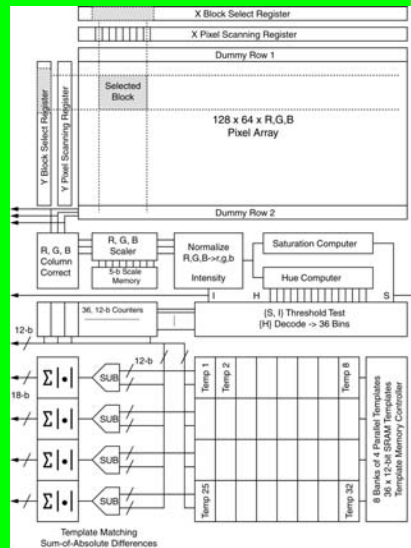
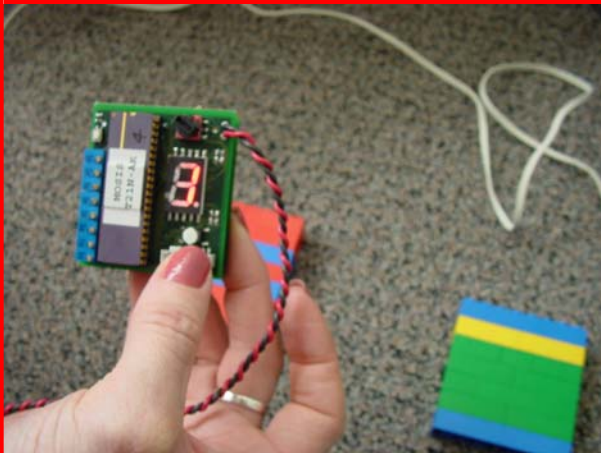


Why Color? : Neuromorphic Color Processing

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Why Color?

Color functions in many wonderful ways in our world. Color can telegraph an information message or convey emotions, or serve as a proxy for an idea or thing. Color can be used to secretly encode information and to break camouflage. We point out a few ways color is used.

Sending a message: Poisonous insects use color to say to you “watch out” if you try to eat me. This effect is so efficient that non-poisonous insects evolve with the same colorful markings. These insects are called mimics. Fruit, when it is ripe and ready to eat often changes to a vibrant color unexpected in nature. In the industrialized world, color is used in supermarkets to attract a buyer’s attention to a specific product

Conveying emotions: Red, the color of blood, raises one’s blood pressure and may lead to a heightened sense of awareness. This idea is not lost on the designers of traffic signs.

Proxy for an idea or thing: Color is used to identify players on sports teams, or membership in a profession (i.e. the military). The national flags of many countries are often identified by a simple combination of colors.

Secretly encoding information and breaking camouflage: Hypercolor sensitivity, i.e. identifying more than the normal three spectral bands, much as the visual system of shrimp, can be used to break camouflage. Human vision is called a Non-Analytic sense. We cannot tell the difference between a yellow light source and two light sources (red and green) that combine to create yellow. Such colors are called *metamers*. However, in principle, a sensing device can. Thus, an instrument can be engineered to discriminate between two surfaces that *look identical* to the human eye.

Identifying Skin Color: It may be possible to develop a sensor that is uniquely tuned to skin color. Skin color can be modeled as a composition of two components: one for melanin, and one for hemoglobin. However, RGB cameras lack the specific spectral tuning to discern skin color specifically. It seems that a special camera or even a sensor sensitive to a single point, could be developed that would localize human skin in a scene.

Aesthetics: Colors are integral to design, dress and other aesthetic aspects.

In short, the color content of the environment is an important quality that is separate from shape and form. From the perspective of the brain, color processing is performed by specialized cells and regions. The ability to sense, perceive and use color information is important in a wide range of activities of intelligent beings.

Basic Problems Identifying Color

There are several basic fundamental problems in understanding color. Firstly, the problem of metamers or two dissimilar lights from a physical point of view that are psychologically identical.

Secondly, the reflected light from a physical surface is, at each point, the product of the wavelength of the illuminating light or lights as well as the surface itself. We tend to be able to identify color under a range of conditions.

Third, the classification of color into specific categories is based not only in human psychology but in human culture and perception as well.

ColorStick

The simplest problem in color identification is to sample a surface using controlled illumination and then classify the resulting color. The spot identification of color can be used in applications where it is sufficient to identify a single color (as in finding the color of an article of clothing), or a temporal sequence of colors (as in set of colors corresponding to a musical melody).

Iguana Robotics has developed the ColorStick. This device is about the size of a fat pen or small flashlight that provides multispectral illumination to a surface. The device classifies the surface into color, or even color families and reports the color via a LED or LCD screen, or a haptic display or spoken voice for the visually impaired.

This device will find use as a toy for children learning color. As a toddler or preschooler presses the stick against a surface it will shout out the name of the color. Multi-lingual versions would an easy way to introduce children to new languages.

Musical tones can be associated with each color. Imagine a game where children find objects corresponding to the notes needed to play “twinkle-twinkle little star!” That would make ear training fun!

