Tooth Adventure

A new approach to oral health best practices awareness

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***Abstract*— According to the World Health Organization (WHO), one of the global goals for oral health 2020 is to "minimize the impact of diseases of oral and craniofacial origin on health and psychosocial development, giving emphasis to promoting oral health and reducing oral disease". Aiming at WHO goal, Tooth Adventure game intends to achieve basic universal primary education by creating awareness on oral health, encouraging children to follow correct oral hygiene behaviors. In order to teach children adequate oral hygiene habits, the game provides information regarding the schedule and number of times they should brush their teeth, recommending brush duration, movements, details about dental floss usage in each teeth and the importance of a correct mouthwash practice. Tooth Adventure provides two different types of levels. One that is played using the mobile phone alone (Tap the bacteria, Brush the bacteria, Dental Floss and Mouthwash modes), and a second one in which the player must use an electronically instrumented toothbrush capable of capturing, in real-time, the performed movements and transmit them to the game. Such mode allows the game to provide feedback to the player about the captured toothbrush movements, and induce him to perform the correct movements in order to kill the different types of bacteria that appear on the teeth. The idea is that such practice will entice the player (even if unconsciously) to follow correct brushing methods, even when not playing.**

Keywords – serious game; oral hygiene; instrumented toothbrush; motion capture.

I. INTRODUCTION

Oral health hygiene affects both developed and underdeveloped countries, particularly when it comes to children, leading to several oral diseases, some of which bearing unrecoverable consequences. According to the World Health Organization (WHO), one of the global goals for oral health 2020 is to "minimize the impact of diseases of oral and craniofacial origin on health and psychosocial development, giving emphasis to promoting oral health and reducing oral disease (..)" [1].

Dental disorders, dental cavities, gingivitis, tooth decay and bad breath, are just but a few examples of the great amount of oral complications that affect children and adults alike, often with severe physical and psychological consequences. Oral hygiene is the most effective practice for keeping the mouth and teeth clean and is required for the healing and regeneration of oral tissues. Commonly, it includes mouthwash, dental floss and tooth brushing, practices of utmost importance for preventing gingivitis, and gum disease, cavities, dental plaque and tartar removal. Cleaning the tongue is also part of an essential part of daily oral hygiene removing dead cells from the dorsal area of the tongue [2, 3].

Different educational dental games have already been proposed giving information how kids should take care of their oral health [4, 5]. Other works concerns the correct time needed for brushing; some inventions present electronic toothbrushes that can detect what time the player should brush and for how long during a regular daily timetable [6-8].

Aiming at WHO goal, this work targets the development of a new serious mobile health game entitled Tooth Adventure. Such as other serious games [9], the Tooth Adventure game goes beyond pure entertainment and intends to achieve basic universal primary education by creating awareness on oral health towards children. It should encourage them to follow correct oral hygiene behaviors and advise on the best practices for brushing their teeth and using dental floss and mouthwash.

In order to teach children adequate oral hygiene habits, the game provides information regarding the schedule and number of times they should brush their teeth, recommended brush duration, movements, details about dental floss usage in each teeth and the importance of a correct mouthwash practice.

This paper describes the developed game, including the level modes, the associated hardware and its integration in the game workflow. A technical evaluation is also performed in order to access the game real time performance.

II. METHODS

Tooth Adventure provides two different types of levels: one that is played using the mobile phone alone (Tap the bacteria, Brush the bacteria, Dental Floss and Mouthwash modes), and a second one in which the player must use an electronically instrumented toothbrush capable of capturing, in real-time, the performed movements and transmit them to the game.

The mode involving the physical toothbrush allows the game to provide feedback to the player about the captured toothbrush movements, and induce him to perform the correct movements in order to kill the different types of bacteria that appear on the teeth. The idea is that such practice will entice the player (even if unconsciously) to follow correct brushing methods, even when not playing.

Each type of bacteria demands a particular type of movement (selected from a set of movements recommended by specialists) in order to be killed, such as placing the brush at a 45-degree angle towards the junction between the tooth and the gums, and moving the brush circularly or backwards and forwards horizontally in very short strokes. At some levels, the killing of bacteria will require the use of mouthwash and dental floss. The game collects all the information concerning the toothbrush movements and other inner game scores (dental floss and mouthwash), providing feedback to the user regarding his oral hygiene performance, and encouraging him to improve his behavior.

