Gesture and Brain Computing Interfaces: Impacts on Next Generation Learning

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ABSTRACT

The next generation of Learning and Human Performance Solutions (L&HPS) are being driven by end-user needs for highly personalized, adaptive, and ubiquitous systems that can be easily and intuitively used via modern computing and communication device platforms. However, shrinking Federal budgets and upcoming Federal acquisition reforms are requiring that these systems also be low cost – both in terms of the cost of component technologies, and the human capital costs required throughout the systems engineering lifecycle.

This paper describes our research efforts in examining and combining Neuro-Technology with synergistic technologies such as Gesture Recognition, Haptics, Facial Expression Recognition, Voice Recognition and Advanced Data Visualization to identify and evaluate new paradigms of advanced "Human-Machine" command/control and feedback interfaces for future training/learning applications. The paper describes our findings in areas such as Neurofeedback, Adaptive Peak Performance Training, Thought Pattern Recognition, etc. The paper also outlines our findings in regards to a set of challenges that lie ahead.

Significantly, our research indicates the strong viability of using low cost, intuitive, stable, and commercially available component technologies that are characterized by active open source software “ecosystems”. Further, these components require low cost human capital skills during systems integration. In our current research, we describe Gesture-based Computing and Brain Computer Interface technologies and examine their viability for enabling low-cost, high value applications to accelerate progress towards achieving the next generation Learning & Human Performance Solutions.

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OUTLINE

In the **Problem** section, we describe the ever-increasing need to deliver advanced Learning and Human Performance (L&HP) capabilities driven by shifting U.S. Department of Defense (DoD) budget priorities and sophisticated Warfighter needs. The key characteristics of such "Next Generation" L&HP solutions, along with the need for a disruptive innovation approach for attaining them (by exploiting not only recent and upcoming technological advancements, but also the human capital inherent in the current and upcoming technology-savvy workforce), are summarized in the **Requirements** section. In the **Challenges** section, we recognize that the attainment of "Next Generation" L&HP solutions presents a "wicked" problem, solving which requires one or more of the approaches described in the **Available Solution Strategies** section. In the **Proposed Solution Framework** section, we describe our multi-faceted evolutionary approach of orchestrating Technologies, Partnerships, Human Capital, End-User Communities, Investments and Capability Spirals towards the development of advanced L&HP solutions. In the **Results** section, we describe outcomes from two Capability Spirals that combined low-cost Human Capital and Technologies (specifically Gesture/Hyper-Gesture Recognition Computer-Brain Interfaces) to develop four proof-of-concept applications of increasing complexity of human-machine interactions: (a) Navigation of Google Earth; (b) Flight control of the Parrot AR Quadricopter Drone; (c) Movement Control of the Bioloid Humanoid Robot; and (d) Human-centric, reality augmented adaptive tutoring of sample lessons in Geography and Algebra. In the **Future Work** section, we extrapolate our approach towards achieving future capabilities in L&HP areas such as Neurofeedback, Adaptive Peak Performance Training, and Thought Pattern Recognition. In the **Conclusion** section, we recognize that Gesture Recognition and Brain Computing Interfaces are at a point of maturity where they have the disruptive innovation potential to profoundly impact next generational learning systems. We also re-iterate the need to focus on the Investments facet of our approach to emphasize the appropriate Resource, Processes and Value (RPV) balance to harness, grow and sustain this disruptive innovation potential.

PROBLEM

The world and societies we live in are growing increasingly complex. The development and spread of information is growing at unfathomable rates. Keeping up with technology enhancements and applicability of those enhancements to benefit our societies, homeland security, and national defense continues to be a challenge. Tie these factors together with a tepid economy and one starts to question how we can continue to advance and grow our knowledge, skills and abilities to stay out in front in the learning, education, training and performance support domains.

The U.S. Government, and in particular, the Department of Defense (DoD) is facing challenges with decreasing budgets, veterans moving into the workforce, next generation Warfighters, a rapidly adaptable adversary and complex operating environments. It is expected that our Military will operate in an era of uncertainty, chaos and persistent conflicts, in one form or another for years to come. We must thus find ways to stay ahead of our adversaries by continuing to train and prepare our Warfighters.

The U.S. Government's efforts to reduce the deficit, coupled with the conclusion of major wars mean budget challenges and cuts for the DoD. Many within the DoD have developed strategic plans to address the challenges that lie ahead in training and maintaining a high quality, ready-to-go service under these budget challenges. For example, the U.S. Army's Training and Doctrine Command (TRADOC) has developed the U.S. Army Learning Concept 2015[1]. The plan is part of an effort to "*drive change through a campaign of learning*." The plan looks at changing the learning models the U.S. Army uses to train their Soldiers. The plan describes techniques for leveraging the advancements in

[1] http://www-tradoc.army.mil/tpubs/pams/tp525-8-2.pdf

technology to build a new learning environment, an environment in which the learner becomes front and center (learner-centric).

