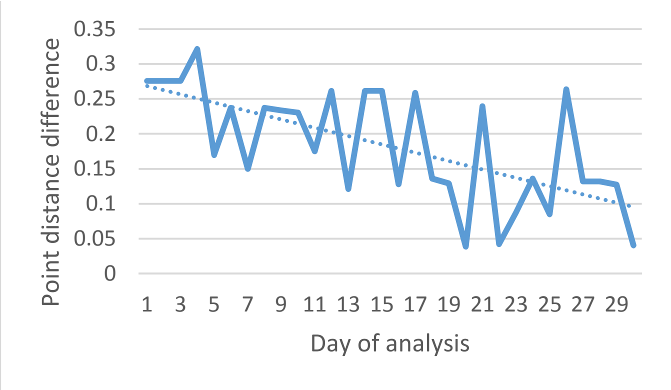

Fig. 4. Posture points distance variation within 30-day time period

The initial point distance of the left pair, had a value of 5.19, and the right pair had a point distance of 5.46, resulting with distance difference of 0.28, which is outside the satisfactory range. The point distance on the last day analysis was 4.97 for the left pair and 4.92 for the right pair, resulting with point distance difference of 0.04. As shown in Fig. 5, the final measurement represents a nearly perfect posture. However, the timespan for such results may vary from one individual to another, depending on any medical history and any other information that may account for certain postural abnormalities.

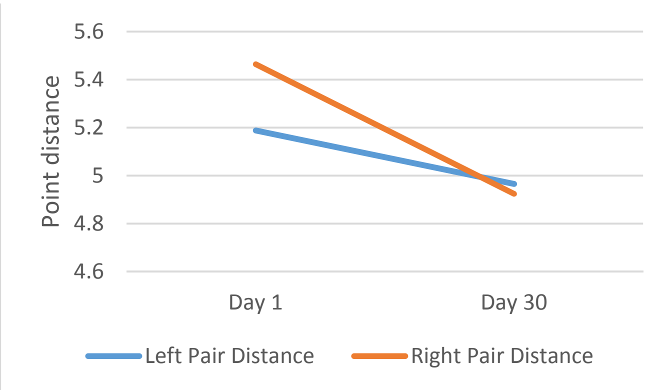

Fig. 5. Left pair and right pair distance reduction within 30-day period

VII. Conclusion And Future Work

The PAA efficiently guided the user to a proper position in front of the smart mirror. Our image processing approach offered simpler and more accurate detection of health issues. A skin detection analysis can be included to obtain even more information about the health of the person. The health status history would allow us to determine different diagnoses with high level of correctness and suggest healthcare preventives.

As a future direction, we will be working on communication with a wearable device, which will be used to obtain data about the health rate, blood pressure and physical activity stress levels. The obtained data will be used to determine the person's walking, running, cycling and sleeping patterns, in order to improve the healthcare preventives suggestions.

Moreover, doing a computerized tomography scan of the user through a mirror will be feasible in the future. This way, additional serious health issues, such as brain tumor, can be detected so that the user can act correspondingly.

Voice scan and vocal cord analysis would allow us detection of mild cold or lung health problems. This can be done by detecting and processing the frequency and wavelengths of the person's voice.

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