Tooth Adventurer was developed for a windows mobile platform under XNA 4 and C#.

A. Game Play

Upon starting the game, the player is presented with an intro video about the game theme. Then, a start screen will show you the game hero, Yoyo the Kangaroo. Yoyo's mission is to fight all bacteria that inflict damage to people's teeth around the world. To do so, Yoyo's starts a journey around the World, fighting the ugliest and strongest types of bacteria. Here, the player can choose between the following options: play menu, credits menu, help menu and sound control. It also provides a direct access to the different social network pages of Tooth Adventure Game, in particular Twitter, Facebook and Google Plus (Fig. 1).

Fig. 1 - Tooth Adventurer main menu screen.

When the player selects the play menu, he is presented with a new interface where he can sweep horizontally to choose between the available active worlds. Currently the game provides 4 different worlds to be played, namely the Australia World, the Aztec World, the Egypt World and the Medieval World (Fig. 2). Each world provides similar gameplay and levels, with the main difference between them being the difficulty degree, different background scenarios and music. The difficulty degree between levels is mainly achieved by the number of bacteria, their health, attack power and movement speed.

At the select level menu screen, inactive and active levels are presented by different types of teeth, which represent different types of games: Tap the bacteria, Brush the Bacteria, Dental Floss and Mouthwash modes. Some levels are represented by a golden tooth icon, giving access to a special level which can only be played with the Tooth Adventure Toothbrush. These special levels are only available to the player during certain periods of the day, corresponding to the recommended brushing times, i.e., 3 times a day and always after meals. The player is rewarded or penalized in terms of game score whenever he complies with or skips one of these brushing times, respectively.

Fig. 2 - Tooth Adventurer world menu screen.

Before each level different oral hygiene tips are also shown to the player (Fig. 3).

Fig. 3 - Tooth Adventurer oral hygiene tips.

B. Levels Type – Software Development

1) Tap the Bacteria

In the levels of type "Tap the Bacteria" the player must kill the bacteria by tapping the screen on top of each bacterium (Fig. 4).

For this kind of levels, a variant of Möller-Trumbore algorithm [10] was used to detect if the player tap above the bacterium mesh. When the player taps the smartphone screen, the 2D coordinates of the tap are used to define a 3D ray with a starting point at the world camera near clipping plane and an ending point at its far clipping plane. An intersection method loops through all ray points and checks if it intersects some triangle of the bacteria actor mesh. If so, the bacterium health is reduced.

Player score is determined by the time taken to kill all bacteria, with the level ending whenever all bacteria has been killed. Whenever bacteria are alive inside Yoyo's mouth, teeth will start to decay, becoming yellowish, with cracks and in the end, completely black and even missing. During this process vibration effects are also performed, to increase player's immersion sensation. These effects also happen in the other level modes, except for the levels of the type "Mouthwash".

Fig. 4 - Tap the Bacteria level example.

2) Brush the Bacteria

In the levels of type "Brush the Bacteria" the player must kill the bacteria by simulating brush movements with their finger on top of each bacterium. There are three different types of brush movements to be simulated with the finger, namely upward and downward vertical movements and circular movements (Fig. 5).

Fig. 5 - Brush the Bacteria help example.

The place and duration of each simulated movement in the game corresponds to the specialist's recommended brush movements for a correct oral hygiene practice. The idea is that by repeatedly playing Tooth Adventure, players will interiorize (even if unaware of it) correct tooth brushing practices, namely to use vertical downward movements in the upper jaw teeth, vertical upward movements in the lower jaw teeth and circular movements in the tongue or in any teeth [11]. The upward and downward vertical movements were implement as quick vertical and horizontal swipes over the screen. The velocity and the amount of points dragged for the player were used to classify the movement as a correct or incorrect movement.

