Phantom Limb Pain Management Using Facial Expression Analysis, Biofeedback and Augmented Reality Interfacing

D. Tzionas, K. Vrenas, S. Eleftheriadis, S. Georgoulis, P. C. Petrantonakis, and L. J. Hadjileontiadis
Dept. of Electrical & Computer Engineering
Aristotle University of Thessaloniki
GR 54124 Thessaloniki, Greece
leontios@auth.gr

***Abstract*—Post-amputation sensation often translates to the feeling of severe pain in the missing limb, referred to as *phantom limb pain* (PLP). A clear and rational treatment regimen is difficult to establish, as long as the underlying pathophysiology is not fully known. In this work, an innovative PLP management system is presented, as a module of an holistic computer-mediated pain management environment, namely *Epione*. The proposed *Epione*-PLP scheme is structured upon advanced facial expression analysis, used to form a dynamic pain meter, which, in turn, is used to trigger biofeedback and augmented reality-based PLP distraction scenarios. The latter incorporate a model of the missing limb for its visualization, in an effort to provide to the amputee the feeling of its existence and control, and, thus, maximize his/her PLP relief. The novel *Epione*-PLP management approach integrates edge-technology within the context of personalized health and it could be used to facilitate easing of PLP patients' suffering, provide efficient progress monitoring and contribute to the increase in their quality of life.**

I. INTRODUCTION

Pain, although it is the oldest medical problem and the universal physical affliction of mankind, it has been little understood in physiology until very recently. Nowadays, pain is generally agreed-upon as an experience which involves more than just physical sensations. The International Association for the Study of Pain (IASP)'s defines pain as 'an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage' [1].

The most common types of pain are [1] *acute pain* (results from disease, inflammation, or injury to tissues) and *chronic pain* (is widely believed to represent disease itself), which both remain a huge problem. One of the peculiar type of pain is the one that relates with the post-amputation sensation. In fact, many amputees are frequently aware of severe *phantom limb pain* (PLP) in the absent limb, since the brain cells affected by amputation do not simply die off, but neurons in the brain remain dynamic and excitable. PLP is real and is often accompanied by other health problems, such as depression.

As pain is directly connected to the patient's everyday life, its management is of great importance to elevated his/her quality of life. The goal of pain management is to easing the suffering and improving the quality of life of those living with pain, enabling them to work, attend school, or participate in other day-to-day activities. Treatment approaches to long term pain include pharmacologic measures, interventional procedures, physical therapy, physical exercise, application of ice and/or heat, and psychological measures, such as biofeedback and cognitive behavioral therapy, like relaxation and the use of imagery as a distraction that provides relief [2]. Actually, pain management sets a challenging field, where edge technology could be incorporated within pain management approaches to create an effective environment that could contribute to better pain handling; hence, improving the quality of life at a global level.

In this work, a PLP management system is presented. This is, actually, a module of an holistic computer-mediated pain management environment, namely *Epione*[1][3]. The proposed *Epione*-PLP scheme uses advanced facial expression analysis, as a means to form a dynamic pain meter, which is then used to trigger biofeedback and augmented reality-based PLP distraction scenarios. The latter are structured upon a model of the missing limb for its visualization, in an effort to create to the amputee the feeling of its existence and control, and, thus, maximize his/her PLP relief. The proposed system introduces a novel environment of PLP management that could assist patients and physicians during the process of easing of suffering, contributing to the new culture of *Personalized Healthcare*[2].

II. BACKGROUND

A. Phantom Limb Pain (PLP)

Ambroise Paré (1510-1590), a French military surgeon, has given the first medical description of post-amputation sensation, who noticed that patients may complain of severe pain in the missing limb following amputation. Paré characterized the post-amputation syndrome in his 'Haquebusses and other guns' and

---

[1] *Epione* (*Ηπιόνη*) was the goddess of the soothing of pain. She was the wife of the medicine god *Asklepios*, and the mother of a number of minor healing gods, including *Hygeia* (Good Health), *Panakeia* (All-Cures) and *Iaso* (Healing).

[2] *Personalized Healthcare* is an important new approach to medicine, providing great benefits to patients, by improving treatment, enabling people to monitor their own health, increasing compliance and providing inputs to computer systems and associated communications networks and embedded devices that will make it possible to organize, interpret and interrogate this information and apply it to tailoring medical treatment. Personalized Healthcare is at the core of the European Community Initiative 'European Research Area 2030: Preparing Europe for a New Renaissance-A Strategic View of the European Research Area' [4].

proposed different models to explain the pain [5] Subsequent studies by Charles Bell (1830), Magendie (1833), Rhone (1842), Guéniot (1861) and others gave detailed descriptions of the phenomenon and, in 1871, Mitchell introduced the term 'phantom limb' [6], [7].

Nowadays, it is common knowledge that virtually all amputees experience phantom sensations after limb amputation; the phantom becomes the site of severe pain, which may be exceedingly difficult to treat. A clear and rational treatment regimen is quite difficult to establish, since the underlying pathophysiology is not fully known. Nevertheless, nerve injury is followed by a series of changes in the peripheral and the central nervous system; hence, these changes play a role in the induction and maintenance of chronic phantom pain [8]. Following a nerve cut, formation of neuromas are seen universally, which show spontaneous and abnormal evoked activity following mechanical or chemical stimulation [9]. The ectopic and increased spontaneous and evoked activity from the periphery is assumed to be the result of a novel expression or up-regulation of sodium channels [10]. The sympathetic nervous system may also play an important role in generating and, in particular, in maintaining PLP [11]. Studies based on electrophysiology have documented the existence of nociceptive specific neurons and wide dynamic range neurons in the cerebral cortex. Following limb amputation and deafferentation of adult monkeys, there is a reorganization of the primary somatosensory cortex, sub-cortex and thalamus [12]. A similar reorganization has been observed in humans based on the information from the magnetoencephalogram. Interestingly, this cerebral reorganization was seen mostly in patients with PLP and there was a linear relationship between pain and degree of reorganization [13].