The challenges our Warfighters will face in the future, the complex environments in which they will operate and the skills and competencies needed to be successful in their missions; coupled upcoming budget challenges and cuts are just a few reasons why it is imperative to continue to find ways to deliver more advanced, cost-effective L&HP capabilities.

REQUIREMENTS

Multiple perspectives must be considered in order to define the requirements for advanced L&HP capabilities driven by shifting U.S. Department of Defense (DoD) budget priorities and sophisticated workforce/Warfighter needs.

From a *capability* perspective, the L&HP stakeholder community has increasingly articulated the need to advance from current L&HP solutions that are unintuitive, stove-piped, monolithic, and manual-task intensive to “Next Generation” transformative L&HP solutions that are more personalized, adaptive and ubiquitous - facilitating effective learning *anywhere*, *anyhow* and *anytime*. Available literature indicates this in no small measure.

From an *economic* perspective, the L&HP market currently exhibits a classical, *sustaining innovation* pattern of realizing diminishing, incremental value with every additional investment action. What is required is a *disruptive innovation* (Christensen, 2003) approach that exploits not only recent and upcoming technological advancements, but also the human capital inherent in the current and upcoming technology-savvy workforce.

From an *acquisition* perspective, there is an increasing need for realizing more value from smaller investments. The Resource, Processes and Value (RPV) theory of innovation (Christensen, Anthony, & Roth, 2004) offers a viable pathway for achieving this by investing in programs and organizations that employ the appropriate RPV mix.

However, the *program* perspective highlights the key requirement – the lack of a well-defined statement of problem and milestones for a “Next Generation” L&HP solution. This presents a “wicked” problem, which we describe in the following section.

CHALLENGE: A “WICKED PROBLEM”

Making a systematic shift towards effective, lower cost, high value L&HP solutions is required in order to develop and sustain a productive workforce and/or war fighting force. However, this presents a classic “Wicked Problem” (Rittel & Webber, 1973) as follows:

1. **Lack of definitive formulation** – it is not possible to write a well-defined statement of problem for a “Next Generation” L&HP solution
2. **No stopping rule**. The search for a “Next Generation” L&HP solution never stops.
3. **Solutions are not right or wrong**: Choosing a “Next Generation” L&HP solution is largely a matter of judgment.
4. **No immediate/ultimate test of a solution**: “Next Generation” L&HP solutions may generate unexpected consequences over time, making it difficult to measure their effectiveness.
5. **Every solution is a “one-shot” operation**: every implemented “Next Generation” L&HP solution has consequences that cannot be undone.
6. **No exhaustively describable set of potential solutions**: there is no finite/limited set of potential “Next Generation” L&HP solutions
7. **Can be considered to be a symptom of another problem**. Achieving the “Next Generation” L&HP solutions is entwined with other problems (demographics, budgets, technology, etc.).
8. **Numerous ways to explain discrepancies**: “Next Generation” L&HP solutions involve many stakeholders, who all will have different ideas about what the problem really is and what its causes are.

AVAILABLE “WICKED PROBLEM” SOLUTION STRATEGIES

Wicked problems cannot be solved by a traditional sequential approach of problem definition, problem analysis and problem solving. However, multiple strategies may be applied (Roberts, 2000) to cope with wicked problems.

- **Authoritative:** Reducing the number of people responsible for solving the problem – to reduce problem complexity by eliminating multiple, often competing agendas/perspectives. The main drawback with this approach is the potential lack of a holistic problem perspective and/or holistic problem solving skills among the problem solvers.
- **Competitive**: Identifying and rating solutions from competing points of view and selecting the “best”

one. However, such an adversarial approach creates a confrontational environment that typically imperils collaboration and cooperation.

- **Collaborative**: Engaging all stakeholders in order to find the best possible solution that satisfies all stakeholders. However, this approach requires extensive focus, effort, and time to establish and sustain a shared understanding and commitment towards solving a wicked problem.

