Feasibility Study:
Sensor head for diffusion imaging system

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9 November 2002

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1 Project aims

1.1 System overview

This project is inspired by a research paper which describes a method for mapping blood vessels under the skin's surface. The aim is to produce a two dimensional map of where blood vessels are located using non-invasive diffuse light reflectance measurements, over a 27×27mm area.[2]

The system can be broken down into three main areas:

1. Computer hardware and software controlling and processing the data returned by the scanning arrangement.

2. Scanning control unit concerned with the positioning of the scanner head.

3. Scanner head concerned with emitting light and detecting the reflected light and passing the information to stage 1.

1.2 Sensor head

This project is concerned with the development of the sensor head for the blood vessel scanning system described above.

1.2.1 Physical size

The head itself must be physically small to ease integration with the scanning control unit. Large heads would be difficult to manoeuvre over a plane, but the complex shape of the human body makes this requirement even more important.

1.2.2 Detection and output

An optical power meter was used in the original specification. The stability and dynamic range of the photosensitive device used in the head is important, as changes in the optical intensity will be relatively small in these tests.

The output must be in a standard form, for example 0-10V, in order to simplify interfacing with the controlling computer and any other systems.

1.3 Medical advantages

The circulatory system is distributed throughout such a large range of the body that information about blood flow is useful in most areas of medicine, both directly and indirectly.[4]

Knowledge of the position of blood vessels and flow through them is essential for this, and non-invasive methods are almost universally preferred over invasive techniques, especially for diagnosis of ailments such as deep vein thrombosis and arteriosclerosis.

2 Milestones

- Preliminary paperwork submission.
- Circuit specification approved.
- First signal generated by the scanning head observed on an oscilloscope.
- Presentation delivered.
- Project report submitted.
- Creation of an image mapping blood vessels in a test subject by the system described in § 1.1 on page 2.[1]

3 Implementation

3.1 Light source

The original paper described an 890nm LED in combination with a gradient index lens as the light source for the sensor.[2] An alternative approach would be to use a laser as the light source, which would provide an approximately collimated beam without a lens.

The use of the laser over the LED would probably be preferable to maintain the simplicity of the system, although the cost of laser diode may be prohibitive.

3.2 Light guidance

The original system used a fibre optic system to guide the light from the source to the scanning site and then back to the detector.[2] Although this provides one possible method of implementation for the sensor head, there are many complications introduced by using optical fibres, for example matching refractive indices and physical device coupling.

An alternative approach would be to mount the source and the detector directly onto the scanning head. This would eliminate the problems associated with the fibre optics, but would require a sensor and detector that are contained in physically very small packages (see § 1.2.1 on the page before).

[1] Image creation is dependant on the interfacing stage.

3.3 Orientation

The orientation of the light source and detector must be adjustable in order to control the effective depth below the skin at which the scanning takes place. This adds further complexity to the idea of mounting the source and detector on the head itself, however assistance from the EEE mechanical workshop would be available.

The orientation could be adjusted either manually or by the controlling software. Because of the time allowed for the project and other commitments, and since this is secondary to the objective or mapping blood vessels, it would be more useful to manually adjust the orientation. An automated adjustment system could be added at a later date if required.

3.4 Light detector

The device chosen for the light detector must not be influenced by daylight. A highly selective frequency response matched to the source would help here. The dynamic range of the detector is also important, as small changes in intensity must be noticeable against a much larger background intensity.

The angular sensitivity of the detector is also important, as directional detection is important for diffusion imaging.

3.5 Original system

Since the specification for this project is to meet or exceed the specifications of a similar project, the exact specifications of the original system need to be determined.

- Hamamatsu L2690 high output power LED.[3, 2]
  - Resin-potted package without reflector.
  - 0.4mm emission size.
  - 890nm peak wavelength emission.
  - 14.0mW radiant flux under 50mA forward current.
- Ensign-Bickford Optics fibre, HCPM 1000 T-10, NA=0.37.[2]
- Melles Griot SELFOC® 0.25 pitch gradient index lens.[2]

- Newport Corporation 835 optical power meter.[2]
  - This product appears to be discontinued and little data is available on its specifications.

4 Requirements and costing

4.1 Light source

It can be shown that the skin is an approximately linear system in terms of light diffusion. This property is useful, as the approximate percentage change of incident light appearing as a light change on the output will be roughly constant if the absolute power of incident light is varied.[2, §3]

There are several advantages of using a laser diode over the LED method chosen in original report. The light will already be collimated, negating the need for an additional collimating lens. Also, the output power of a laser diode is normally higher than for an LED, so the signal to be detected will have a larger range, reducing the constraints on the detector.

Another consideration would be that the laser light would be completely monochromatic, so a highly frequency selection light detector could be used to reduce ambient noise.

Using a laser diode, however, would result in a much more expensive solution than if an LED was used as the light source. Since the exact specification of the original system cannot be completely determined because of lack of information on obsolete products, some experimentation with different components will be needed. The high cost of laser diode modules (around £100) may be prohibitive in this case.

The cost of using an LED in combination with a collimating lens as the light source would be around £15-£30, with the lens being the most expensive part of the system.

