Machine Vision and the World Wide Web: Design & Training Aids

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Keywords: Machine Vision, World Wide Web (WWW), Remote Access Teaching, Interactive Image Processing.

Abstract

The World Wide Web (WWW) offers the chance to generate a comprehensive collection of reference material, expert systems, programs, databases, image archives, image analysis and other tools for assisting practising vision systems design engineers. The WWW is also an ideal medium for disseminating material for training students, educating would-be customers and new users of Machine Vision systems technology. The paper explores the potential for WWW-based material, and highlights some of the resources that are available today. A major purpose of this article, however, is to appeal for help in developing a comprehensive set of design and reference material that will allow highly reliable and accurate visual inspection, monitoring and control systems to be designed in future, with a minimum of effort.

1. World Wide Web as an Engineering Resource

Although the WWW contains a wealth of valuable reference material covering a very wide range of technical topics, it is not structured or catalogued in any systematic way. In particular, the material relating to Machine Vision was prepared in a piece-meal fashion, with no systematic nomenclature, nor co-ordination of ideas among the various contributors. Moreover, many important topics are not covered at all. Since the WWW is developing extremely rapidly, no paper-based survey article, however comprehensive, will remain up to date for more than a few weeks. The challenge that faces each worker in this subject is to be fully aware of the resources available via this very powerful medium. With this in mind, two of the authors have established an on-line directory of resources relating to Machine Vision [1].

It is reasonable to expect that learned societies should play a critical rôle in the development of suitable libraries of reference material on Machine Vision and other subjects that fall within their field of interest. This paper is written in the hope that it will encourage both SPIE and MVA to take a lead in developing suitable reference and teaching material, as well as software tools intended to assist designers of Machine Vision systems [1]. This article describes some of the relevant material that the authors have made available on the WWW and identifies various other areas where they feel it does not yet provide adequate cover. It is also intended to publicise the on-line directory just mentioned and encourage colleagues to use it and help the authors to keep it up to date.

Machine vision is a multi-disciplinary subject and therefore requires the harmonious integration of a broad range of technologies, including mechanical engineering, optics, electronics and software. There is a severe shortage of properly trained systems integrators, as we have pointed out in several earlier publications. [2, 3, 4, 5] The need for improved computer-based education and design tools for Machine Vision has been understood for some time and has already resulted in some valuable facilities, some of which will be mentioned later in this article. The skills and experience that established practitioners have accumulated during their working lives must not be lost; somehow we must encapsulate their knowledge in some convenient form, possibly an expert system or database. As we have hinted, a start has been made in this task but, to date, it has been based on whatever computing platform was favoured by the worker. We now have a real chance to build "universal" tools, based on the WWW. Compatible WWW browsers exist for all major operating systems, so that "static" multi-platform training and reference material is straightforward. In theory, at least, Java programs can run on most operating systems, and hence should be able to provide the basis for building a wide range of interactive tools that can be run on virtually any computer. Thus, we can begin to look forward to the day when such facilities as interactive image processing, ray tracing, image synthesis and vision system modelling can all be performed on the client's own computer, using standard software.

Questions and Answers

Who is prepared to prepare free material, on Machine Vision or any other subject, for the WWW? Commercial organisations are understandably secretive about their activities and technical skills, believing that by publicising how they work will weaken their chances of attracting further business. Given a suitable environment of equipment, cash and other resources, many academics will willingly develop and publish new ideas with little regard for the financial return. However, they are unlikely to do so if they do will not gain the academic credit that is important for their career development. So far, publication on the WWW has not achieved the kudos that a refereed journal possesses. Again, learned societies, such as SPIE and MVA, can help a lot, simply by encouraging academic authors to publicise their ideas and research results on the WWW. The solution is straightforward: learned societies should provide some mechanism for *"refereeing"* WWW sites. ("*Endorsing"* is a better word, since the material will probably be publicly available on the author's own WWW server, before it is "blessed" by an independent peer review process.) There are many highly experienced and very talented consultants and other individuals working in Machine Vision who possess a wealth of information that would be invaluable to their colleagues, but who are forced to concentrate upon the mundane matter of making a living. Research councils and other grant awarding bodies could help a lot, by funding the development of suitable WWW material by companies, academics, consultants and knowledgeable individuals working in their own time. To summarise, we must not be tempted to rely on the good will and altruism of individuals who dedicate their time on "unprofitable" activities; we must make it possible for this development work to take place in a properly organised manner, with proper funding.

Is the WWW capable of providing really useful material for vision system design engineers? Many people feel that the WWW is full of trivia and the Internet's tarnished reputation is certainly justified in many cases. However, we should not let the hobbyist, and other non-technical users of the WWW limit our perspective of the prospects for disseminating academically respectable and useful technical material.

Must all information and software tools be free? Of course not! Some standard reference material, such as the familiar lens formulae, colour-axis conversion equations, colour temperature tables, human visual sensitivity curves, etc. is already so widely disseminated that its inclusion on the WWW is unlikely to breach copyright. Some other material, such as technical data relating to cameras, lamps and other key Machine Vision products is made available freely by equipment manufacturers. However, certain other proprietary material, such as optical design programs, modelling and image processing software, etc. will almost inevitably be expensive. Of course, many companies provide generous discounts for users in educational institutions, while "demonstration" packages allow would-be customers to evaluate the package before committing themselves to buying of the complete version. We should encourage companies to release "cut down" versions of expensive software, so that they can be used on a large range of undemanding applications.