On the other hand, there is a kind of bacteria that can only be killed if the player drags the finger over it while creating small circular movements. The principle behind the circle detection algorithm is based on the assumption that all circle's edge points have the same distance to its center, which equals to the circle's radius. For a given set of dragged points, the center and radius are calculated by finding a bounding rectangle for the specified set of points. Then, for each point it is calculated the mean distance between the provided points and the estimated circle closest point, checking if the value falls into a certain range. If the range is too big, the specified shape is not a circle, since its edge points are too further away from the estimated circle. Ideally, the value should be close to 0, meaning that all specified edge points fit very well the estimated circle. Depending on the difficulty level, a distortion factor is adjusted, e.g., allowing ellipsoid shapes to also kill some bacteria in easier levels.

When a correct movement is detected, one uses the same Ray Cast intersection algorithm to determine if a bacterium has been hit. In the case of vertical and horizontal movements, the ray origin is determined by the middle point of the swipe movement performed, while in the circular case, the ray origin is defined by the centroid of the circular movement.

3) Dental Floss

Dental floss levels are played using two fingers on the screen (multi-touch) to create a virtual dental floss. One of the fingers must be inside the mouth and the other outside, otherwise the virtual dental floss will not be created (Fig. 6). While playing the game, the player must move simultaneously both fingers, creating a waving effect (vertical and horizontal variations) that kills the bacteria in the gaps between the teeth.

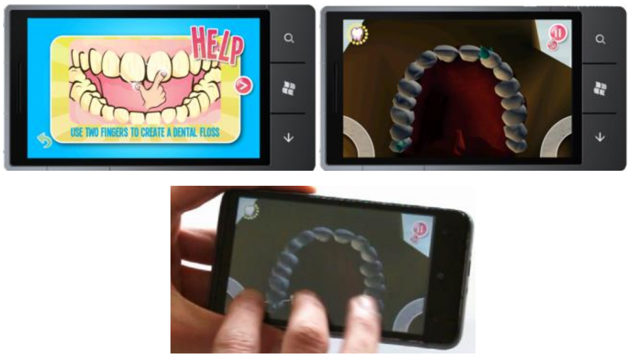

Fig. 6 - Dental Floss level example.

The implementation of the dental floss behavior was achieved using virtual (invisible) bounding rectangles, placed in each gap between the teeth. Whenever the player places his fingers correctly, one calculates a line (dashed line in Fig. 7) between each finger touch place (stars in Fig. 7). Then, in each game loop, the bounding rectangle closest to the fingers line is selected and the fingers line is divided in two other lines, one starting at one of the players fingers and ending at the middle point of the rectangle side closest to the finger point, and the other, applying the same strategy for the second finger. Only the last two lines are actually displayed to the player.

Each dental floss level is divided in two parts, one for each jaw of Yoyo. In each part the player has a predefined amount of time to kill all bacteria, after which the camera will move to the other jaw and the live bacteria inflict a certain amount of damage to Yoyo's oral health. Once more, the idea is to aware the player for the use of dental floss and to instruct him about the correct usage of this important oral hygiene practice.

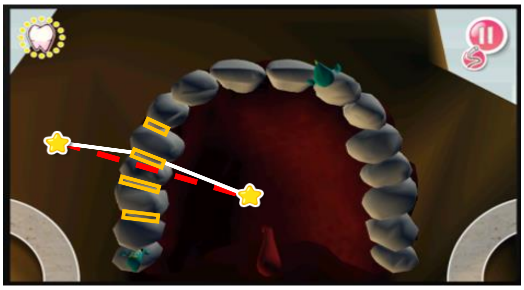

Fig. 7 - Dental Floss Level Implementation

4) Mouthwash

In this type of levels the player finds himself inside Yoyo's mouth full with a liquid substance, the mouthwash. As the level evolves, bacteria will start to appear in several places inside Yoyo's mouth, and can only be killed by mouthwash bubbles (Fig. 8).

To make the number of bubbles increase, and improve the mouthwash power to kill bacteria, the player must shake the phone. The longer and faster the shakes are, the more bubbles will be produced. As time goes by without shaking the phone, bubbles start to disappear and the power to kill bacteria reduces. The shaking motion is detected by evaluating left-right and up-down variation of the smartphone accelerometer.