PROPOSED SOLUTION FRAMEWORK

We propose a **collaborative, spiral development** approach for solving the "Wicked Problem" of achieving effective, low cost, high value L&HP solutions. We have framed our multi-faceted, innovation solution framework towards meeting the "Next Generation" L&HP market drivers & challenges using a quadrant chart (Figure 1) where the left end of the x-axis represents higher cost L&HP solutions and the right end represents lower cost L&HP solutions. The bottom end of the y-axis represents the capability of current L&HP solutions – which are largely unintuitive, stove-piped, monolithic, and manual-task intensive, and the top-end represent "Next Generation" transformative L&HP solutions that are more "learner-centric" i.e. personalized, adaptive and ubiquitous - facilitating effective learning *anywhere*, *anyhow* and *anytime*. We posit that the current L&HP market operates somewhere in the bottom-left quadrant, whereas the market drivers are directed towards the top-right quadrant. The solution approach we propose is represented in the form of a set of coordinated trajectories from current to "next generation" L&HP solutions by incrementally achieving a series of milestones along each of the following trajectories:

- **End-User Communities**: Engaging a heterogeneous mix of L&HP solution end-user communities offers multiple perspectives to L&HP challenges requiring creative and disruptive solutions.
- **Partnerships**: Key partnerships and joint efforts facilitate free flow of ideas across traditional solution development and organizational boundaries.
- **Human Capital**: L&HP solution development teams that represent an optimal mix of low-cost, technology savvy and experienced systems engineering human capital unlocks human ingenuity – a key component of disruptive innovation.
- **Technologies**: Continuously leveraging current and emerging Government, Research and Commercial technologies that are stable, low cost, customizable, and easy to use enables significant leaps in the evolution of L&HP capabilities.
- **Capability Spirals**: Using an agile, rapid development methodology to continually "spiral in" existing capabilities, and "spin out" the next increment of capability in the hands of L&HP solution end users to not only validate solution

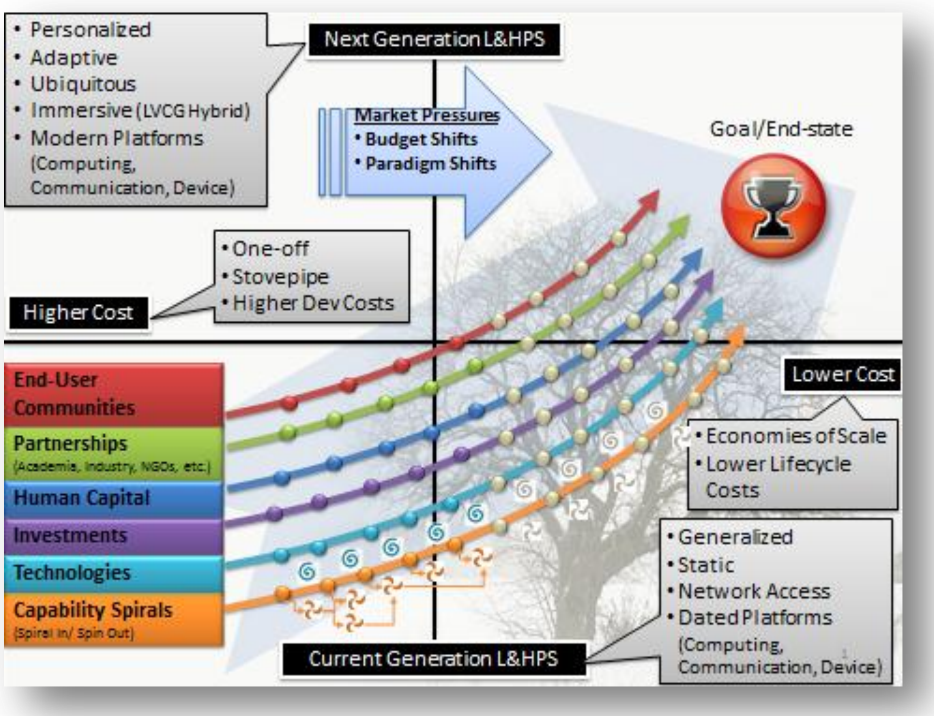


Figure 1: Our Approach to Facilitate Disruptive Innovation in the L&HP Market

concepts, but also define next capability increment(s).

- **Investments**: A series of investments that continuously ensure high value returns by engaging performing organizations with the optimal RPV – i.e. resources (assets such as workforce, capital, etc.), processes (ways of producing goods and services), and values (criteria by which prioritization decisions are made)

Our incremental spiral approach was very well received by a senior DoD leader who likened it to climbing a tree to reach the top (goal) – the process involves the development of "branches" which may lead away from the top, but are key enablers of the way to the top. We recognize and respectfully acknowledge the wisdom of his words by depicting our approach against the silhouette of a tree.

