RTT	**RTT TECHNOLOGY TOPIC** **December 2005**
	Smart Superphones

In last month's Hot Topic, we talked about three types of phone, standard phones, smart phones and superphones.

Standard phones are voice dominant and/or voice/text dominant. Standard phones change the way we relate to one another. These phones have relatively basic imaging and audio capture capabilities.

Smart phones change the way we organise our work and social lives. They have more advanced imaging and audio capture capabilities than standard phones.

Superphones (also known as 'future phones' in that they do not really exist yet) change the way in which we relate to the physical world around us.

In this month's Hot Topic, we explore the superphone in more detail and show how superphone functionality will be combined with smart phone functionality in a new generation of 'Smart Superphones'.

The Superphone Defined

Superphones have advanced audio and image capture capabilities that are equal to or better than human audio and video processing systems, have equivalent memory resources but significantly better memory retrieval than human memory systems, a better sense of direction than most humans and an enhanced ability to sense temperature, gravitational forces and electromagnetic fields.

The Semi Superphone

In a sense we already have the ingredients for a **semi superphone** in that we can capture 20 KHz or more of audio bandwidth using solid state microphones, we can capture low g gravity gradients using sub 2g 3 axis accelerometers and have low cost phones today that include a temperature sensor, digital compass and positioning capabilities.

This is not enough to aspire to superphone status. A superphone has to be as good as or better than humans at more or less everything.

This means having imaging bandwidth that is at least perceptually equivalent to our own human visual system and be able to see and hear the world in three dimensions.

This is after all why humans have two ears and two eyes which gives us our ability to gauge distance and depth, which gives us our ability to respond and react to danger or opportunity.

Imaging resolution even with high end CCD's (Kodak are now sampling a 44 Megapixel CCD) is still short of present human resolution (about 2OO megapixels).

Imaging processing systems are also still significantly dumber than humans when it comes to taking spatial decisions based on complex multi channel inputs.

For example, a racing driver driving a Formula One Car around a race track uses audio, visual, vibrational and wind speed information in subtle and significant ways which are presently hard to replicate either in terms of capture bandwidth or information processing in artificial intelligence systems.

However leaving aside how audio and visual information is actually used, there are some areas where devices are better at 'seeing' the real world than we are.

CCD and CMOS sensors for example are capable of capturing and processing photons well into the non visible infra red spectrum (up to 900 nanometers for CMOS and over 1000 nanometers for CCD) - the basis for present night vision systems.

So what does this have to do with cellular phone and/or camera phone design ?

Imaging capabilities in Superphones

We have already devoted three Hot Topics this year to imaging in cellular phones, our February Hot Topic 'Camera Phone Design', March Hot Topic '' Digital Cameras and their impact on Camera Phone Design' and April Hot Topic ' The Camcorder Effect - Camcorders and their impact on Camera Phone Design'.

However in the six months since April, phones have more or less doubled their imaging resolution and more importantly have made significant advances in image quality (the two factors being notably **non** interdependent). So the topic is well worth revisiting.

RF Processing and Image Processing Commonality

We approached the mysteries of the image processing pipe (as it is described by the camera cognoscenti) from the perspective of knowing a lot about RF signal processing and not a lot about image processing. Fortuitously there are many similarities between the two.

In RF signal processing, the three major system performance requirements are **sensitivity** (the ability to detect wanted signal energy in the presence of a noise floor), **selectivity** (the ability to detect wanted signal energy in the presence of interfering signals) and **stability** (the ability to achieve sensitivity and selectivity over time, temperature and a wide range of operating conditions).

Noise is actually a composite of Gaussian white noise introduced by the devices used to process (filter and amplify) the signal and distortion with the added complication of non linear effects that create harmonic distortion.

Image processing is very similar. The lens is the equivalent of the radio antenna but collects photons (radiant energy in the visible optical bands), rather than RF energy.

Radio Waves and Light Waves

Radio waves are useable in terms of our ability to collect wanted energy from them from a few KHz (let's say 3 KHz) to 300 GHz above which the atmosphere becomes to all intents and purposes completely opaque.

In wavelength terms assuming radio waves travel at 300,000,000 metres per second, this means our wavelengths of interest scale from 100 kilometers (very long wave) to .0001 meter (300 GHz).

Optical wavelengths of (human) visible interest scale from 300 to 700 nanometers but lets say we are also interested in ultra violet (below 300 nanometers) and infrared (above 700 nanometers. Let's be imaginative and say we are interested in the 100 to 1000 nanometer band. Assuming light waves also travel at 300,000,000 meters per second (of which more later), this means a frequency of interest from .000001 meters to .0000001 meters or 3000 to 30,000 Teraherz.(A nanometer by the way is one billionth of a meter).

Image noise and linear and non linear distortions

So having collected our radiant energy in a lens we subject it to a number of distortion processes partly through the lens itself (optical aberrations) and then via the sensor and colour filter array.

The sensor array converts the photons into electrons (an obliging property of silicon) but in the process introduces noise. The combination of lens imperfections and sensor noise introduce ambiguity into the image pipe which needs to be dealt with by image processing algorithms.