From the aforementioned, it is likely that the first PLP events occur in the periphery, which subsequently generates a cascade of events that sweep more centrally and also recruit cortical brain structures [8].

The occurrence of PLP seems to be independent of age in adults, gender and level, or side of amputation [14]. Moreover, the incidence of PLP is similar following civilian or military accidents [15]. Several studies have shown that 75% of patients develop pain within the first few days after amputation [16]. However, phantom pain may be delayed for months or years. PLP is described as shooting, stabbing, boring, squeezing, throbbing, and burning [16]. Moreover, PLP is primarily localized in distal parts of the missing limb (fingers and palms in upper limb amputees and toes, instep, top of the foot and ankle in lower limb amputees) [17].

B. PLP Management Strategies

Treatment of PLP can be classified as medical, non-medical and surgical [8]. In general, treatment should be based on non-invasive techniques as surgical procedures carry a risk of further deafferentation resulting in even more pain. In this vein, some PLP management strategies have been proposed, based on medication [18]. However, some others try to provide the amputee with alternative ways to handle the PLP suffering, with the 'mirror box'-based being the most well-known therapy, introduced by Dr. Ramachandran [19] at the University of California San Diego.

Fig. 1. An example of the use of the 'miror box'-based therapy by a left-hand amputee. The patient places his normal hand on one side and looks into the mirror getting the illusion that the amputated hand has returned [20].

'Mirror-box'-based therapy is a drug free treatment and has been described in medical literature to be of benefit to 80% of users (some even report numbers as high as 95%) and that rehabilitation can be dramatically improved by integrating physical and mental practice. This is achieved by utilizing mirrors to trick patients' brains into thinking that they were moving their missing limb. The use of visual feedback with the 'mirror box' as a technique accelerates the recover from PLP. In fact, the patient places the affected limb inside the 'mirror box' and his/her unaffected limb in front of the mirror. Seeing the reflection of the unaffected limb, the patient thus receives visual feedback from a virtual image of his/her affected limb appearing as if it is normal (Fig. 1) [20].

There is, however, great variability in the experienced authenticity of the 'mirror box' illusion and its ability to alleviate PLP. The effect of this positive visual feedback to the amputee can be very therapeutic. The latter translates into reposition of phantom limbs, which were perceived to be held in painful or awkward positions, into non-painful postures, giving temporary relief from PLP. Amputees' perceptions of their phantom limbs, however, often differ greatly from their original limbs [21]. In such cases, the phantom limb can be shorter, or longer, vary in thickness, have gaps or be continuous, in comparison to the original limb. This is one cause for the inability of the 'mirror box' illusion to provide any therapeutic value in some cases, as the reflected image bears no resemblance to the phantom limb as it is perceived by the amputee. These irregularly shaped phantoms cannot be viewed in the mirror, as it necessarily reflects the image of the intact arm.

To circumvent the aforementioned disadvantages, Augmented Reality (AR)-based 'mirror box' illusion simulation has been proposed [22]. There, a 3-dimension (3D) graphical representation of an arm on a flat screen that is controlled by a wireless data glove is implemented. The latter is worn on the intact arm, whilst the phantom appears on the flat screen in place of the mirror. As the intact arm moves, the arm on the screen representing the phantom also moves in unison. This AR-based PLP management approach has shown some evidence of successful PLP relief [22]; thus, its concept was adopted and extended further when placed within the *Epione* pain management environment, as described in the succeeding sections.

III. EPIONE PAIN MANAGEMENT ENVIRONMENT

A. *Epione's Components*

Epione is an integrated pain management environment that includes adaptation to personalized pain behavior via facial expression monitoring, adapted 3D distraction strategies, wireless biofeedback and AR -based limb reconstruction [3]. These are all combined and implemented in a revolutionary 'vault-like' 3D-space (*Epione Vault*). The latter, draws information from social networks (e.g., Facebook, Tweeter, Skype) via Web services and/or user's feeds, creating a personal space at the *Epione Server*, where the patient interacts and communicates with more 'natural' modalities (e.g., gestures, voice commands). Friends, colleagues, personal physicians, supporting groups, are all visualized and distributed in a user-defined hierarchy at the Epione Vault 3D space, creating an on-line network of interaction and socialization. A series of relaxing and imagery activities within the Epione Vault (e.g., 3D navigation through Microsoft Virtual Earth, user-defined relaxing-entertaining environments) are initiated, following the physician's therapy schedule.

During the interaction, a user-transparent monitoring system, based on the PC webcam video capturing, continuously analyzes the user's facial expression, by involving advanced face detection-tracking-classification algorithms, informing the *Epione Control Center* (Epione CC) with the appropriate feedback for his/her current pain level. According to the latter, the Epione CC performs the appropriate adjustments (e.g., triggering appropriate RSS feeds into the Epione Vault that fit to the user's interest, alters the biofeedback intensity of the wearable wireless TENS[3]), trying to increase the distraction and decrease the pain feeling.