RESULTS

Our review of Gartner's Emerging Technologies Hype Cycle (Fenn, 2012) enabled us to identify several current and upcoming technologies that have disruptive innovation potential with regard to L&HP solutions (see Figure 2). Of these, we focused on specific technologies that were available in the form of low-cost (<$1,000 per system) commercially available products that could be used to study the application of Gesture/Hyper-Gesture Recognition and Computer-Brain Interfaces. We aimed at developing and demonstrating transformative L&HP concepts by integrating: (a) the commercially available Microsoft Kinect® gaming system as our Gesture Recognition subsystem; (b) the *SixthSense* wearable gestural interface device (Mistry & Maes, 2009) to interact with real world objects using hyper-gestures and reality augmentation; and (c) the EMotiv EPOC Headset as our Brain Computing Interface subsystem. We selected these technologies on account of their: (a) functionality; (b) total lifecycle cost; (c) ease of use; (d) ease of customization; (e) robustness; (f) quality of performance; and (g) consistency of performance. We identified several L&HP application perspectives to guide our capability development including: human-machine interfacing; immersive learning, and intelligent tutoring. Our results are described below.

Spiral 1: In our initial spiral, we focused on the following:

- Technologies: We specifically focused on: (a) the commercially available Microsoft Kinect® gaming system as our Gesture Recognition subsystem; and (b) the EMotiv EPOC Headset as our Brain

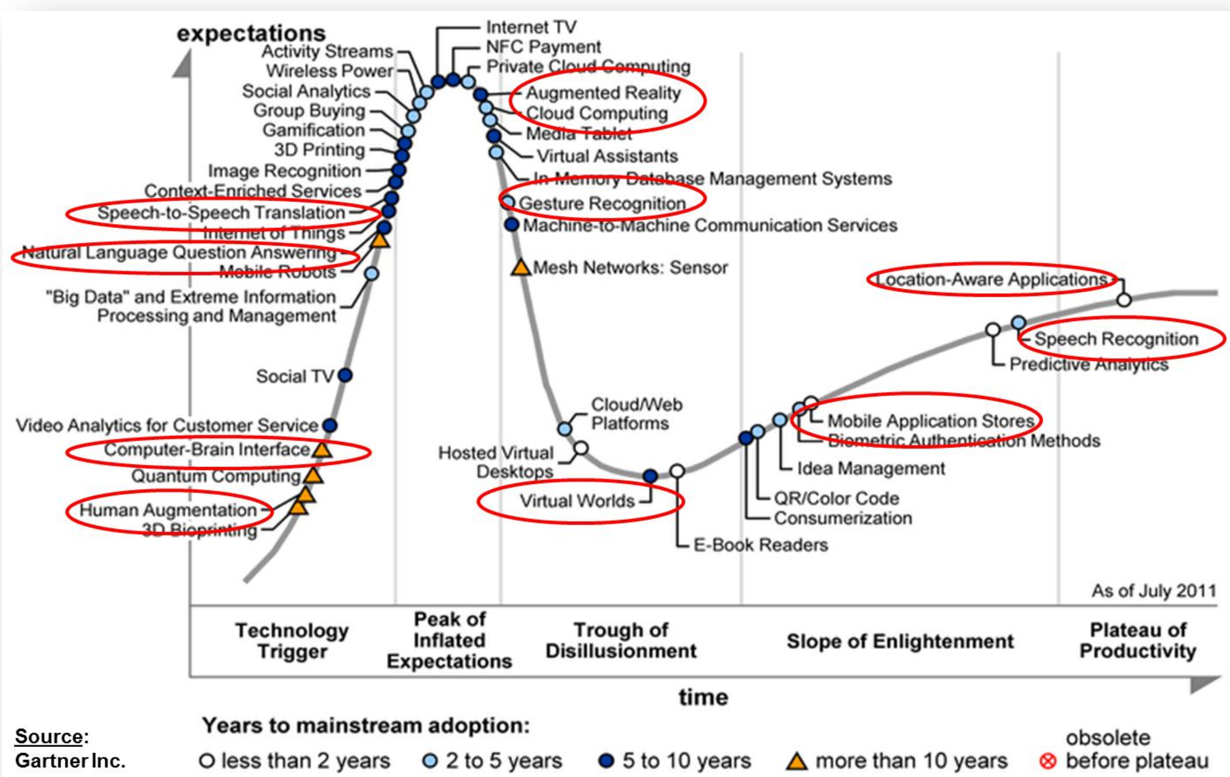


Figure 2: Gartner's Emerging Technologies Hype Cycle 2011

Computing Interface subsystem.

- Human Capital: Our development team was comprised of 4 (four) Sophomore-Junior level research students from a local university who were guided by a senior Principal Investigator.
- Capability Spin-outs: We developed 3 specific capability spin-outs of increasing complexity of human-machine interactions that demonstrated progressively advanced capabilities : (a) Navigation of Google Earth; (b) Flight control of the Parrot AR Quadricopter Drone; and (c) Movement Control of the Bioloid Humanoid Robot
- End User Communities: We looked towards the Geographical Intelligence (GEOINT) Analysis, Surveillance, and Robotics end user communities for developing the end user needs.
- Partnerships: We encouraged our student research team to seek out publicly available information in the open-source and academic communities. We also helped them establish initial contact with the EMotiv EPOC Headset vendor.