It will also be useful to the tens of million of visually impaired, colorblind, and aesthetically impaired people in the world who would like to dress themselves in a color-coordinated way.

It has a host of applications in any industry, product, or environment where color is important.

Processing stages of the ColorStick

Sensing head

The sensing head consists of several light sources. In the case of the ColorStick assistive device, we use 4 or more LEDs and a single photo transistor to sense light reflected back from a surface.

LEDs can be relatively expensive (i.e. $> .50$ each) and we need a range of colors. In the current version the most important LEDs are Red, Green, Blue, and Yellow.

If cost is an issue, an alternative ColorStick design calls for a single light source plus 4 phototransistors. Each phototransistor would be covered by a cheap plastic filter to bandwidth limit the light reaching the sensing element.

During sampling applications, the LEDs are turned on sequentially and a measurement is made of the returned light from the surface to be measured. In the current implementation, we use a 10bit A/D converter to sample the current. We sample each surface 8 times, this gives us about 12 bits of total resolution. In principle a lower resolution A/D might be used. We could then take more samples to achieve the same effective resolution. There would be a negligible impact in the perceived rate it would take to sample and process the color target.

Preprocessing

Once the sampling is made, we normalize the incoming signal and apply scaling factors. These scaling factors are dependent on the following attributes of the sensor: The



Figure 1. The uses of the ColorStick
(A) ColorStick used as an Assistive device for the blind. The color stick can recognize the color of items of clothing. (B) A child plays with a prototype version of the ColorStick. (C) A closer view of the toy concept ColorStick

voltage level used to turn on the LEDs, the LEDs used, and any resistors used to limit current through the LEDs, and the type of phototransistor used.

In principle, there are some steps that might be taken in this stage to compensate for line-voltage fluctuation. Currently, however we use a stabilized voltage source. If cost is a concern, the DC-DC converter used to stabilize the voltage from the onboard battery might be eliminated. In that case, methods of reducing/eliminating the effects of line voltage fluctuations could be developed

Color Opponency Space

While the human eye has effectively three types of cones, the perception of color seems to depend to a large extent on the construction of a color opponency space. There are three color channels in the human eye. They are: Red-Green opponency, Blue-Yellow opponency, and light-dark opponency.

The ColorStick follows this human perceptual model and converts the incoming signal to the color opponency space.

This operation amounts to a simple matrix-vector multiplication.

Iguana has found color opponency to be more robust *perceptually* than other color classification tools (i.e. HSI Space, for example), at least for use in our device.

Rule-Based classification

From anthropological studies, scientists know that most cultures have linguistic labels for 11 and sometimes 12 base colors. These colors are: Red, Pink, Orange, Yellow,

Brown (tan), Green, Blue-Green (sometimes used), Blue, Purple, Grey, White, and Black. This classification is culturally specific.

Our own casual observation of a range of human users, confirmed that this set of color families corresponded to what people thought of as “color.”

In principle, the ColorStick can recognize a very wide range of colors. But, we found in a small group study that too many color classifications was confusing and not very useful for most applications.

In addition to these color classifications we applied the modifiers DARK and LIGHT to the above 12 colors. The default response is no modifier. Thus there are a total of $(2+1)*12=34$ distinct responses of the color stick.

A collection of about 20 or so “if-then rules” analyze the opponency space and produce a robust classification of the target into 1 of the 12 color families and then applies a modifier.

How does the ColorStick differ from other devices that measure color?

Color devices we are familiar with typically do not *perceive* color, but rather perform a kind of table look up to match sensed values to prototypes tables stored in memory.

An example of this is the Pantone color sensor.

Other devices use components that sense markers that are *specially designed*. Thus for example, it is trivial to use a table lookup approach to recognize a well defined pallet of data.

For example, Mountford has developed a system that senses pre-defined colored targets. Such a system would not recognize colors for which it is not trained and in the way humans perceive color.

The strongest point of our system is that it takes into account physiology, psychology and the anthropology of color in creating a robust set of rules for color classification. Our system should work over a much wider range of colors than simple color classifiers.

Further our system should work much more robustly to novel colors. Our system does not require a pre-specified pallet.

Cost reduction using a custom hybrid ASIC

The processing described above is amenable to implementation in a custom hybrid chip. The basic processing structure is a series: sensing->normalization->linear transformation->comparisons-> decision making.

In principle, the first four processing stages could be done in an analog circuit with the backend comparisons being done with logic. We anticipate that a design could be made without the use of an A/D for example.

There are obviously risks associated with the construction of an ASIC. The risks include project timeline risks in development as well as risks in manufacturing the device in a timely fashion.