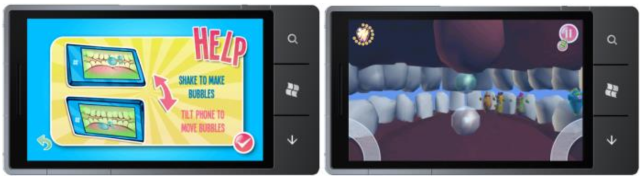

Fig. 8 - Mouthwash level example.

The mouthwash level was implemented using the Farseer Physics Engine (v3.2) which allowed the creation of bacteria actors obeying to natural physics rules inside Yoyo's mouth. All bacteria are implemented as spherical bounding boxes that move under different velocities and can collide with other objects. These bacteria will appear in random positions and move and bounce with different velocities and accelerations (according to the level difficulty).

To kill the bacteria the player must physically collide the mouthwash bubbles on top of each bacterium for a certain amount of time – depending on the amount of active bubbles and the health of the bacterium. To this extent, the player must use the phone accelerometer (by tilting the phone counterclockwise, clockwise, forward and backward respectively) to move the mouthwash bubbles throughout the mouth area towards the bacteria.

5) Virtual Toothbrush Level

The levels represented by the golden tooth are special levels which can only be played with the Tooth Adventure Toothbrush, an electronically instrumented toothbrush which is able to capture the physical movements being made and send it to the phone running the game (described in hardware section D). In order to increase the availability of this type of level to a greater number of players, one has opted to implement the motion capture electronics in an independent device which is coupled with rubber bands to any standard toothbrush (Fig. 9).

This special level is made available to the player according to the elapsed time after the last time it was previously played. The reason for this is to control and educate players about the correct times to brush their teeth. Furthermore, if this level was always available, it could provide the wrong idea that the player should brush their teeth as many times as possible.

Fig. 9 - Virtual Toothbrush level explanation.

This level gameplay is very similar to levels of type "Brush the Bacteria", but instead of using his fingers to simulate the brush movements, now the player has to actually use a real toothbrush to produce the correct movements to kill bacteria. The Tooth Adventure Toothbrush captures all the movements (position and orientation) in real time, simulating the movements on a virtual toothbrush over Yoyo's teeth. The implementation of this gameplay feature was achieved by adapting the toothbrush yaw orientation to a spline that follows the jaw contour. According to the physical toothbrush orientation, the virtual toothbrush will be placed in the corresponding closest spline position. The physical toothbrush roll angle is transferred to the virtual world by rotating the virtual toothbrush model over the corresponding spline tangents (Fig. 10).

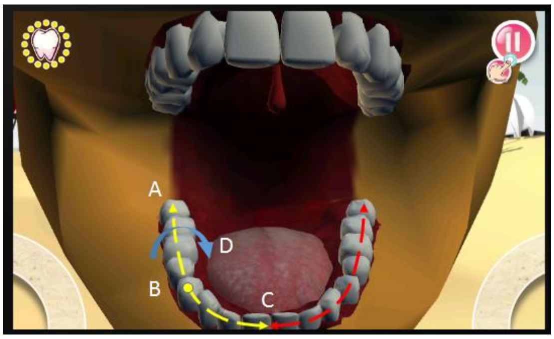

Fig. 10 - Virtual Toothbrush trajectory interpretation.

Every golden tooth level is implemented in a way to simulate the correct brushing practice, in particular by presetting bacteria in specific places of the teeth (inside, outside and above), so that all teeth get correctly cleaned and the player spends about 30 seconds in each jaw quadrant. This levels also induce the player to perform correct movements in order to kill the different bacteria that appear on the teeth.