The Human Visual System

Interestingly this is not dissimilar to the human visual system where we sample the real optical analogue world with two parallel sampling grids consisting of cones and rods. Cones are centred around the middle of the retina and work in medium to bright light and are colour sensitive. Rods are concentrated in an area outside the cones. There are less of them. They are optimised for low light conditions but are not colour sensitive. This is why we see in black and white at night. If you look at a distant dim object (a star at night) it will be easier to see if you shift your gaze off centre.

Anyway, a sensor array emulates the functionality of the cones in the human visual system. It has to deliver similar or better dynamic range, similar or better colour accuity and perceptually similar resolution. Note that although the number of cones equates to 200 Megapixels, no one seems quite sure why we need that much resolution - answers on a (e- mail) postcard please to.....

So image processing is just like RF signal processing EXCEPT THAT it has to take into account the idiosyncrasies of the human visual system. Note also that although humans are superficially alike (two arms, two legs, two eyes, etc) we are also intrinsically different in terms of optical performance.

Some of us are colour blind, some of us have better resolution.

Scientists have solved this by creating an 'ideal observer', a sort of 'model man' against which we can judge artificial optical and image processing systems.

The idiosyncrasies of the Human Visual System

The human visual system was first described in detail (in the western world at least) by **Johannes Kepler (1571-1630)** who codified the fundamental laws of physiological optics.

Rene Descartes (1596 to 1650) verified much of Kepler's work and added some things (like the coordinate system) which have proved indispensable in present day imaging systems.

Isaac Newton (1642 to 1726) worked on the laws of colour mixture ('the rays to speak properly are not coloured') and did unspeakable experiments on himself pushing bodkins(long pins) into his eye. He anticipated the modern understanding of visual colour perception based on the activity of peripheral receptors sensitive to a physical dimension (wavelength). All that stuff with the apple was a bit of a sideshow.

In **1801 Thomas Young** proposed that the eye contained three classes of receptor each of which responded over a broad spectral range. These ideas were developed by Helmholtz and became the basis of Young/Helmholtz trichromatic theory.

This optical wavelength business was all a bit curious and still is. **Anders Jonas Angstrom (1814-1874)** decided quite sensibly that light should be measured in wavelengths and that given that the radiant energy was coming from the sun, then it would be a good idea to relate the measurements to a hydrogen atom.

Thus an Angstrom was defined as being equivalent to the diameter of a hydrogen atom and equivalent to one tenth on a nanometer. This means that a nanometer is equivalent to 10 hydrogen atoms sitting shoulder to shoulder (assuming this is what hydrogen atoms like doing).

Now this is reasonably remarkable given that in 1850, the meter was an ill defined measure.

In the 1790's (when Fourier was thinking about his transforms during the French revolution), his compatriots were deciding that the meter should be made equivalent to one ten millionth of the length of the meridian running through Paris from the pole to the equator (on the basis that Paris was and still is the centre of the world if not the universe in general).

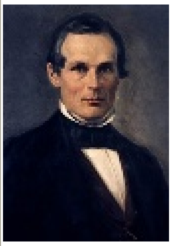
Unfortunately this distance was miscalculated (a failure to account for the flattening of the world by rotation) and so the meter was set to an arbitrary length referenced to a bar of rather dull platinum iridium alloy.

This was redefined in 1889 using an equally arbitrary and equally dull length of platinum iridium, then redefined again in 1960 with a definition based on a wavelength of krypton 86 radiation (the stuff that Superman uses so at least slightly less dull).

In 1983 the meter was redefined as the length of the path travelled by light in a vacuum during a time interval of 1/299792458 of a second which effectively determined the speed of light as 299,792,458 meters per second.

This is not the same basis upon which radio waves are measured and not the same way that Angstroms are measured. Any explanation of this would be warmly welcomed - answers on an (e -mail) postcard to...

Anyway, Anders Jonas Angstrom's work was carried on by his son **Knut** and formed a body of work that remains directly relevant today to the science of optical measurement. (A big hurray for Sweden).

The Angstroms	
Anders Jonas Angstrom 1814-1874	**Knut Angstrom 1857-1910**
	

The optical pipe and pixels

Which brings us back to pixels.

Pixels and People

We said that the sensor array emulates the functionality of the human visual system in that it takes point measurements of light intensity at three wavelengths (red, green and blue).

A 4 megapixel sensor will have four million pixels most of which will be capturing photons and turning them into an electron count that can be used to describe luminance (brightness) and colour (chrominance).

Interestingly pixels behave very similarly to people.There are black pixels and white pixels and 254 shades of grey pixel in between. Pixels of similar colour tend to congregate together. A white pixel in a predominantly black pixel area stands out as being a bit unusual (an outlier). There are good pixels and bad pixels. Some bad pixels start life as good pixels but become bad later in life. Noisy pixels can be a big problem not only to themselves but also to their neighbours. Pixels see life through red, green, blue or clear spectacles but lack the natural colour balancing properties of the human visual system. Their behaviour is however fairly predictable both spatially in a still image and temporally in a moving image.

