WHITE PAPER

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Another Look at the Future of Medical Processing

Five years revisited

*Five years ago, the authors of this paper published their view of future trends in medical imaging in a paper titled, "**The future of medical imaging**."[1] Now, this paper will revisit those visions to reflect upon changes that have taken place and take another look forward at medical imaging.*

One main driver for the future of medical care remains the same as it was five years ago: making healthcare personal. As expected, there has been progress, but improvements are moving faster than anticipated due to rapidly advancing technology in everything from smart phones and applications to the cloud, all playing a key role in the development of personal medicine.

Another trend that continues is the movement of healthcare from diagnostic- and treatment-oriented to preventive, while continuously improving on all three. This effort is aided by the enormous amount of medical data that can be available in the cloud but hindered by the legalities and processes around sharing medical information and the ability to make sense from such massive data sets. As usual, technology will pave the path with workload-optimized servers running advanced analytics to analyze the data and send useful information to personal clouds, allowing healthcare to move in the direction of preventive (or "predictive") medicine.

Personal and precise

With advancements in technology, a new perspective pushes the envelope. Dr. Clifford Dacso, a professor and researcher at Baylor College of Medicine in Houston, TX, puts it this way:

"People are now separated into one of four categories when describing medicine: 1) those of whom the treatment helps without side effects, 2) those of whom it helps but has side effects, 3) those of whom it does not help but with no side effects and 4) those of whom it does not help but has side effects. It is time medicine is made personal."

What Dr. Dacso points out is the long-standing medical tradition of putting people into manageable groups, each group to be treated the same way, rather than seeing them as individuals and treating them as such. Dr. Dacso, like many visionaries in the field, believes a change towards personal medicine is coming and with it, great benefits.

He goes on to say, "Someday we will all die from a chronic disease. This means we will have either completely eliminated catastrophic diseases or will have made them chronic." So, not only will people be treated on an individual basis, but medicine will move from treating chronic illnesses to preventing them or at least preventing the acute episodes of the chronic illness.

A key aspect of this vision is to increase the accuracy of medical treatment. Dr. Emad Ebbini, Professor of Electrical and Computer Engineering at the University of Minnesota and the President of the International Society of Therapeutic Ultrasound, believes that "precision will lead to safety and efficacy in ways that we could not have predicted only ten years ago." So the technology that makes it personal will also make it more accurate. Accuracy will make treatment safer, more consistent and available at a lower cost while giving a broader reach to the furthest parts of our global society.

Technology updates

Since the previous paper, many things have happened in the realm of technology. The three vectors of value: performance, price and power dissipation have all expanded. Powerful computers in the form of smart phones and tablets are carried in pockets and rarely leave the owner's possession. Cloud computing connects and enhances these devices, significantly changing the way we envision medicine and medical imaging.

Smart phones

The computers carried in our pockets have expanded their role from just being a phone, a camera and music player. Applications allow for gaming, tracking investments, managing diets and gathering vital signs. This is just the beginning.

Cloud computing

Cloud computing has been around for years, but it was called the Internet. Now, it has expanded in reach and capability so that it is difficult to find a place where it isn't available. It's a way of life. Leaving our interface to the cloud (e.g., smart phone, etc.) at home is hindering.

The clutter and the cloud

The new trend is connecting anything and everything to the cloud, not just smart phones. All sorts of sensors (even medical sensors) can be tied to the cloud, and there can be micro-clouds. Smart phones can control many smart sensors while at the same time being controlled by a larger cloud. The smart phone becomes a personal, micro-cloud while the larger cloud perhaps becomes a cloud for use in the home, car, coffee shop or office. Of course all of them are connected to each other through even more clouds. The "clutter" around the cloud is similar to the concept of the "swarm" around the cloud shown in Figure 1 but is a more positive term because it can be used to connect all sorts of useful stuff to the cloud, allowing an unlimited vision for personalized health.