Within a matter of weeks, our team developed functional, easy-to-use, robust, consistent and high-quality capabilities which we were able to successfully demonstrate to a variety of audiences. Our results and observations are summarized below.

[1] Capability Achieved: Google Earth™ Interface for Intelligence Analyses

Development Timeframe: May 31st – June 6th, 2011

Technologies Applied & Costs:

- Emotiv SDK (Headset included): $ 3,000 (now only $500)
- Microsoft Xbox Kinect: $ 150
- Google Earth, FAAST, OpenNI, NITE: Open Source Software (OSS)

Degree of Difficulty: Difficult, many separate, interdependent tools to integrate

Human Capital Applied & Costs: 200 hours among 4 Sophomore-level research interns (Engineering/Computer Science Majors)

Functionality: Rudimentary navigation controls based on Neuro-Signals (Emotions, Brain Wave Pattern), Gesture, Facial Expression, Voice and Motion Recognition (Gyroscope)

User training time: 20 min.

Reliability: Good

Performance: Adequate, with moderate consistency

[2] Capability Achieved: Remote Control of Parrot Quadricopter AR Drone for Surveillance

Development Timeframe: June 17th –June 30th, 2011: Gesture Control,

July 11th- Aug 8th, Sept. 6th – Oct. 21st, 2011 (Intermittent): Neural control

Technologies Applied & Costs:

- AR.Drone x2: $600 + Spare parts: $250
- Emotiv SDK/Headset, Kinect: $0 (see above)
- AR.Drone API, Python AR.Drone wrapper: Open Source

Degree of Difficulty: Difficult, many separate, interdependent tools to integrate

Human Capital Applied & Costs: 200 hours among 4 Sophomore-level research interns (see above)

Functionality: Rudimentary flight controls based on Neuro-Signal (Emotions, Brain Wave Pattern) Recognition, Gesture Control, and Head-Mounted 3D Viewing (Video Feed from Drone)

User Training time: 40 min.

Reliability: Poor – tendency to malfunction

Performance: Coarse degree of control

Observations: Most of the reliability and performance issues were due to the AR.Drone's API, which would often be unresponsive to commands.

[3] Capability Achieved: Human Motion Mimicking by Bioloid Humanoid Robot for Robot Control

Development Timeframe: July 22nd – Aug 5th, 2011 (Intermittent): Neural control; Nov 5th – Nov 7th, 2011: Gesture Control,

Technologies Applied & Costs:

- Bioloid Robot: $1200 + Zigbee: $15
- RoboPlus SDK: $0
- Emotiv SDK/Headset, Kinect: $0 (see above)
- Microsoft Kinect SDK, Zigbee Library: Open Source

Degree of Difficulty: Moderately Difficult owing to proprietary Robot platform

Human Capital Applied & Costs: 192 hours among 4 Sophomore-level research interns (see above) plus 16 hours Principal Engineer

Functionality: Rudimentary robot controls based on Neuro-Signal (Emotions, Brain Wave Pattern), Gesture, Facial Expression, Voice and Motion Recognition (Gyroscope)

User Training time: 40 min.

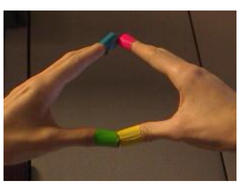
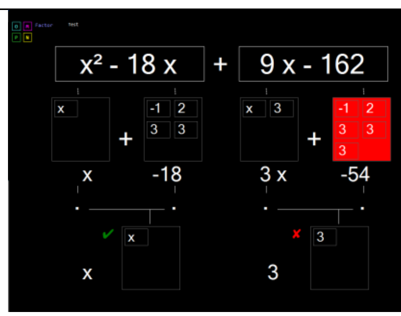
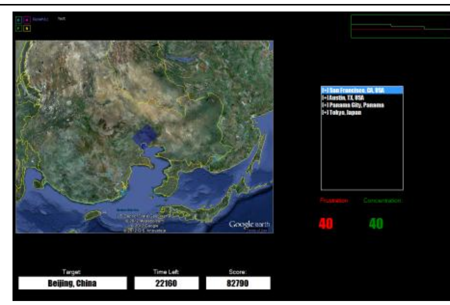
Reliability: Good
Performance: Good degree of control, but expandable to full range of robot actions

Spiral 2: For Spiral 2 (currently ongoing), we are exploring the possibilities of providing the learner with a "Personal Learning Assistant" (PLA) that would persist with the learner to provide immediate feedback and assistance to the learner as they go about everyday tasks and scenarios. In Spiral 2, we are augmenting our Spiral 1 as follows:

- Technologies: We are adding an implementation of the *SixthSense* wearable gestural interface device (Mistry & Maes, 2009) to interact with real world objects using hyper-gestures and reality augmentation.
- Human Capital: Our development team has been reduced to 2 (two) Junior level research students from a local university who were guided by the same senior Principal Investigator.
- Capability Spin-out: We have developed a human-centric, reality augmented adaptive tutor for sample lessons in Geography and Algebra (See Table 1)
- End User Communities: We consulted the Learning & Human Performance user community for developing the end user needs.
- Partnerships: We encouraged our student research team to seek out publicly available information in the open-source and academic communities.