6) Score

In each level, the score at each time t, $S(t)$, is given according to the performance of the player using the following equation:

$$S(t) = S(t-1) + \lambda \cdot K_{kill} \cdot n_{dead} - \sum_{i=1}^{n_{alive}} AP_i \cdot H_i$$

where, $AP = \lambda \cdot K_{AP}$ and $H = \lambda \cdot K_{Health} \cdot \alpha$ with $\alpha \in [0,1]$. AP represents the attack power of a given bacterium and corresponds to the Yoyo's oral health damage, determining the speed that the bacterium leads to the decay of the tooth; H is the bacterium health that determines the amount of damage needed to kill each bacterium (taps, brush movements, dental floss slides and mouthwash bubbles collisions); K_{AP}, K_{Health} and K_{kill} represent constant values concerning the predefined attack power and health of the bacterium, and points won by killing one, respectively; λ is a difficulty factor associated with each level; n_{dead} and n_{alive} correspond to the number of killed and alive bacteria, respectively, since the last time point.

During level playing, in the middle of the circular health display (upper right corner) there is a tooth, whose aspect decays according to the game performance of the player. Each time the player kills a bacterium, the circular display gets more filled and the tooth acquires a healthier aspect. Whenever there are bacteria alive inside the mouth, the tooth will start to look darker and unhealthier.

7) Levels

Different XML files were to store level information according to the characteristics and 3D position that the bacteria will appear in the Yoyo's mouth. The XML file also contains information regarding the health and attack power constants for each bacterium. Moreover, all information regarding the worlds menu and levels selection menu are also described in their respective XML file. The current high score, inactive and active worlds and levels and settings are also stored in XML files.

C. 3D Models

The XNA Framework (Microsoft) was the primarily technology used for the game development, while the virtual models were created using Blender 3D modeling software and exported in .fbx format.

Due to the mobile platform performance limitation, each model was designed with a limited number of faces and animations. The virtual model of Yoyo the Kangaroo is limited to 3000 faces and 1 animation, while each bacterium was limited to 500 faces and 2 animations. Surface mesh simplification was accomplished by decimating the models until achieving each imposed face limitation, followed by a surface remeshing and an automatic vertex relaxing smooth in Blender 3D.

After model preparation a digital skeleton was bound to the 3D mesh through a manual rigging process, specifying its internal skeletal structure and how the input motion deforms its surface. Yoyo the Kangaroo skeleton was specified with 16 bones (1 in each foot, 2 in each leg, 1 as root, 2 in each arm and 5 in the head). Each bacteria skeleton has 9 bones (1 as tail, 1 as root, 1 in each arm and 5 in the head). Then, faces near a bone were associated to a deformation group through a skinning process. This process allowed deforming the body surface according to the skeleton movement. Defining some poses along the time frame (2 seconds), the animation is created by smoothly interpolating skeleton from pose *i* to pose *i+1*.

Each bacteria was animated with one attack movement and one dying action. Yoyo performs a running animation waving at the player on each level start and then keeps the mouth oriented to the screen.

D. Hardware development

The acquisition hardware specifically developed for the Tooth Adventure Toothbrush device was selected to ensure the capture of all inertial movements in real time and *Plug and Play* to any toothbrush (Fig. 11 - Tooth Adventure Toothbrush device hardware schematic.Fig. 11). To this end, the requisites of this system are: a) absolute device orientation; b) wireless data transmission; and c) miniaturization.

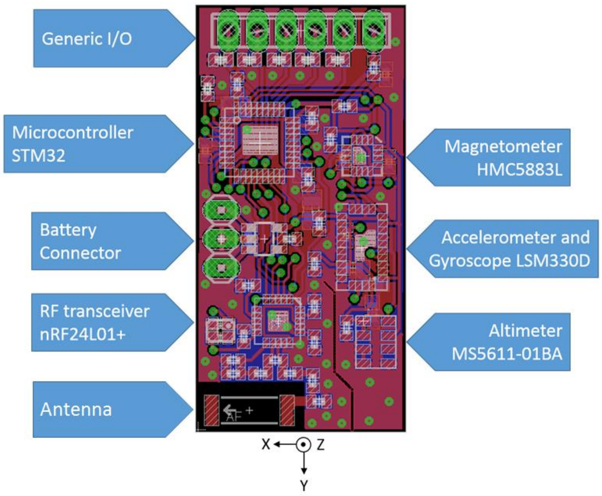

Fig. 11 - Tooth Adventure Toothbrush device hardware schematic.