Using a 3D limb model (e.g., hand model) embedded in the Epione Vault via augmented reality (AR), the user, by wearing specific AR-glasses, gets the feeling of the missing limb, and by wearing wireless accelerometers could move the reconstructed hand to perform specific tasks. In this way an 'augmented mirror box' is developed to allow artificial visual feedback to be remotely generated (i.e., generated independently of contralateral limb movement), thus facilitating presentation of non-contingent phantom limb movement. If phantom pain experience is influenced by contradictory proprioceptive and visual feedback, manipulation of the association between 'felt' movements and visually presented movements could have therapeutic potential.

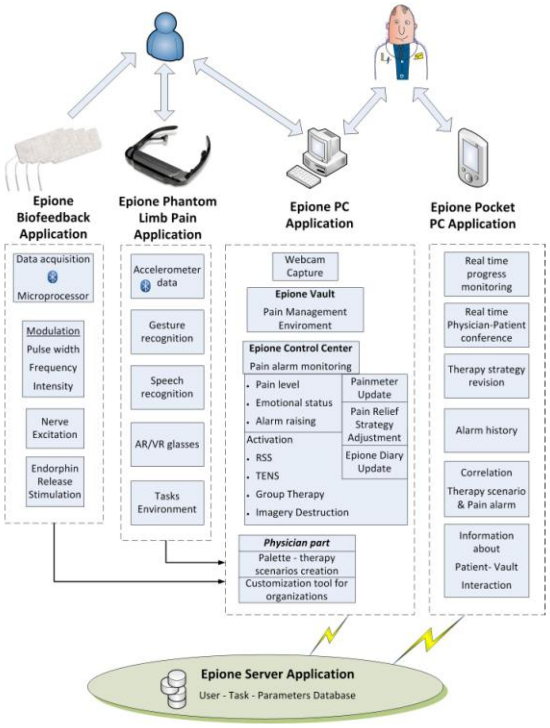

Fig. 2. Organizational block-diagram of the Epione pain management environment [3].

All interactions and pain episodes are archived in the *Epione Diary*, at the *Epione Server* site, so statistical analysis, comparisons and reports are also outputted from *Epione*, providing valuable information, both to the patient (self-monitoring) and the physician (patient-monitoring). The latter, by also using the Pocket PC interface of *Epione* (*Epione On-the-Go*), is capable of interacting with the on-line patients (e.g., via direct connection and live interaction) and/or review the statistics (e.g., pain alarms, usage of specific tasks) of his/her patients, according to the scheduled therapy plan, evaluate his/her progress and adjust the therapy plan, even when he/she is away from his/her office.

B. *Epione's Architecture*

The organizational architecture of *Epione* is depicted in Fig. 2. From the latter, the client-server structure is evident, providing different modalities of communication and activation of the corresponding application components, according to the pain management scenarios. In Fig. 2, the interconnection of the proposed Epione-PLP module to the total functionality of Epione is clearly shown. This relationship is thoroughly described in the following section[4].

IV. THE PROPOSED EPIONE-PLP MODULE

The proposed Epione-PLP management scheme consists of three basic parts; that is, the advanced facial

---

[3] Transcutaneous electrical nerve stimulation (TENS) is the popularized name for electrical stimulation produced by a portable stimulator and used as a biofeedback system for the pain treatment [23].

[4] For a thorough description of all Epione's modules, the reader should refer to [3].

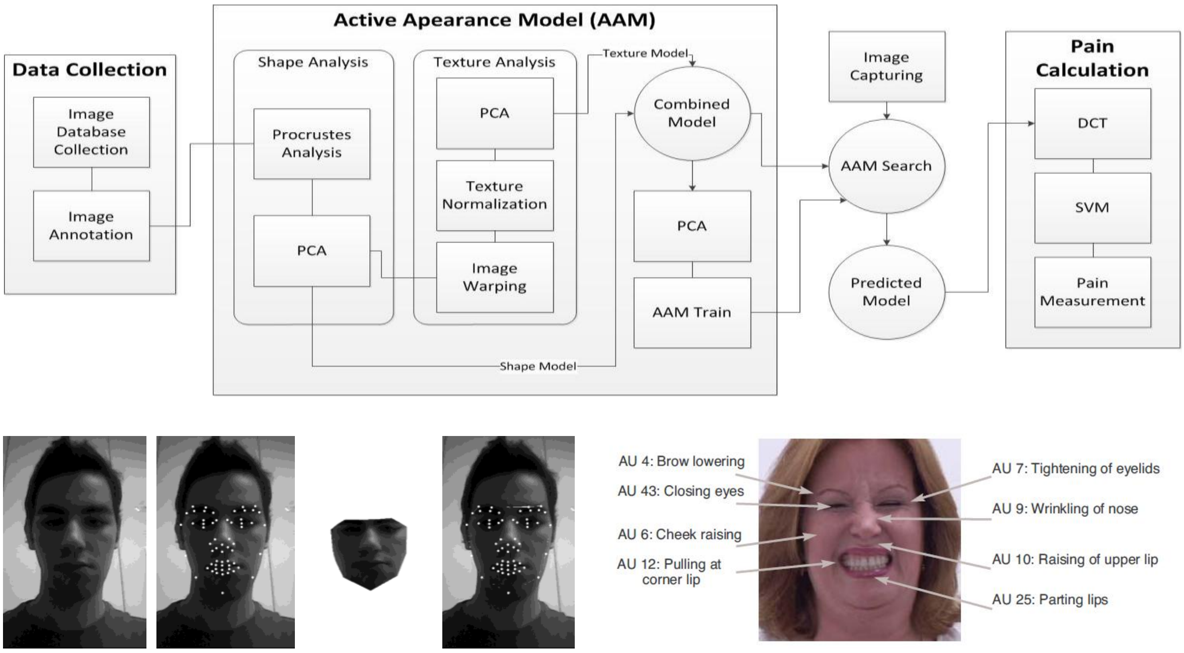

Fig. 3. (up) Block-diagram of the Epione's patient's pain status identification; (bottom) An example of the predicted image model when applied to the original image (left); An example of facial actions associated when a person is in pain. In this example, the activated action units (AUs), defined by the Facial Action Coding System (FACS) [28], are: 4, 6, 7, 9, 10, 12, 25 and 43 (right).