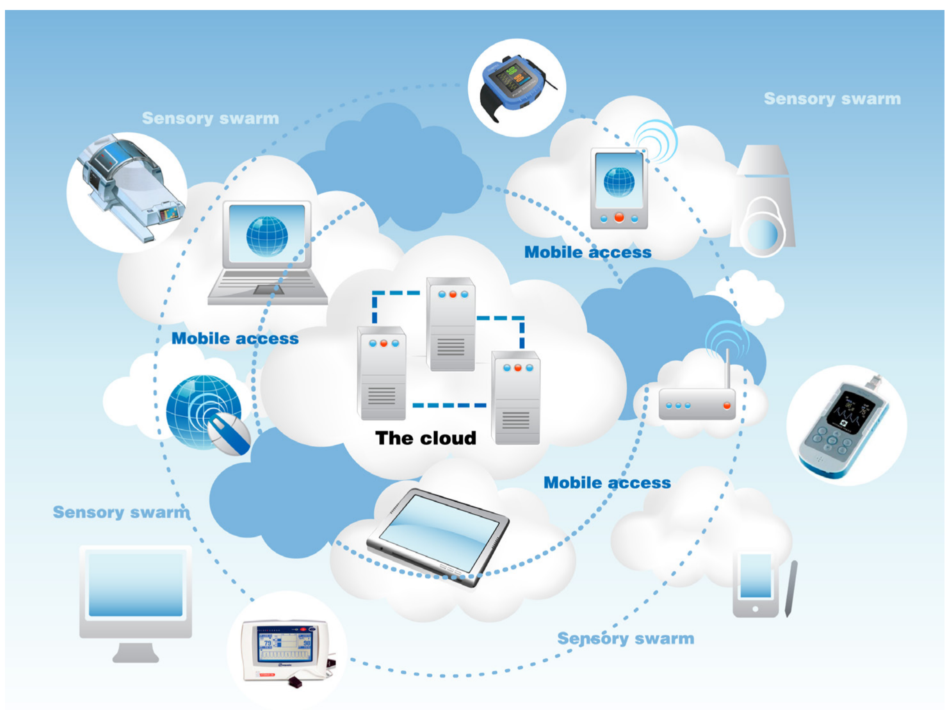

Figure 1: The swarm around the cloud.

The connected home

The clutter and the cloud allow for instrumenting homes with many of the diagnostic tools only found in hospitals and clinics today. Vital signs will be continually monitored, and other aspects of one's health will be under constant scrutiny. With the pervasiveness of the cloud and clutter, gaps in health monitoring when outside the home will be alleviated. Monitoring will be a continuous activity, following people wherever they go. With all of this technology at one's fingertips doctor's opinion start to become the second opinion. The first opinion being the technology constantly monitoring vital signs and other health aspects. This first opinion, available to a doctor will allow that second opinion to be not only better but earlier so that it is not done to treat the illness but to prevent it, tying back to the earlier mentioned trend on preventive medicine.

Technology will be able to form this first opinion thanks to a combination of the soon-to-be pervasive sensors continuously collecting personal data and the advanced algorithms and computing capability that will make sense of it all.

Analytics in technology

One of the growing areas of vision research is understanding humans: what they are doing, how they are feeling, what is their intent, etc. While this research has enormous potential in the fields of security, retail, automotive and others, it also plays a big part in the future of personal medicine.

Imagine a home outfitted with hundreds of small, inexpensive, power-efficient sensors all tied together to a processing machine. This compute engine may be a smart phone, home computer or a remote connection where the processing is done elsewhere. For now, let's just call this a personal cloud.

A personal cloud will take the information from a home sensor network and run advanced analytic algorithms on the data. The data from the visual sensors will be used in everything from person detection and segmentation, to action recognition, to face, head and eye tracking.

Five years ago, the authors of this paper wrote about technology in the home being able to sense when someone has fallen or even when they are beginning to get unstable on their feet. As useful as those capabilities are, they are very simple implementations when given the ability to process data from visual, audio and biometric sensors. The personal cloud will be able to notice subtle changes that develop over time and can alert a person or their physician if appropriate. For instance, it could detect a change in energy level and tie it to a particular event – perhaps the changing of a medication or a particular meal that was consumed. It could even chart your mood, which may or may not help you avoid certain activities (or people) that medically may not be in one's best interest.