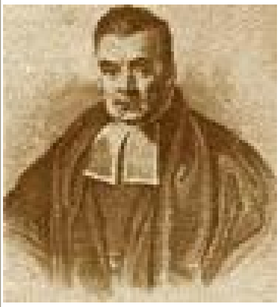
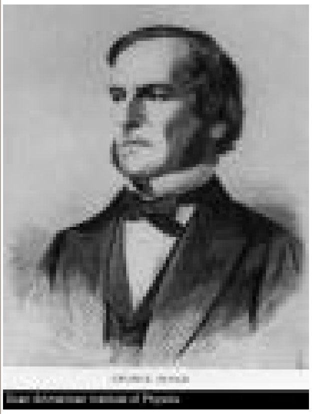
The big decision

In RF signal processing, we have to take a final decision as to whether a 0 is a 0 or a 1 is a 1 or whether a bit represents a +1 or -1 (see the October Hot Topic 'Matrix Maths in Mobile Phones' for more on this.

In the same way, a decision has to be taken in the image pipe - is this a black pixel or a white pixel ?(or one of 254 shades of pixel in between) or a green, red or blue pixel of a certain intensity and should that pixel be there or actually moved along a bit. Given that pixels are arranged in 4 by 4 or 8 by 8 or 16 by 16 macroblocks this is like a game of suduko or if preferred a slightly complicated form of noughts and crosses (diagonals are important in the pixel world).

Pixels that do not fit a given set of rules can be changed to meet the rules. These decision can be based on comparing a point pixel value with that of it's neighbours. Simplistically it is this principle that is applied to image enhancement in the image pipe (noise reduction, blur reduction, edge sharpening) and to image manipulation either in or after the image pipe (colour balancing etc).

Which gives us an excuse to introduce our three **'mathematicians of the month'**, the **Reverend Thomas Bayes** (the clerics of middle England and their role in cellular phone design), **George Boole** and **Augustus De Morgan**.(All promised as part of our pre Christmas treat).

Mathematicians of the Month		
The Reverend Thomas Bayes	**George Boole**	**Augustus De Morgan**
		

The Reverend Thomas Bayes (1702-1761) is arguably the father of 'conditional probability theory' in which 'a hypothesis is confirmed by any body data that its truth renders probable'. He is most well known for his 1764 paper 'An Essay Toward Solving a Problem in the Doctrine of Chances' and his principles are widely used in gambling (of which Thomas Bayes would have disapproved) and image processing and image enhancement algorithms.

For instance, conditional probability theory is the basis for context modelling. For example an area of blue sky with occasional white clouds will obey a certain rule set prescribed by the context (a sunny day), a dull day sets a different context in which greys will dominate and contrast will be less pronounced. Adaptive algorithms can be developed that are spatially and/or context driven, conditioned by the image statistics and or any other available context information.

George Boole(1815-1864) developed Bayes work by introducing more precise conditional language, the eponymous Boolean operators of **OR** (any one of the terms are present, more than one term may be present), **AND** (all terms are present), **NOT** (the first term but not the second term is present) and **XOR** (exclusive **OR**, one or other term is present but not both).

Every time we use a search engine we are using a combination of Boolean operators and Bayesian conditional probabilities but Boole is also present in almost every decision taken in the image processing pipe.

Augustus De Morgan ((1806-1871) was working in parallel to Boole on limits and boundaries and the convergence of mathematical series (or at least the description of convergence in precise mathematical terms). He is probably most famous for De Morgan's Law which applied to people and pixels goes something like this;

In a particular group of people

Most people have shirts

Most people have shoes

Therefore some people have both shirts and shoes

In a particular group of pixels

Most pixels have chrominance value x

Most pixels have chrominance value y

Therefore some pixels have both value x and y

More specifically, the work of Augustus De Morgan is directly applied to the truncation of iterative algorithms so that an optimum trade off can be achieved between accuracy and time - the longer the calculation the more accurate it becomes but the more clock cycles it consumes. The modern image processing pipe is full of these rate/distortion, complexity/distortion, delay/distortion 'trade off' calculations.

So the Reverend Bayes, George Boole and Augustus De Morgan have had and are still having a fundamental impact on the way in which we manage and manipulate image signals that have particular statistical propertoies and exhibit specific behavioural characteristics. They allow us to pose the thesis that 'this cannot be a black pixel because.....

The role of middle England clerics in SuperPhone Design

Their role in Superphone Design is however far more fundamental.

Early Superphones will be capable but dumb. They may be able to see and hear as well as we can but they cannot think like us. This requires the power of reason and logical analysis to be applied.

This really explains why so called smart phones have only appealed to a minority of mobile phone subscribers. Smart Phones declared role in life is to make us more efficient. Some of us, many of us, do not want to be made more efficient.

Most of us however would like some practical help in the way that we relate to the real world around us - knowing where we are, where we need to go, seeing in the dark, hearing sounds that are below our acoustic hearing threshold and having a device that can help us make intuitive and expanded sense of the surrounding physical world of light, sound, gravity, vibration, temperature, time, space.

This is the promise of the Smart SuperPhone- the future phone that will deliver future user and telecom value.

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