4.2 Light detector

The project specification requires that "the function of an optical power meter must be met using some sort of photosensitive element". Four common light-sensitive devices are available:

- Light defendant resistors
- Photodiodes and CCDs
- Phototransistors
- Photovoltaic cells

4.2.1 Passive detectors

Light dependant resistors and photodiodes are passive components. They will allow different amounts of current to flow through them depending on the amount of light incident upon them. CCDs are basically arrays of photodiodes or photo MOS capacitors. Since only a single measurement will be taken at once, CCD arrays will not be required.[1]

Because they would be required to detect very small changes in light intensity against a much larger background level, the changes in current would also be very small. These small changes could be lost in background noise generated by the components themselves and from ambient conditions.[5]

4.2.2 Active detectors

Phototransistors are active components rather like standard bipolar transistors, except conduction in the base region is controlled by the incident light on the device. The current passing through the device would be amplified, but approximately proportional to the optical intensity incident on the phototransistor's base region.

With careful biasing to set the transistor into its active region for the ambient light level, small changes in the light level could be made to produce a significant change in output current which could be process further either in hardware or software before constructing any images.

Photovoltaic cells have a relatively low resistance, and create a potential difference between their two poles. The short-circuit current is approximately linear as compared to the incident luminance

4.3 General requirements

Ambient conditions should affect the system as little as possible, especially as relatively small changes are being measured by the device. In order to increase the accuracy and noise rejection of the system, several points have to be considered:

- Wavelength/frequency selection
- Directionality
- Stability and dynamic range

4.3.1 Wavelength/frequency selection

Ambient light has components with many different wavelengths, the exact mix of which depend on levels of natural light combined with the levels and types of artificial lighting in the room along with reflections from nearby objects. The type of ambient light cannot be accurately and precisely determined in advance.

However, if the wavelength of the light emitted by the source is known, using a highly selective detector should cut down on the noise produced by the ambient light, by only recording the small component of ambient light that exists in its sensitive region.

4.3.2 Directionality

Ambient light will fall onto the detector from a range of angles, but the position of the scanning area will be known in advance. The detector should only be influenced by light levels in from a set direction to reduce noise from ambient light levels.

4.3.3 Stability and dynamic range

The detection device must be able to react to a relatively small change in intensities, which must lie somewhere within the device's dynamic range. For a device such as a transistor, the dynamic range can be adjusted with biasing.

There is no need to include zero to the maximum brightness in the dynamic range, as this would create very small changes in the output of the detector. In order to give the maximum change in output, the dynamic range of the detector should match the variation of light intensities that it will be measuring.

In most components, slight variations in operation over time are acceptable. However, with equipment sensitive to small changes such as for this project, small changes in the parameters could dramatically affect the system, so stable components will be required.

External factors can also affect the stability of a device. Ambient light and temperature will be factors affecting the operating parameters of a device. If control of these factors is not practical, a high degree of rejection in the device will be required.

4.4 Conclusions

Cost constraints make justification of a laser difficult, so a red, NIR or IR LED would probably be the best light source (<£5) along with an appropriate lens system (£10-25).

Since few details of the original optical power meter are available, I would suggest obtaining a selection of photodiodes and phototransistors which properties similar to those required for the project (£1-£5 each). A final decision could be made after testing by prototyping.

5 Time scale

A full time plan is included in the form of the attached Gantt chart. Milestones and deadlines are summarised here.

- Project deadlines

17 March 2003	Presentation week.
12 May 2003	Report submitted.

- Other milestones

11 November 2002	Preliminary paperwork submission.
25 November 2002	Circuit design approval.
15 December 2002	First signal observed.
2 March 2003	System produces first image.

6 Risk Assessment

6.1 Laser

This risk assessment has been compiled from guidelines set forward by UMIST and the University of Leeds[7, 6]

6.1.1 Risk to eyes

Even weak laser beams entering the eye can cause partial or complete loss of sight in the affected eye. This risk is also present for stray reflections of the laser beam.

6.1.2 Risk to skin

Powerful lasers can burn the skin, with increased risk from ultra-violet lasers which can produce an effect similar to accelerated sunburn.

6.1.3 Electrical properties

Most lasers will use high currents and/or voltages internally, which could potentially be hazardous if misused.

6.1.4 Minimising risk

Risks cannot be completely eliminated when working with lasers. They can be substantially reduced by following some simple guidelines

- Use the lowest practical laser output.
- Use shields to constrain the laser beam.
- Designate and restrict access to the laser area whilst in use.
- Remove all reflective surfaces not required for the scanning system, eg wristwatches.
- Always follow the manufacturer's guidelines on operating lasers.

References

[1] Booth, K., and Hill, S.
The Essence of Optoelectronics, first ed.
Prentice Hall, 1998.

[2] Fridolin, I., and Lindberg, L. G.
Optical non-invasive technique for vessel imaging.
Phys. Med. Biol., 45 (2000), 3765–3778.

[3] Hamamatsu Photonics.
Light emitting diode.
`http://usa.hamamatsu.com/hcpdf/catsandguides/Led.pdf`.

[4] Roberts, V. C.
Blood flow measurement, first ed.
Sector Publishing Ltd, 1972.

[5] Siemens Solar Industries.
Silicon photovoltaic cells, photodiodes and phototransistors.
`http://www.powerpulse.net/powerpulse/archive/pdf/aa_050701a.pdf`, 2001.

[6] UMIST Safety Office.
Code of practice for use of lasers.
`http://www2.umist.ac.uk/staff/safety/pdfs/CoP%20on%20lasers%20%20.pdf`,
`http://meteo.phy.umist.ac.uk/~jm/code_of_practice_for_use_of_lase.htm`.

[7] University of Leeds Radiation Protection Service.
Laser work in a laboratory.
`http://education.leeds.ac.uk/~preproom/SafetySite/laserr.pdf`.