It may sound like this technology is very far off, but five years ago the world had not yet seen the fastest selling consumer device in history: the Microsoft Kinect[2]. That motion-sensing input device revolutionized home gaming by interpreting gestures and body position. Beyond gaming, 3D imaging is being used by a company by the name of Mantis-Vision to capture complete rooms in 3D[3]. For example, once captured, a crime scene can be electronically reconstructed back at the police station. With this as today's reality, one can imagine having dozens or hundreds of sensors collecting this type of data and attaching it to your personal cloud. The possibilities go far beyond any visions mentioned in this paper. With all of the data collected in the cloud and reduced to useful information, a doctor can ask a different set of questions: questions based on the information. In some cases, questions that once needed to be asked to help doctors make a diagnosis will no longer need to be asked as the answers will already be in the information gathered by personal technology.

One can only imagine

One contribution to medicine from the cloud is the ability to separate the care giver from the one being cared for. With the cloud, the caregiver doesn't have to live in the same house as the one cared for. They can live in another house, town or state and still know how the patient is doing while the one being cared for can live independently. Virtual house calls, for example are in use around the world. The virtual house call has advantages, especially for regions of the world where there are few doctors, not to mention working remotely from many patients. All that is necessary is that both the doctor and patient have access to the cloud. The work done by Dr. Devi Shetty is a great example of this (**en.wikipedia.org/wiki/Devi_Shetty**).

Beyond a virtual house call, the next imaginable step is remote surgical procedures. This is where technology meets one of its highest-performance processing demands. The demand for extremely low latency (delay) between the surgeon and the patient, the requirement for near infinite precision in the image processing necessary to accurately perform the procedure and the need for clear communications in the language of all of the professionals involved (not to mention the patient).

Figure 2: The next step in virtual medicine could be remote surgeries.

This all sounds like science fiction, but compare that to how far technology has advanced in phones, making video phone calls mainstream. Video communication systems like Skype™ or Facetime™ have made video conferencing an everyday event. It wasn't long ago when video conferencing was only for the corporate crowd, and even then, it wasn't very good – it was hard to make the connection, the video was poor, the latency was excessive, double talk was disastrous and the system was not smart enough to know who or where to point the camera. That experience seems to have past and most people make video calls rather than audio calls with little concern. It won't be long before the same level of concern for remote operation or virtual house calls permeates the medical field.

Ultra-low power

Beyond processing demands, technology has also improved in the area of ultra-low powered (ULP) devices. An example of leading research in ULP is the work at MIT by Dr. Anantha Chandrakasan and his students. They have demonstrated the ability to create ULP processors with the ability to operate from body heat[4], how to exploit accelerators for ultra-low-power processing[5] and harvesting energy from a biological source[6]. MIT is not alone in this drive for ULP technology. Another activity worth mentioning is the work being driven by venture capital company, Rainbow Medical[7] where they are funding new technology developments and new medical devices based on that technology in Israel. One of those technology developments is to create the ability for the body to produce the energy needed to keep the implanted technology working. They are on both sides of the creation and use of technology in medicine.

One of the early uses of ULP was restoring sight to the blind. More than a decade ago, several innovators from Texas Instruments began engaging with Dr. Mark Humayun when he and his team at Johns Hopkins University dreamt of a technology capable of restoring sight to the blind. Now, at the University of Southern California, Dr. Humayun and his team have an approved solution for those with retinitis pigmentosa and macular degeneration. Here is a quote from Dr. James Weiland on the success of the research team:

"The FDA approved commercial implant, as described in the paper[8], has 60 pixels. On the research side, we have tested a complete system with 240 pixels and are working towards a system with 1000 pixels, but these are not yet available for humans. To improve the overall performance of the patients, we can utilize the external camera processing system to optimize the information we give to the patients. What we have shown is that machine vision can identify an obstacle free path (using stereoscopic vision) and that we can detect and identify objects from a list."

That's a powerful statement. By using machine vision, a previously blind patient can now have 60 pixels of vision with a possibility of 1,000 pixels in the future. It's truly miraculous.

Another example using different vector of technology, cost, comes from a company in Israel by the name of CNOGA (**www.cnoga.com**). Its technology uses video cameras to noninvasively measure vital signs and bio markers such as blood pressure, pulse rate, blood oxygen and carbon dioxide, hemoglobin or glucose levels. It does this through real-time color tissue photography by simply focusing on the person's skin or internal capillary tissue. Future applications of this technology can lead to noninvasively identifying biomarkers for diseases such as cancer and chronic obstructive pulmonary disease.