Once again, within a matter of about 4 weeks (approximately 120 hrs of student research labor to date), our team of two student research interns developed a functional, easy-to-use, robust, consistent and high-quality adaptive tutoring capability (see table below) which we were able to successfully demonstrate to a variety of audiences.

Table 1: Spiral 2 Results

 **Figure 1: Hypergesture Markers**	 **Figure 2: Adaptive Algebra Tutor**	 **Figure 3: Adaptive Geography Quiz**
A Namaste gesture brings up the main screen for hyper-gestures, and once four "M-N-O-P" cursors passes through the box in the middle; learner can hide the N finger (right thumb) and begin to draw using gestures. Symbols and actions made with these gestures allow the user to interact with the computer in a natural manner.	The Learner clicks the problem button by hovering over it with the M marker, and pinching the O and P markers (left hand, green and blue) together to initiate a mouse click. Each step of the factorization is broken down separately. To start the current step, learner hovers over the equation with a box around it. The PLA provides immediate feedback in the form of hints and right/wrong signs. At any time during this exercise, if the learner's **Frustration** level goes over a threshold, the PLA completes the step for the learner, showing them the proper way to solve it. If the learner's **Concentration** level goes above a threshold, a hint is displayed.	The Learner is presented with a map that has a square reticule on it that is initially red, but when the Learner places the M marker over a target location using Hyper-gestures, it turns blue. At this point, the Learner must achieve a **Concentration** level of 50 or greater in order to indicate that he/she found the target location. The PLA adapts to the Learner's **Frustration** level: the higher the Frustration level, the slower the clock ticks, the lower the Frustration level, the faster the clock ticks. Once a city is found, it is added to the finished cities list and the score is added to the total (the score is the time remaining when the city was found).

FUTURE WORK

In the following, we present our outlook for future research and development in terms of the points we foresee along the Technologies and Capability Spiral trajectories.

Capabilities Outlook

Neurofeedback is a technique used to improve the brain's ability to operate more effectively. During neurofeedback training, a monitoring device is used to provide real-time feedback about the state of the brain as it performs a variety of tasks. Neurofeedback training experiments have been conducted in many different areas including, but not limited to, children with Attention Deficit Hyperactivity Disorder (AD/HD) (Lubar 1995), patients dealing with depression and alcoholism (Saxby 1995) and even athletes to determine its effects on performance (Vernon, 2005). Research argues that if you can understand the brain patterns you can exercise or challenge the brain's performance to help strengthen our understanding and the learning process. We are aiming to apply statistical analysis to the data collected by our PLA capability on the learner's cognitive states of mind such as *concentration, boredom* and *frustration* in order to understand patterns where the brain is operating most effectively during a learning activity.

In a similar vein, research in expert peak performance zones has been conducted using similar neurofeedback devices along with heart rate monitoring. This research was focused on increasing the pace and efficiency of skill learning by modeling psychophysiological characteristics of expertise and developing sensor-based feedback to accelerate novice-to-expert transition (Berka, 2009), This type of **adaptive peak performance** research using neurofeedback and other sensor related information becomes intriguing when paired with some of the low-cost alternatives discussed in this paper.

Through our research we have also explored methods of transforming vague neurological signals into more content rich signals, specifically turning our **thoughts to speech**. The principal goal was to enable text entry and subsequent speech synthesis using the Emotiv EPOC neuro headset. We believe that this research has many applications, everything from assisting those with disabilities to those working in hands-free environments (e.g., medical procedures). Also in a place or situation where a person may wish to send a message without having to speak (e.g. clandestine operations), this type of thought to text/speech environment could prove to be very effective.

We are also interested in exploring concepts related to **neuroplasticity** - the notion that the human brain can rewire itself. This has been shown to be true among those who suffered from serious physical impairments such a blindness or stroke. Neuroscientists have demonstrated that unused parts of the brain, e.g. the visual cortex, rewired themselves to perform different functions even in adulthood. This has been exploited in training programs for healthy adults as well, a notable example being the website Lumosity. This is of note to us since it makes us wonder if we could exploit this phenomenon to improve learning. There is research being conducted into the use of brain computer interfaces in neuroplastic experiments.