To ensure the smooth movement with reduced glitches the embedded algorithm computes new orientations at a rate of 250Hz followed by a cumulative moving average. This high update rate would force the mobile phone to a high CPU usage and reducing game performance. A downsampling by a factor of 10 was applied before sending data to the phone to reduce such effect.

One important hardware requisite was the need for the device to operate in a complete wireless environment, otherwise its use in real world scenarios would become much compromised. To this extent, all communications between the Tooth Adventure Toothbrush and the windows phone device are performed using the UDP protocol over a WI-FI connection, and the device is powered by a small portable battery which is charged when the device is placed in its base.

The main hardware board is divided in four main modules: a) a 10 degrees of freedom (DOFs) inertial measurement unit, b) a Wi-Fly RN-131C wireless 802.11b/g networking module and a 2.4GHz GFSK RF transceiver, c) a power management module and d) an embedded STM32 ARM processor.

1) 10 DoF Inertial Measurement Unit

The 10 DOFs IMU features a 6-axis LSM330D accelerometer and gyroscope, a 3-axis HMC5883L magnetometer and a MS5611-01BA. The inter-IC communication is accomplished through a shared I2C protocol with all three chips at clock frequencies up to 400 kHz.

The LSM330D, HMC5883L, and MS5611-01BA have many configurable options, including selectable resolutions for the altimeter and dynamically selectable sensitivities for the gyro, accelerometer, and magnetometer. The devices were configured as follow:

Gyroscope: one 16-bit word per axis (±500)
Accelerometer: one 16-bit word per axis (±4 g)
Magnetometer: one 12-bit word per axis (± 1.3 Ga)
Altimeter: 24-bit pressure word (4096 LSb/mbar)

The nine independent rotation, acceleration, and magnetic readings provide all the data needed to make an attitude and heading reference system (AHRS). Readings from the absolute pressure sensor can be easily converted to altitudes, giving a total of ten independent measurements.

The gyro can be used to accurately track rotation on a short timescale, while the accelerometer and compass help compensate for gyro drift over time, by providing an absolute frame of reference.

Using the Robert Mahony *et al.*, Direction Cosine Matrix (DCM) based AHRS algorithm, one calculates the orientation and height of the toothbrush [12-14].

To this end, the respective axes of the two chips (HMC5883L and LSM330D) need to be aligned on the board to facilitate these sensor fusion calculations.

2) Wireless data transmission

Transmitting data to a remote device, in this case a smartphone with Windows Phone OS 7.1, is accomplished using a Wi-Fly RN-131C wireless 802.11b/g networking module. Due to an OS limitation, the Bluetooth Serial Port (SSP) API is not accessible.

To overcome this issue, an intermediate router, TP-LINK TL-WR702N, located under the Tooth Adventure Base (Fig. 12), is used to create a private wireless 802.11b/g network, allowing a fast communication between the toothbrush device and the smartphone. The data is packaged and sent using the UDP protocol in broadcast configuration. The UDP protocol was selected mainly because of its connectionless nature, being suited for applications that cannot tolerate too much latency but can tolerate some data errors.

The Wi-Fly module incorporates a 2.4GHz radio, processor, TCP/IP stack, real-time clock, crypto accelerator, power management and analog sensor interfaces. The module only requires four connections (PWR, TX, RX, GND) to create a wireless data connection. This connections (RS232 protocol) are exposed under the main hardware board and connected to the STM32 ARM microcontroller.

The WiFly GSX module is programmed at power-up by the microcontroller with a simple ASCII language command with predefined parameters to connect to the private network. The wireless data rate plays an important role with the UDP protocol, given that for increased data rates, more packets are lost. To address this issue, the wireless data rate was fixed at a low 2Mbit/sec, providing a good balance between data rate and packets loss.

Fig. 12 - Virtual Toothbrush device, base and game.

The communication between microcontroller and the Wi-Fly module was established using a baudrate of 115200 bps.

A single-chip 2.4GHz GFSK RF transceiver (nRF24L01+) is used at the main hardware board for dedicated wireless connection and for future expansion modules, such as an interactive Tooth Adventure Base.