expression analysis, the biofeedback system and the AR-based PL modeling and interfacing.

A. *Advanced Facial Expression Analysis*

The aim of this part is pain quantification. In general, pain is typically assessed by patient self-report. Self-reported pain, however, is difficult to interpret and may be impaired or in some circumstances (i.e., young children and the severely ill) not even possible [24], [25]. To circumvent these problems, behavioral scientists have identified reliable and valid facial indicators of pain. Hitherto, these methods have required manual measurement by highly skilled human observers.

In the Epione, an approach for automatically recognizing acute pain without the need for human observers was implemented; hence, pain is automatically detected. The patient's pain status identification is realized following the steps of the block-diagram illustrated in Fig. 3 (up). In particular, a statistical approach (Active Appearance Model-AAM [26]) is adopted, in which a model is built from analyzing the appearance of a set of labeled image examples where structures vary in shape or texture, it is possible to learn what are plausible variations and what are not. A new image can be interpreted by finding the best plausible match of the model to the image data. Frame-level ground truth was calculated from presence/absence and intensity of facial actions previously associated with pain. Active appearance models (AAM) (Fig. 3 (bottom-left)) were used to decouple shape and appearance in the digitized face images. Support vector machines (SVM) [27] were further employed using information from the change of the activated action units (AUs), defined by the Facial Action Coding System (FACS) [28] (Fig. 3 (bottom-right)), within the representations from the AAM predicted model, resulting in a pain level classification. The latter is formed by the following equation:

$$\text{Pain} = AU4 + (AU6 \| AU7) + (AU9 \| AU10) + AU43, \quad (1)$$

that is, the sum of AU4, AU6 or AU7 (whichever is higher) AU9 or AU10 (whichever is higher) and AU43 to yield a 16-point scale of pain [AUs are scored on a 6-point intensity scale that ranges from 0 (absent) to 5 (maximum intensity). Eye closing (AU43) binary (0 = absent, 1 = present)].

B. *Biofeedback System*

This part aims at providing a biofeedback to the patient using the regulation of the TENS activity [23] (Fig. 4), according to the pain level estimated by (1). Basic science studies show that high and low frequency TENS produce their effects by activation of opioid receptors in the central nervous system [29].

In particular, high frequency TENS activates delta-opioid receptors both in the spinal cord and supraspinally (in the medulla) while low frequency TENS activates mu-opioid receptors both in the spinal cord and supraspinally. Further high frequency TENS reduces excitation of central neurons that transmit nociceptive information, reduces release of excitatory neurotransmitters (glutamate) and increases the release of inhibitory neurotransmitters (GABA) in the spinal cord, and activates muscarinic receptors centrally to produce analgesia (in effect, temporarily blocking the pain gate). Low frequency TENS also releases serotonin and activates serotonin receptors in the spinal cord, releases GABA, and activates muscarinic receptors to reduce excitability of nociceptive neurons in the spinal cord.

The biofeedback system is realized as a wearable device[5], involving TENS, which cover the complete range of transcutaneously applied currents used for nerve excitation [23]. TENS are connected to the skin using two or more electrodes. The battery-operated TENS unit is able to modulate pulse width, frequency and intensity according to the Epione CC handling at high frequency (>50 Hz) with an intensity below motor contraction (sensory intensity) or low frequency (<10 Hz) with an intensity that produces motor contraction. Data are handled by a local microprocessor and transmitted to the Epione CC via Bluetooth link.

C. AR-based PL Modeling and Interfacing

The role of this part is to implement an AR-based PL modeling and interfacing, as a means for not only creating the 'mirror box' illusion, but, in an extended perspective, to facilitate the functionality of the recreated missing limb into real-life scenarios. A missing limb 3D model (e.g., hand model, Fig. 5-up) is used to provide various degrees of freedom. As to establish completely independence between the existing and the AR-reconstructed limb, a wireless accelerometer [6] (Fig. 5- down-left), mounted on the missing limb site, is used to capture the movement of the remaining part of the amputee limb, driving the movements of the AR-reconstructed limb[7]. To this end, by acquiring information from patient's gestures/voice commands activity, using the wireless accelerometer (Fig. 5-down-left) and speech recognition [8], and transmitting it via Bluetooth to the Epione Vault, multimodal interaction and task performance (e.g., gesture-based navigation throughout the Microsoft Virtual Earth using the reconstructed missing limb) is feasible using AR-based glasses[9](Fig. 5-down-right). In particular, the latter provide stereoscopic preview of the Epione Vault to the amputee (Fig. 6), in order to enhance his/her illusion about the reconstructed missing limb. The amputee can then interact with the Epione Vault, either following specific tasks with varied difficulty (e.g., trying to touch specific colored squares with the AR-based limb-Fig. 6 (up)), and/or using free gesture interaction (e.g., handling Epione Vault facilities-Fig. 6 (bottom)). In addition, the use of AR-based interfacing enables the superposition of the missing limb reconstruction to the real world (via its embedded camera), thus, clearly enhancing the illusion of the limb replacement, independently from the intact one. An example is given in Fig. 7, where the amputee chats with his friends through the Epione Vault handling the communication with the AR-based hand through an AR-based interfacing that augments the reality with this embedded functionality. This allows for free-gesturing in a real-life setting, with the facility to use his/her reconstructed limb as s/he uses the intact one, and enhances imagery interaction (hence PLP relief) in a more experiential way.