We also wish to explore the application of advanced **analytics** (e.g. operations research techniques) to the vast amounts of data collected by Gesture-Recognition and Brain Computer Interface technologies in order to measure effectiveness of L&HP techniques and better advise the design of both general and personalized instructional and learning environments. For instance, in our Spiral 2 capability, we could apply basic techniques to identify specific steps in the algebra problem solving scenario where: (a) a group of learners commonly experiences high frustration level; and/or (b) where a specific learner experiences a high frustration level.

We agree with prominent futurists that there would be a significant "leap" to new paradigms of learning when Gesture-Recognition and Brain Computer Interface technologies evolve to the point of being embedded in a person's clothing and eventually wired directed into various human biological systems. Then, learning concepts and mechanisms currently described in the science fiction media would become reality!

Technologies Outlook

Gesture Recognition: Microsoft's Kinect provided an excellent starting point, but it had its drawbacks. The first is its lower fidelity. The accuracy is tuned for full body capture allowing for broad gesture like waving or stepping, however it has trouble recognizing finer motions of the hand. Microsoft is purportedly working on software that would enable such detailed detection. Also, the Kinect needs to be set up as an external device with the user standing in a set range from the device, and so can only be used in certain environments. However, this does allow the device to track multiple users and their respective locations allowing for cooperation and interaction. Another way that this technology can be used is in the creation of immersive learning environments by combining the real world with simulation. For example, the "real" learner could be immersed in a simulated medical operating room environment where they would be able to interact with the simulation using gestures to complete tasks.

Hyper-Gesture Recognition: Our current method for hyper-gesture recognition is based on an open source MIT project called SixthSense – which relies on coloring one's fingertips and using a webcam to track their movements. Because of the reduced size of webcams, this device can be worn and is hence portable. Currently we are using a branched version of the open-source SixthSense code, which adds gesture recognition and demonstration applications on top of Touchless, a C# library developed by Microsoft's Office Laboratory for the purpose of object tracking. In the light of significant code integration challenges with SixthSense (primarily owing to its lack of a modular code architecture), we are considering working directly with the following:

- **Touchless** is structured as a library with components for the camera, calibration, of course object tracking, and so can be integrated far easier into other software. The new version from GitHub, which is more recent and more accurate than the one used by SixthSense performs better, although it is still sensitive to light and glare.
- **OpenCV** is an open source computer vision library written in C/C++, with ports to most languages such as Python and Java (upcoming). The Java port will be designed to run on Android as well. OpenCV can also work on Windows, Mac, and Linux. OpenCV is more mature and functional than Touchless - in addition to basic color glob tracking, it appears to support methods for finger tracking simply by looking for appropriately colored convex curves. It also has other features such face recognition, shape fitting, hand gesture recognition, object recognition, and motion tracking. Like Touchless, it is webcam based. However, since its feature list is so extensive, it is necessarily complex and so may require more development (Human Capital) time.

We are also pursuing other heightened gesture recognition technologies which work beyond webcam based tracking. A logical step is to embrace the new technology from Leap Motion who is currently marketing a Kinect like device to capture hand gestures with super high accuracy. They claim to have 200 times the fidelity of any device currently on the market, but they have yet to release the actual technical specifications. The device is quite small and the interface supports full 3D as well as a free developer kit. The product is slated to arrive on the market in 2012.

Brain Computing Interfaces (BCI): While commercial grade neural implants are on the distant horizon, noninvasive brain computer interface (BCI) technologies will continue to play an integral role in our efforts. The most effective noninvasive method is Electroencephalogram (EEG) capture. The Emotiv EPOC headset is a consumer EEG capture device that comes with its own software and Software Development Kit (SDK); and presently offers an excellent balance of features, performance, hardware/software modularity and robustness for its price. The EPOC software, in addition to facial gestures, can detect the user's cognitive state as well as trained neural commands. We plan to focus heavily on the cognitive state as it is most useful for teaching. Most sophisticated EEG headsets on the market today are designed for medical use and are usually cumbersome – the EPOC is not so. Also, we have access to the raw EEG signals coming from the EPOC, which enables use of technologies like BCI2000.

Looking forward, Emotiv has announced plans on releasing headsets that use new dry, or in their words "semi-dry" sensors. Headsets with dry sensors already exist, but again, they are targeted to medical applications and have no associated SDK. There is anticipation that these sensors will be miniaturized to the point of being concealed in clothing. Even further in future, we again look to actually implanting the capture devices inside the brain.