3) Embedded processor and communication

Achieving a real-time tracking of the toothbrush, important to create a smooth motion in Tooth Adventure, is a complex and time-consuming operation for an embedded processor. Some newer embedded processor such as the Cortex-M3 family from ARM, ease this problem by providing high clock speeds (up to 72MHz) and single-cycle arithmetic operations which help boost the AHRS algorithm throughput.

In essence, the DCM method is actually a complementary filter forming an attitude estimate by combining the gyro angular rates (which have a low-frequency bias but are pretty good at high frequencies) with low-frequency attitude references (e.g. magnetic heading and an IMU-based gravity vector estimate). So, the high frequency components of the integrated gyro measurements are passed, along with the low-frequency attitudes derived from the references; the low frequency gyro biases are rejected.

Then these measures are feed in a PI controller, with the integral gain, Ki, determining the filter crossover frequency, and the proportional gain, Kp, trades the damping and high-frequency noise suppression. The AHRS feedback controller provides 3 output angles (Yaw, Pitch and Roll angles).

The transmitted data format between smartphone and toothbrush are summarized in Table I.

TABLE I. COMMAND SYNTAX BETWEEN TOOTHBRUSH AND PHONE.

	Toothbrush to Phone								
@	***float 1***	***float 2***	***float 3***	***byte 4***	***byte 5***	***byte 6***	***byte 7***	***#***	***Definition***
Begin	***Angle***	***Angle***	***Angle***	***Acc***	***Acc***	***Acc***	***Check sum***	***End***	
@	yaw	pitch	roll	accX	accY	accZ	0x00	#	Data transmitted

4) Motion Transformation

Moving the virtual toothbrush around the teeth is accomplished by using the data frame values of yaw, pitch and roll, in combination with a spline defined by the center of each teeth (Fig. 10).

Based on the yaw angle (limited from 0º to +90º) of the physical toothbrush, the virtual toothbrush is placed on the corresponding point of the previously calculated spline. The roll angle (limited from -100º to +100º) is used to produce the rotation around the spline tangential axis. Near -100º the virtual toothbrush is completely on the outer side of the teeth, at 0º it is above the teeth and at +100º it is at the inner most part of the teeth. The physical pitch angle also influences the virtual toothbrush representation by defining its tilt. Acceleration in the X and Z axis are used to simulate a toothbrush jitter and increase the toothpaste bubbles.

After each 30 seconds, the player must change the toothbrush position to match the orientation defined in game.

5) System Calibration

The *Plug and Play* and removable features of our solution demand for a configuration process before playing the Virtual Toothbrush Level. This is something very common in recent digital games that employ sensor interfaces (e.g., most Wii games contain a calibration phase of the motion tracking sensor attached).

To successfully accomplish the device calibration procedure, the Toothbrush must be placed in a horizontal position in front of the teeth after starting the game. This process takes up to 10 *seconds* to calibrate.

After this phase, one is *able* to initiate the game with full and accurate tracking of movements performed.

III. EVALUATION

Validation of the developed game was twofold: first, a technical test to check the performance of the game, as well as the performance and accuracy of the electronically instrumented toothbrush; and secondly, a user evaluation to investigate what would be the children reaction to the game and evaluate their increased awareness in oral hygiene. In the present work, one will present the first evaluation procedure and results, while discussing the methodology to be applied to assess the second in future work.

1) Technical Evaluation

Although user evaluation is the most significant form of evaluating a new serious game, a technical evaluation cannot be discarded to evaluate the overall computational performance of the proposed game and associated hardware. Thus, a technical evaluation encompassing the usage of three mobile devices (Samsung Omnia 7, HTC 7 Trophy and HTC HD7) was performed to analyze the following performance aspects: a) in-game frames per second (FPS), namely minimum/maximum range and average range; and b) number of frames received by UDP in the independent thread in the mobile game.

The first evaluation was performed by measuring the achieved FPS while running each level mode and for each mobile device. The maximum and minimum FPS were obtained without any bacterium displayed (only Yoyo's mouth model and the remaining in-game icons) and with the maximum number of bacteria allowed (whose number was limited to avoid excessive CPU usage and consequent inoperability of the device), respectively. On the other hand, the average range of FPS were obtained while playing the game with the average number of bacteria for a given level. The results are summarized in Table II.