In discussions with Dr. Yosef Segman, CEO of CNOGA[9], it seems that the extent of its capability is yet to be explored. It is only a matter of time before this technology will find its way into homes and neighborhoods, making lives healthier and more comfortable with age, ultimately allowing for the last days of life to be lived comfortably at home with ubiquitous non-invasive monitoring.

Yes, it all sounds like science fiction, but it is happening and becoming more of a reality every day. In the tragically short-lived TV show “FireFly,” a character once remarked, “That sounds like something out of science fiction.” To which his wife replied, “You live in a spaceship, dear.” This is the point medical advancements have reached. The future sounds like science fiction, but every day advancements prove otherwise.

The app

Anyone who has downloaded an app to count calories, track exercise or monitor sleep, has already seen how medical care has become more personal in the last five years.

Figure 3: Apps tracking personal health metrics are an example of the use of technology to personalize health.

These apps are just the beginning steps in a personal healthcare revolution. Most of the apps available today are for tracking, monitoring and collecting information. There are an amazing number of useful medical apps out there already, which has led to the spawning of several sites to help navigate through them all. The site **iMedicalApps** calls itself the leading physician publication on mobile medicine and puts out a weekly list of notable medical apps released. In a **recent list**, the site reviewed the apps UCheck and Dysnatremia. UCheck makes use of a kit to perform a semi-automated urine analysis. **Dysnatremia** describes itself as a tool that allows doctors to perform a differential diagnosis of patients with hyponatremia and hypernatremia.

Both of these apps are signs of what is to come – apps that will be able to diagnose medical conditions, providing that first opinion before we see a doctor.

Another example is the early disease detection smart phone app developed by four Dartmouth engineering graduates that uses a sweat collection device to identify proteins within a person’s sweat using a process called densitometry. Using the information gathered from the biosensor, this application is designed to catch anything from Alzheimer's to Type 2 diabetes in the early stages of progression[10].

The future holds a great deal. Someday a full body scan will be part of an annual physical, allowing better diagnosis of health issues including the ability to predict issues early enough to be proactive rather than reactive. This will also find its way into the personal realm as we invent our way to the Tricorder, another example of technology once considered science fiction.

Digital signal processing

One aspect of advancements in semiconductors is the ability to use its rapidly increasing performance to find new directions in the world of signal processing. As new signals and new ways to process those signals are found, there will be continual "aha" moments. One of those "aha" moments happened recently when a guitar company discovered a new processing algorithm.

The story goes like this:

> Texas Instruments was asked to visit the Paul Reed Smith Guitar Company to evaluate new signal processing technology the company had created. The technology was based on its need to solve a latency problem with electric guitars. The solution to this problem had not come from the classical digital signal processing world, meaning they had either rediscovered DSP or discovered something new. The conclusion was that it was something new, and it has been exciting to see this new concept find its way into medical applications. There have also been comments from medical researchers on how this technology could, among other things, significantly reduce the amount of radiation needed to take an x-ray.

The future is here

There are some areas in the medical world where technology is currently being used that sound so futuristic – it's hard to believe the technology already exists. The really exciting aspect is imagining where this technology will take us.

One such area is the use of additive manufacturing (AM) technologies to fabricate physical objects one layer at a time by an additive process that bonds the layers together. Also known as 3D printing, this technology holds amazing promise for the world of medicine.

In an **article published in *The New England Journal of Medicine***[11] in May, 2013, two doctors from the University of Michigan described how they saved a baby's life by implanting a bioresorbable tracheal splint created with a 3D printer with information from a computed tomographic image of the patient's airway. Here is the amazing conclusion to this article:

> “This case shows that high-resolution imaging, computer-aided design, and biomaterial three-dimensional printing together can facilitate the creation of implantable devices for conditions that are anatomically specific for a given patient.”

It’s very exciting to imagine what conditions can be fixed or mitigated with custom specific implantables. But there’s so much more that 3D printing enables. Bespoke Innovations uses 3D printing to create customized prosthetic limbs that, in addition to being created to look however someone might want, would also cost a tenth of the price compared to artificial limbs made using traditional methods[12].