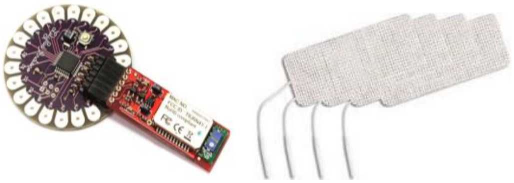

Fig. 4. LilyPad Arduino microprocessor (left) and the TENS electrodes (right).

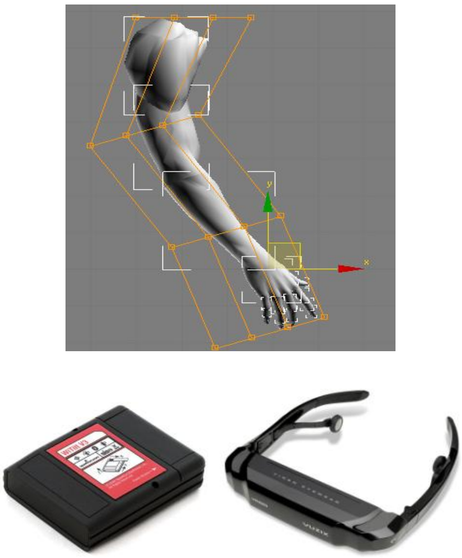

Fig. 5. The hand model used (up), the Wireless accelerometer Sparkfun Witilt v3.0 (down-left), and the AR Vuzix iWear VR920 glasses (down-right).

V. TECHNOLOGIES USED

The technologies used for the development of *Epione*-PLP were: (i) Servers: IIS 7.0; SQL Server 2008 R2, (ii) Development Tools: Visual Studio 2010 Professional, Visual Studio 2008 Professional SP1 - Other Technologies: .NET Framework 4.0 (C#, WPF, WCF, ASP.NET); Windows 7 Professional; Windows Mobile 7.0; XML Web Services; MS DirectX 11, Microsoft Expression Suite 3, Microsoft Speech API (SAPI) 5.3, MATLAB R2010a, Autodesk 3D Studio Max 2010, Facebook API (Facebook Developer Toolkit), Twitter API (twitterizer), Skype API, Bing Maps 3D, OpenCV (emguCV)., (iii) Hardware: Vuzix iWear VR920, Arduino Lilypad, Sparkfun Witilt v3.0.

---

[5] LilyPad Arduino (http://www.arduino.cc/en/Main/ArduinoBoardLilyPad), which is a microcontroller board designed for wearables and e-textiles. It can be sewn to fabric and similarly mounted power supplies, sensors and actuators with conductive thread.

[6] WiTilt v3.0 (http://www.sparkfun.com/commerce/product_info.php?products_id=8563) with tilt output in degrees, triple axis accelerometer (MMA7260) and single axis gyro (MLX90609-150).

[7] For the extreme case where there is no remaining part for the mounting of the accelerometer, the latter it is placed on the other hand and mirrored to the user in the Epione Vault.

[8] Microsoft Speech API (SAPI) 5.3

[9] Vuzix iWear VR920 (http://www.vuzix.com/iwear/products_vr920.html).