Future of Gesture-Recognition and BCIs: We acknowledge and humbly endorse the vision of prominent futurists - that Gesture-Recognition and Brain Computing Interface technologies will eventually be imbedded within our own bodies, thus ignoring the noisy exterior environments and directly observing the user's proprioception (the sense feeling the location of their limbs with respect to their body) and neural activity. Depending on the location of the implants, the user may be able to learn to control the interface with gestures that never get manifested physically. Also, instead of just passively receiving signals, the implants may be able to generate them, tricking the user's mind into thinking they are touching a real object that actually only exists in the digital world. Techniques such as Transcranial Magnetic Stimulation (**TMS**) would allow us to directly stimulate desired portions of the brain. TMS uses powerful electromagnets to induce a current inside someone's brain. It allows for noninvasive study of the brain and is under heavy research.

There are possible ethical and practical issues here, though. Theoretically the devices could be compromised - allowing someone to confuse the user's brain. Also, they are a permanent modification, so even if they can be turned off, the implants are always present. Finally, if the device malfunctions it may cause brain and nerve damage.

Complementary Technologies: The above technologies would not be able to realize their full potential value without the evolution of the following complementary technologies.

Visualization technologies are already evolving from computer monitors, projectors/ micro-projectors to augmented reality (AR) such as Google Glasses that projects an image directly into one of the learner's eyes. The next paradigm would be unobtrusive devices such as augmented reality contact lenses; and a more permanent solution would be an augmented reality corneal implant.

Computing devices to synthesize and craft an appropriate response to the learner's signals – including gestures, hyper-gestures, and neural signals. Owing to strides in miniaturization, such devices have been getting progressively smaller at a consistent rate – from personal/laptop computers to immensely more portable post-PC devices such as tablets and smartphones – some of which even have micro-projectors. The Cloud Computing paradigm is the ultimate solution where all the computing is done on a remote, distributed computing platform via network services.

Other technologies provide several useful capacities. **Multitouch**, which is available in a commercial form from Microsoft, offers the opportunity to increase the current set of human-machine "touch" interactions although it does not offer portability. An open source project called **Dasher**, which was originally developed to help the disabled, can easily be repurposed to allow for speedy text input using gestures even in noisy environments (Note: The above sentence was typed uniquely with Dasher and the Emotive headset as a proof of concept). **Haptics** or force-feedback addresses the intangibility issues associated with gesture/hyper-gesture recognition by allowing the user to "feel" digital constructions as if they were real providing greater possible dexterity.

CONCLUSION

Our research and development of two spirals per our collaborative, iterative, multi-faceted, innovation-based solution approach indicates that Gesture Recognition and Brain Computing Interfaces are at a point of maturity where they have the disruptive innovation potential to profoundly impact next generational learning systems by providing a set of unique capabilities that would otherwise be cumbersome and expensive to achieve using traditional and current L&HP technologies. Our survey of current research suggests that these technologies are actively being investigated for application in areas such as Neurofeedback, Adaptive Peak Performance Training, Thought Pattern Recognition, etc. The trajectory of current research and development suggests that the application of Gesture Recognition and Brain Computing Interfaces would result in powerful yet economically viable capabilities that provide more intuitive human-machine interfaces, immersive learning environments, and tutoring algorithms that can easily adapt to the learning context and state of mind of the learner.

The significant adaptability, immersion and personalization implications of the use of gesture based and brain computing interfaces on the learning, education, training and performance support communities provide "game-changing" possibilities. These devices and practices continue to open up new windows of effective, immersive opportunities. For example, the ability to build content and learning experiences that adapt to a learner's thought pattern or neural feedback could provide a true living and learning ecosystem. Learning practitioners will certainly need to make adjustments to their training plans and designs to take advantage of these continuously evolving devices and practices.

The implication of gesture based and brain computing interfaces on L&HP solution system engineers (including designers and developers) is also profound. From a design perspective, they can and should design to exploit the new paradigms of human-machine interfacing capabilities that these technologies help facilitate. They should also develop system architectures that are not locked into a specific vendor's API or the current capability state of a technology; but is flexible to accommodate future, unknown capabilities that may emerge. This can be achieved using architecture patterns such as Service Oriented Architecture (SOA), and a disciplined layered/modular architecture. We have identified a very high-level system architecture for "Next Generation" L&HP solutions which is beyond the scope of the current paper.

Finally, we conclude with the need to focus on the Investments Trajectory and urge the US Government budget/acquisition decision makers to encourage and foster the appropriate Resource, Processes and Value

(RPV) balance to harness, grow and sustain the disruptive innovation potential of Gesture/Hyper-Gesture Recognition and Computer-Brain Interfaces in achieving Next Generation" transformative L&HP solutions. A complete treatment of the application of the RPV theory to Government acquisition processes is beyond the scope of the current paper.

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