The ColorCam

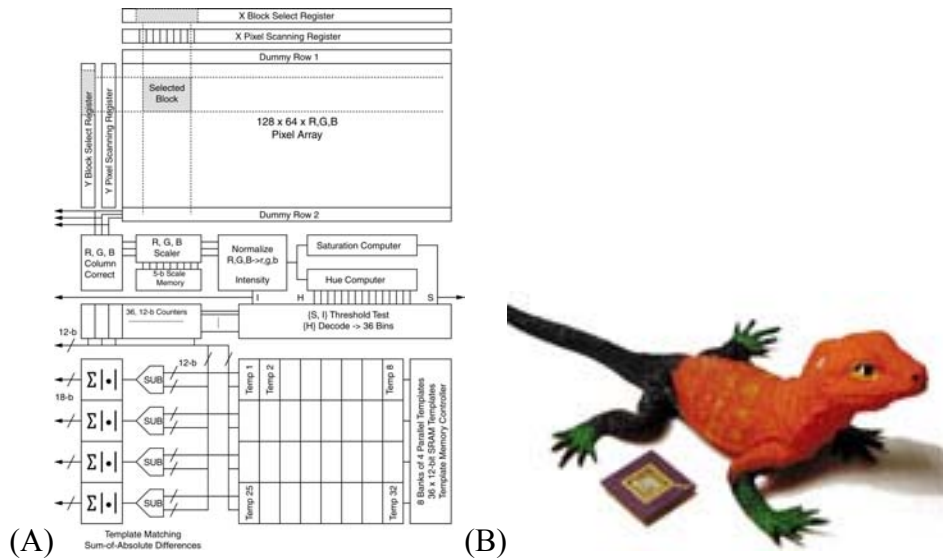


Figure 2 (A) Neuromorphic Processing Architecture of the Color Cam (B) photo of first chip.

Overview

Combining colors and counting the relative ratio of the color content of items adds a new dimension. Color Histogramming based object recognition is a well known technique for identifying objects in the environment. Researchers at Iguana robotics have, for the first time, developed a *stand-alone chip* that integrates color sensing, color space transformation, histogramming, and histogram matching *in a single device*.

The histogramming algorithm is ideally suited for integration into a compact single chip IMAGER+COMPUTATION or SYSTEM-ON-A-CHIP. The reason is that the histogramming algorithm operates sequentially, analyzing each pixel one at a time and then accumulating a statistic representation of the image being viewed. No onboard storage is needed for image memory. This fact allows us to create a device that reaps many benefits.

This device runs at better than frame rate and uses far less power, is far smaller and compact and is far less expensive than techniques involving conventional CMOS images+dsp arrangements. We call this chip the “ColorCam.”

The ColorCam chip will find a number of applications in toys and beyond. For example, the Color Cam chip could allow one toy to recognize another toy with a given color pattern.

The Color Cam might be used to learn language. Imagine a play set with a multi-color cup, saucer, knives, forks etc. He child would arrange items in front of it and a back in processor, receiving information from the color cam as to the relative positions of the objects would respond in French describing the position of the objects. As the child

rearranges things, the description would change. Thus, allow the interactive acquisition of language.

The Color Cam could also be used to recognize locations, such as the locations on a game board. Imagine small robotic “animals” moving around a kind of Jurassic park game board. When they came to a green patch they would start making munching sounds like they were eating. They would then explore and find their way to the blue patch watering hole. When the colorful t-rex approached they would make “alarm sounds” and try to run away.

The Color Cam might be used to recognized hand gestures from a child. Imagine a glove made so that the fingers are each a different color. As the kid changed his/her hand configuration, there would be different proportions of color exposed. These would be recognized as different “gestures” and would allow the kid to give commands to his toy.

Processing Stages

An overview of the first generation chip is shown in Figure 2A. As can be seen, the first generation device used a 128x64 pixel imager. RGB pixel information flowing from the sensor block is normalized and then Hue and Saturation content of the pixel is found via a table look-up circuit.

If the pixel saturation exceeds a preset threshold, the hue value of the pixel is counted. If it does not reach the given threshold it is thrown away. The information is then accumulated in 36 counters that divide the hue space, uniformly or non-uniformly into 36 regions. Once accumulation of pixel information is achieved over a region of interest, a SAD circuit finds a minimum match over a set of stored templates.

Currently, we are working on a 3rd generation device that will address, on chip, problems of scaling, light source color changes and other issues.

Appendix: When does the ColorStick fail?

The ColorStick generates its own light source and senses reflected light. When the ColorStick senses given off not only the reflected light, but also light that has been transmitted through the item as well. In principle there are ways of detecting this situation. Rules can be developed that will sense the ambient light (indicating that the ColorStick is not firmly placed on a surface or the occurrence or sensing on a transparent surface) and appropriate actions can be taken.

The ColorStick does not work well on shiny surfaces (i.e. mirrors). Again, in principle, appropriate rules can be developed to handle these cases.

The ColorStick will not work well with patterns in its current implementation. Patterns can lead to erroneous results due to the ColorStick averaging all the colors in the pattern and reporting a single color. Fortunately, if the user takes several samples, and these samples give different readings, then we can assume that we have a pattern. We are developing techniques to identify patterns as well.

The current implementation of the ColorStick has sensing nozzle that is not completely opaque to light. Hence, if the ColorStick is used outdoors, in direct sunlight it may give erroneous readings.

Finally, the ColorStick correctly classifies a large range of colors. In the version of code running on ColorStick 001, we see occasional errors with dark green and light yellow versus pink and pink versus tan. We plan to correct this classification in the next code release.