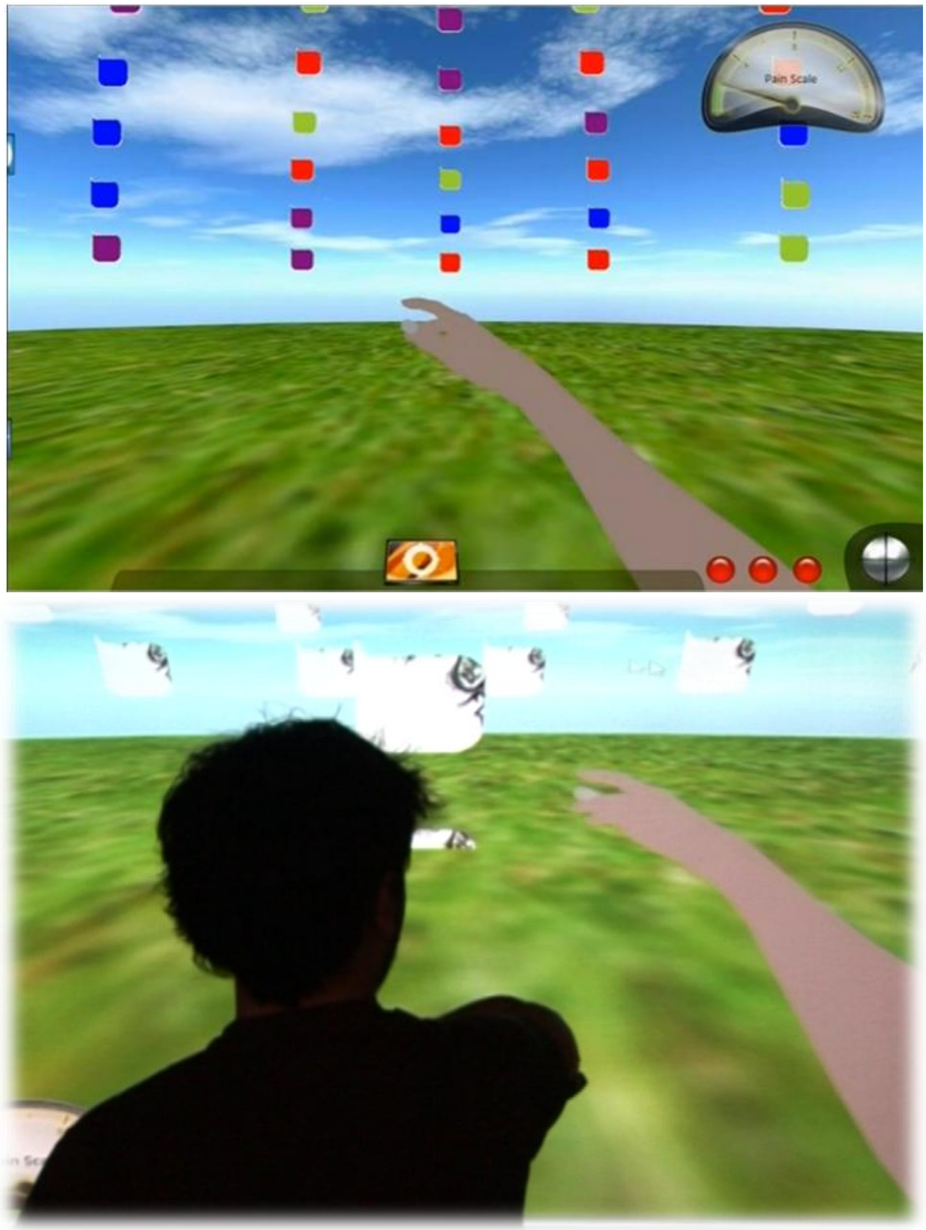

Fig. 6. The interaction with the Epione Vault using the AR-based reconstructed right hand for a task of clicking the correct colored square (up) and task of selecting items (down).

VI. DISCUCSSION

Epione-PLP scheme is a revolutionary PLP management that provides to PLP sufferers an integrated pain management environment. It is the first pain management tool, which translates the medical needs to technology-based procedures that take into account patient's response in an adaptive way that fulfills each patient's specific therapeutic needs and provide to the physician a plethora of treatment scenarios.

The innovations behind Epione-PLP consist of a broader approach to the problem examined. Most pain management centers gather information from the patient in a static way, simply using questionnaires in order to set up different therapeutic tasks. In this case, the physician has to consider a variety of parameters combined with patient's pain behavior in order to construct the optimum course for each one. On the contrary, the proposed system is designed to circumvent the above drawbacks considering the user’s needs. In particular, based on computer vision inference algorithms and social behavior markers, *Epione* combines all the necessary information to automatically construct the appropriate computer-based pain management environment (Epione Vault) for each patient. This turns the PLP management to a socially supported activity that combines both the personalized sensation of PLP relief with the support of the community environment.

Moreover, it incorporates biofeedback stimulation (TENS) during the therapeutic session, adjusted, accordingly, to the activation of pain alarms. The involvement of transparent monitoring of the patient's