There are several places now using 3D printing to make accurate models of a patient’s body parts to allow the surgical team to simulate procedures in advance, which translates to safer, more accurate and more efficient surgeries.

Another way technology is improving surgical procedures is by raising the level of precision possible. The ability to provide high-performance real-time signal processing to the field of High Intensity Focused Ultrasound (HIFU) creates another one of those areas where the currently possible is hard to believe.

Dr. Emad Ebbini, quoted earlier in the paper, believes that HIFU is really starting to take off with a variety of applications showing promise with several of these in the clinic. Improvements in data acquisition and signal processing increase the specificity of the interaction between the ultrasound and the tissue, making focused treatment in the sub-mm range possible. This means a future of highly specific imaging modes that range from purely thermal to purely mechanical and anywhere in between. Example end applications are the targeted thermal treatment of tumors and highly localized drug delivery, including usage of the mechanical effects of ultrasound to create a transient effect to let drugs be administered through the blood brain barrier.

The promise of highly efficacious and safe use of HIFU in noninvasive surgery is further strengthened by the recent introduction and demonstration of dual-mode ultrasound array (DMUA) systems. DMUAs are capable of delivering therapeutic levels of focused ultrasound and imaging the tissue response using the same transducer elements. The inherent registration between the imaging and therapeutic coordinate systems, together with real-time adaptive refocusing makes it possible to account for tissue motion and deformation during the treatment. A high-performance computing (HPC) solution allows the physician to focus on tracking the target tissue to a virtual scalpel (the mm-size HIFU focus) in real time. This technology will allow for the application of bloodless surgery with exquisite precision in applications like renal denervation, which was recently proposed for the treatment of hypertension in patients who do not respond to conventional medical treatments.

There is great potential for HIFU, 3D printing and other technological advances to improve our health, treatments and ability to live healthy lives. And thanks to cloud computing, we will have our good health wherever we go. We are beginning to hear new concepts like big data, analytics, data mining, high-performance computing and smart sensors. All these working together will take the massive amount of medical data and create the information a doctor will need to keep patients healthy. They will help provide a future before only imagined.

Technology will:

- eliminate catastrophic diseases
- manage chronic diseases
- make the last days of lives comfortable at home

So, what can one look forward to in the world of medicine? The simple answer is that imaginations are the only limiting factor (and, yes, the speed of light). We include the speed of light because much of the increase in performance will be determined on how we manage the speed of light. But assuming those two limitations won't go away; personal health will be under our control. The technology surrounding us will become a first opinion and refer people to doctors for the second and likely final opinion. The resulting actions will be more prevention than intervention. People will ultimately live out their days comfortably with chronic diseases managed, catastrophic diseases downgraded to chronic and looking towards the science fiction technologies of tomorrow.

See you in another five years.

Reference

1 Nadeski, M., Frantz G., "**The Future of Medical Imaging**," 2008.

2 **en.wikipedia.org/wiki/Microsoft_Kinect**

3 **www.mantis-vision.com/**

4 Kwong, J., Y. K. Ramadass, N. Verma, and A. Chandrakasan, "**A 65nm Sub-Vt Microcontroller with Integrated SRAM and Switched Capacitor DC-DC Converter**," *IEEE Journal of Solid-State Circuits*, vol. 44, no. 1, pp. 115–126, January 2009.

5 Kwong, J., A. P. Chandrakasan, "**An Energy-Efficient Biomedical Signal Processing Platform**," *IEEE Journal of Solid-State Circuits*, vol.46, no.7, pp.1742-1753, July 2011.

6 Mercier, P. P., A. C. Lysaght, S. Bandyopadhyay, A. P. Chandrakasan, K. M. Stankovic, "**Energy extraction from the biologic battery in the inner ear**," *Nature Biotechnology*, Nov. 2012.

7 **www.rainbowmd.com/**

8 Humayun, M s, etal, "Interim Results from the International Trial of Second Sight's Visual Prosthesis", *The American Academy of Ophthalmology*, Elsevier, 2011

9 **www.cnoga.com**

10 **www.vision-systems.com/articles/2013/04/smartphone-system-detects-disease.html**

11 **www.nejm.org/doi/full/10.1056/NEJMc1206319**

12 **www.bespokeinnovations.com/**

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