TABLE II. TOOTH ADVENTURE PERFORMANCE

Model	Measure	Tap	Brush	Dental Floss	Mouthwash
Omnia 7	**min/max**	[9-19]	[8-17]	[9-18]	[13-24]
	average	[13-16]	[14-16]	[14-17]	[19-22]
7 Trophy	**min/max**	[9-20]	[10-19]	[11-20]	[10-21]
	average	[15-16]	[14-15]	[16-18]	[18-20]
HD7	**min/max**	[9-20]	[9-19]	[11-18]	[14-21]
	average	[15-17]	[12-15]	[16-18]	[18-21]

The second technical evaluation comprehends the analysis of the number of frames received using the abovementioned Wi-Fi connection. To this extent, each transmitted and received frame was associated with a time stamp, and the number of received frames in each second was measured and averaged.

The independent thread used was able to receive 20 FPS of data with the orientation of the Tooth Adventure Toothbrush. Note that the Wi-Fly module sends an average of 25 FPS, meaning that 5 frames are discarded due to errors (using the checksum feature) or lost due to connection and reading issues. Nevertheless, taking into account the number of FPS achieved by the mobile game application, the transmitted data rate is enough for an efficient movement of the virtual toothbrush during gameplay.

The results obtained allow one to conclude that there is no significant differences in performance between each of the tested devices. This is a rather unexpected result, since the game makes significant use of several different components of the mobile device, namely CPU-GPU, memory, wireless network module and accelerometer sensors. Based on these results, we intend to perform the same tests in more recent devices, where increased FPS are expected.

A third evaluation would encompass the use of a precision external motion tracking system to validate the orientation of the toothbrush device and virtual model. Due to the absence of such device at the time of evaluation, such evaluation was only performed qualitatively by visually assessing the correspondence between real brush movements and virtual ones. A good correspondence was achieved for the range of orientations and roll angles permitted. As future work, the angle displacement should be quantitatively assessed using the proposed external motion tracking system.

2) User Evaluation

The methodology to assess educational advantages of the proposed game must be performed with the target player, children. Therefore, a group of children, with ages from 9 to 12 years, will be separated into two groups (with at least 15 children each): a) group A (control group) to whom the correct oral hygiene behaviors and advices on the best practices for brushing their teeth, usage of dental floss and mouthwash will be theoretically described without gameplay; and b) group B for whom the same practices will be described and highlighted while playing the Tooth Adventure game. The session time in each group is programmed for 60 minutes, over a period of 1 week. After this exposure, a questionnaire will be prepared and presented to the children in order to evaluate their awareness regarding oral hygiene behaviors.

From the questionnaire, one should be able to determine if the Tooth Adventure game improved their awareness in oral hygiene, compared to the theoretical learning in the control group. The questionnaire resorts to assessing their awareness in the following 6 main aspects: oral hygiene practices; diet habits for a good oral hygiene; mouthwash usage importance; dental floss usage importance; correct toothbrush movements; and recommended brushing schedule, frequency and duration.

IV. CONCLUSION

This work proposes a mobile game specifically aiming at the awareness of continuous oral hygiene practices in children. To this extent, the game introduces a novel peripheral device to be attached to a real toothbrush, capable of capturing all motion movements of the toothbrush. The motion movements captured are then send to the mobile game in order to control a virtual toothbrush, with which the player can overcome a series of different levels.

Both the hardware developed and digital game were evaluated technically, by assessing the performance of the major device components being used in different situations, namely CPU-GPU, memory, network and accelerometer sensors.

Interesting topics for future work include:

a) Personalization of the different game elements (toothbrush powers, mouthwash color and power, etc.), as a reward for good in game performances.

b) Develop new bacteria with different characteristics and animations;

c) Include more super powers for each type of levels;

d) Provide detailed information and analysis to the player about his brush movements’ correctness in the virtual toothbrush levels;

e) Include the option of sending a report to the dentist, based on the performance achieved in the virtual toothbrush level, with qualitative information, regarding brush movements, duration and schedule.

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