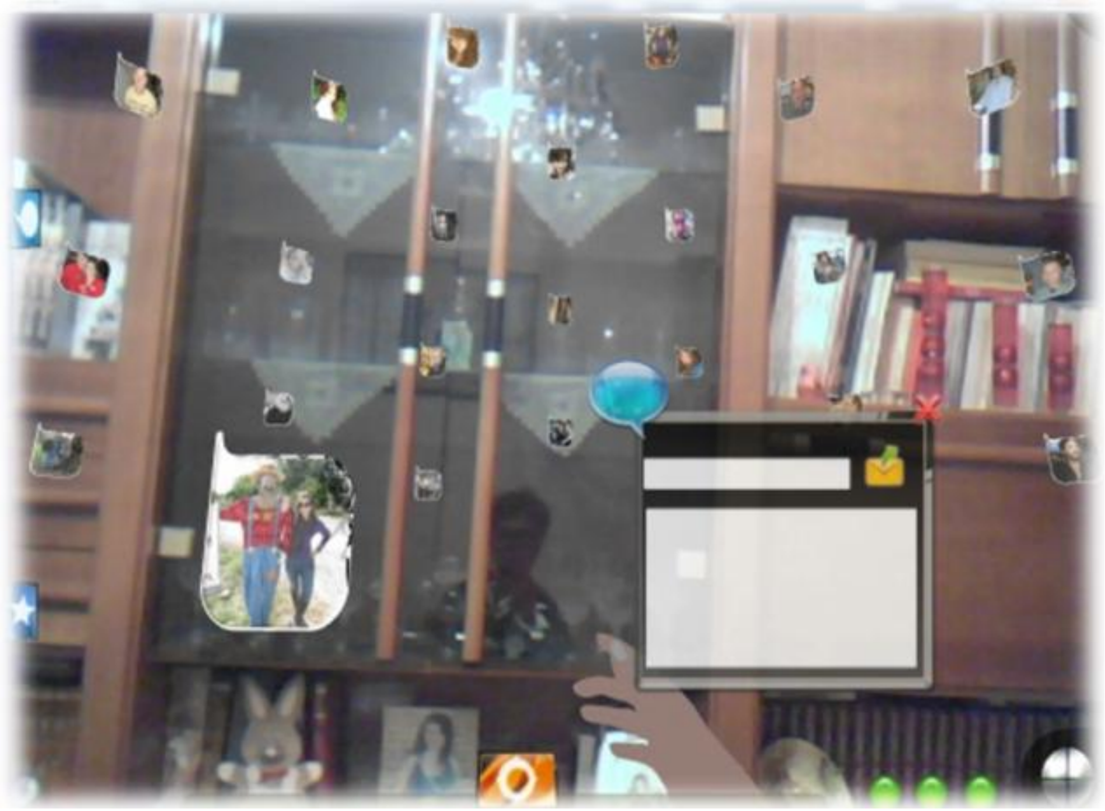

Fig. 7. The interaction with the Epione Vault using the AR-based reconstructed right hand, for a task of chating with the communicty of amputee's friends, in an augmented reality user-scenario (being in his room at his home).

interaction with the Epione Vault, the adaptivity of the latter to increase distraction, imagery relaxation and variety in therapeutic scenarios (according to the pain type and/or patient's categorization), along with the AR-based solution for the PLP relief makes Epione an integrated solution for the pain management problem towards normalization of the pain management procedures to each patient's needs (personalized healthcare).

Until now, pain management software refers to questionnaire analysis and patient's history data gathering. Using advanced signal processing and cutting-edge technology Epione-PLP provides an integrated PLP management environment, which is closer to the patient's needs and, therefore, realistic and more efficient. The AR-based experiential feeling of the reconstructed limb extends further the concept of the 'mirror box' illusion, setting it to a more realistic environment, which could support the reconstruction of the body image to the amputee, in a way that his/her body would efficiently handle a series of experiences. As explained in [20], phantom limb experience depends on integrating experiences from at least five different sources: (i) from the stump neuromas; (ii) from remapping, e.g., the spontaneous activity from the face is ascribed to the phantom; (iii) the monitoring of corollary discharge from motor commands to the limb; (iv) a primordial, genetically determined, internal ‘image’ of one’s body; and (v) vivid somatic memories of painful sensations or posture of the original limb being ‘carried’ over into the phantom.

In the case of PLP e.g., due to amputated hand, messages from the motor cortex in the front part of the brain continue to be sent toward the muscles in the hand, even though the hand is missing. In fact, the part of the brain that controls movement does not ‘know’ that the hand is missing [20]. It is likely that these movement commands are simultaneously monitored by the parietal lobes, which are concerned with body image. In a normal person, messages from the frontal lobe are sent either directly, or via the cerebellum, to the parietal lobes, which monitor the commands and simultaneously receive feedback from the arm about its position and velocity of movement. There is, of course, no feedback from a phantom arm, but the monitoring of motor commands might continue to occur in the parietal lobes, and thus the patient vividly feels movements in the phantom. The visualization of the missing limb through the AR-based interfacing could help the amputee to better organize his sense of his body image and create the appropriate feedback to stop painful movements, such as ‘clenching spasms’ in the phantom hand.

The Epione-PLP scheme could foresee various updates and extensions. For example, further increase in the variety of PLP tasks, including various 3D models of different missing limbs and further customization of pain therapy tasks to different pain sources and patient's age (kids, elders) could make it more effective and adaptive. In addition, from a technological perspective, further optimization of the equipment (e.g., more 'transparent' AR-based glasses and even smaller interfaces (e.g., accelerometers), and portability, via the implementation of the Epione-PLP interface on a PDA, would maximize its added value. Finally, its large-scale experimental use by a variety of patients could contribute to its optimization and user-acceptability, as its resulting refinement would provide the user with an efficient PLP management environment.

VII. CONCLUSIONS

In this work, an innovative phantom limb pain management environment, namely Epione-PLP scheme, has been presented. Epione-PLP (as a module of an integrated pain management environment) uses advanced signal processing techniques to analyze the user's facial expressions in a real-time context, resulting in a quantitative pain meter index. The latter is used to form the level of biofeedback to the user and adaptively adjust Epione's 3D AR-based interacting environment. The AR-based interfacing extends the 'mirror box' illusion and sets the experiential sensation of the body image to a more realistic setting. In this way, a more complete information handling strategy is initiated that eases down the user's PLP feeling. The design and development of Epione-PLP allows for flexible expansion to different user-scenarios, providing personalized PLP relief and management, contributing to a better quality of life.

REFERENCES

[1] IASP Task Force on Taxonomy, "Part III: Pain terms, a current list with definitions and notes on usage," in *Classification of Chronic Pain*, 2nd ed., H. Merskey and N. Bogduk, Eds. Seattle: IASP Press, 1994, pp. 209-214 (updated by the IASP Council in Kyoto, November 29-30, 2007).

[2] F. Francesca, P. Bader, D. Echtle, F. Giunta, and J. Williams, *Guidelines on Pain Management*, European Association of Urology 2007, available at: http://www.uroweb.org/fileadmin/user_upload/Guidelines/21_Pain_Management_2007.pdf

[3] S. Georgoulis, S. Eleftheriadis, D. Tzionas, K. Vrenas, P. Petrantonakis, and L. J. Hadjileontiadis, "Epione: An Innovative Pain Management System Using Facial Expression Analysis, Biofeedback and Augmented Reality-Based Distraction," Intert. Conf. on Intelligent Networking and Collaborative Systems (INCoS 2010), Thessaloniki, Greece, November 24 -26, 2010 (to appear).

[4] www.erab2010.com

[5] K. G. Sogenannte, "Erstbeschreibung des phantomschmerzes von Ambroise Paré," Fortschr Med, vol. 108, pp. 62-66, 1990.

[6] T. Furukawa, "Charles Bell's description of the phantom phenomenon in 1830," *Neurology*; vol. 40, p. 1830, 1990.

[7] H. A. Whitaker, "A historical note on phantom limb," *Neurology* vol. 29, p. 273, 1979

[8] L. Nikolajsen and T. S. Jensen, "Phantom limb pain," *British Journal of Anaesthesia*, vol. 87, no. 1, pp. 107-116, 2001.

[9] P. D. Wall and M. Gutnick, "Ongoing activity in peripheral nerves: the physiology and pharmacology of impulses originating from a neuroma," *Exp Neurol*, vol. 43, pp. 580-593, 1974.

[10] M. Devor, R. Govrin-Lippman, and K. Angelides, "Na+ channels immunolocalization in peripheral mammalian axons and changes following nerve injury and neuroma formation," *J Neurosci*, vol. 135, pp. 1976-1992, 1993.

[11] C. Chabal, L. Jacobson, L. Russell, and K. J. Burchiel, "Pain responses to perineuromal injection of normal saline, epinephrine, and lidocaine in humans," *Pain*, vol. 49, pp. 9-12, 1992.

[12] S. L. Florence and J. H. Kaas, "Large-scale reorganization at multiple levels of the somatosensory pathway follows therapeutic amputation of the hand in monkeys," *J Neurosci*, vol. 15, pp. 8083-8095, 1995.

[13] H. Flor, T. Elbert, W. Mühlnickel, C. Pantev, C. Wienbruch, and E. Taub, "Cortical reorganization and phantom phenomena in congenital and traumatic upper-extremity amputees," *Exp Brain Res*, vol. 119, pp. 205-212, 1998.

[14] R. A. Sherman and C. J. Sherman, "Prevalence and characteristics of chronic phantom limb pain among American veterans. Results of a trial survey," *Am J Phys Med*, vol. 62, pp. 227-238, 1983.

[15] —, "A comparison of phantom sensations Phantom limb pain among amputees whose amputations were of civilian and militaryorigins," *Pain*, vol. 21, pp. 91-97, 1985.

[16] T. S. Jensen, B. Krebs, J. Nielsen, and P. Rasmussen, "Phantom limb, phantom pain and stump pain in amputees during the first 6 months following limb amputation," *Pain*, vol. 17, pp. 243-256, 1983.

[17] L. Nikolajsen, S. Ilkjñr, K. Krùner, J. H. Christensen, and T. S. Jensen, "The influence of preamputation pain on postamputation stump and phantom pain," *Pain*, vol. 72, pp. 393-405, 1997.

[18] K. Sato, H. Higuchi, and Y. Hishikawa, "Management of phantom limb pain and sensation with Milnacipran," *J Neuropsychiatry Clin Neurosci.*, vol. 20, no. 3, p. 368, 2008.

[19] V. S. Ramachandran and S. Blakeslee, *Phantoms in the brain: Probing the mysteries of the human mind*, New York: William Morrow & Company, 1998.

[20] V. S. Ramachandran and W. Hirstein, "The perception of phantom limbs: The D.O. Hebb lecture," *Brain*, vol. 9, no. 121, pp. 1603–1630, 1998.

[21] Wright A. Wellcome Trust Sci Art Project, 1997 http://www.medphys.ucl.ac.uk/mgi/alexa/alexawright.html

[22] K. O'Neill, A. dePaor, M. MacLachlan, and G. McDarby, "An investigation into the performance of Augmented Reality for use in the treatment of Phantom Limb Pain in Amputees," In G. M. Craddock, L. P. McCormack, R. B. Reilly and H. T. P. Knops (Eds.) *Assistive technology: shaping the future: AAATE'03*, vol 11-Assistive technology research series, IOS Press, 2003, pp. 1016-1020.

[23] R. M. Dubinsky and M. Janis, "Assessment: efficacy of transcutaneous electric nerve stimulation in the treatment of pain in neurologic disorders (an evidence-based review): report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology," *Neurology*, vol. 74, no. 2, pp. 173–176, 2010.

[24] R. Cornelius, *The Science of Emotion*, Upper Saddler River: Prentice Hall, 1996.

[25] T. Hadjistavropoulos and K. D. Craig, "Social influences and the communication of pain," in *Pain: Psychological perspectives*, T. Hadjistavropoulos and K. D. Craig, Eds. New York: Erlbaum, 2004.

[26] T. F. Cootes and C. J. Taylor "Statistical models of appearance for computer vision," http://personalpages. manchester.ac.uk/staff/timothy.f.cootes/Models/appmodels.pdf

[27] C. Cortes and V. Vapnik, "Support-Vector Networks," *Machine Learning*, vol. 20, no. 3, pp. 273-297, 1995.

[28] P. Ekman, W. Friesen, and J. Hager, *Facial Action Coding System: Research Nexus*. Salt Lake City: Network Research Information, USA, 2002.

[29] L. S. Chesterton, N. E. Foster, C. C. Wright, G. D. Baxter, and P. Barlas, "Effects of TENS frequency, intensity and stimulation site parameter manipulation on pressure pain thresholds in healthy human subjects," *Pain* vol. 106, nos. 1-2, pp. 73–80, 2003.