Is the WWW fast enough to be useful in practice? The WWW is an excellent medium for distributing notes, diagrams, half-tone images and other teaching material to a class of students and, of course, they need not all be sitting in the same room! For this reason, the WWW is well suited to distance learning and it is this aspect that we shall discuss in this part of the paper. At this point, we must briefly mention the speed of response of the WWW, which is often frustratingly slow; European users, for example, quickly learn that accessing large amounts items of information held on a server in the USA is only feasible in the morning, before the East Coast of North America gets to work. Excessive delays can be avoided by intelligent WWW design practice, the use of dedicated networks (Intranet) and mirror sites.

The strongest arguments supporting the development of new design tools [4] based on the WWW must come from consideration of the nature and needs of Machine Vision itself, rather than the WWW as a medium for information and software distribution.

2. Static Information on the World Wide Web

Table 1 summarises the type of information that the authors suggest would be useful for vision systems engineers and which could all be provided by a *static* (non-interactive) WWW server. Preparing static material is little different from using a word processor, since there are some good WYSIWYG tools available for web authoring; it is not necessary to program in HTML. For those interested in developing their own Web resources, the authors recommend the *NCSA HTML Primer* [6] and one of the many beginner's guides to PERL programming [7]. Much of the material mentioned in Table 1 is already available via the WWW, although at present, there is no systematic nomenclature, structure or organisation to this. A directory of useful WWW material relating to Machine Vision has been compiled by two of the authors (PFW & BGB) and is updated regularly by them. [1] However, the authors of this article perceive that there are some notable omissions, in the information that is currently available. However, they wish to emphasise that some of these deficiencies may be apparent, rather than real, due to their lack of awareness of WWW resources. In order to assist the authors to construct a comprehensive directory of Machine Vision resources, readers are encouraged to send suggestions for additional links, via email to *whelanp@eeng.dcu.ie.*

Data	**Examples: Typical Information**
Optical properties of bulk materials, taking no account of surface finish. Include spectral response, fluorescence, UV & IR reflectance, phosphorescence, etc. Data required for opaque & transparent solids and liquids	Common materials: paper, steel, brass, aluminium, polythene, oak, glass, water, etc. Coatings: lacquer, paint, optical coatings, electroplating, silver, gold, dyes, stains, etc. Common surface contaminants: oil, water, soot, rust, mildew, etc. Optical materials: light absorbent, light diffusing, coatings, etc
X-ray properties of materials	Common materials: steel, brass, aluminium, polythene, oak, glass, water, etc.
Models of optical behaviour of surfaces, classified by degree of "roughness"	Reflectance, polarisation, diffraction
Components. Must be accessible by type, not just by manufacturer. Detailed data sheets should be available on-line	Bar code readers. Cameras: see below. Digitisers / frame stores, see below. Image displays. Lighting: lamps, illuminaires, fibre optics, lasers, LEDs, specialised lighting units. Mechanical handling: robots, (X,Y)-tables, conveyors, indexing mechanisms, etc. Optical devices: lenses, mirrors, filters, polarisers, gratings, $^1/_4$-wave plates, etc Parts reject mechanisms: solenoids, air blast, etc. Product marking: ink jet printers, bar code printers. Proximity sensors: electro-optical, fibre optic, magnetic, capacitative, pneumatic
Cameras & specialised image forming systems	Cameras: array, line-scan. Computed tomography (CT) sensors Computer controlled lighting systems. Gamma-imagers x-ray imagers. High resolution cameras. High-precision mechanical scanners Infra-red imagers. Laser scanners. Magnetic resonance scanners Microwave imagers. Range mapping systems. Ultra-sonic imagers. Ultra-violet imagers. "Wheel-spoke" scan, random-scan, radial-scan, variable-scan cameras
News, hints, warnings, tips, success stories, research projects, commercial installations, new components, devices & techniques. Include a broad range of "news" items. Information disseminated rapidly, without bothering unduly ab formal structure	Lighting / viewing techniques, etc. Materials. New optical components, cameras, etc. Complete machines, e.g. inspecting car body panels, knitted woollen goods, etc. Company / business news Conferences, meetings, courses, etc. New publications. New funding programmes. Books, conference proceedings, journal artic market intelligence reports. Video recordings and other teaching material available, training courses
Physics of light	Lens formulae (Lens design / ray tracing programs are additional to this) Colour-axis conversion formulae [1], Optical set-up reference compendium
Image processing algorithms	Reference compendium, possibly with on-line interactive demonstration. See below
Robotics	Co-ordinate axis transformations. Robot configuration and work Envelope. Commercial devices, technical data: speed, payload, accuracy, end effectors, etc.
Software. Commercial and shareware [1] image processing software, intended specifically for Machine Vision	Training / education. Problem analysis. Target (low-speed, shop floor applications). Laboratory analysis tools.
Hardware. Commercial image processing hardware intended specifically for Machine Vision	Data relating to plug-in boards for standard computers or rack-mounting
Systems	Stand-alone systems for niche applications, e.g. inspecting eggs, glass vials, etc.

Table 1 Possible non-interactive WWW resources providing reference material for Machine Vision.

3. Remote Access Education of Machine Vision Engineers

Significant opportunities exist for the development and introduction of on-line postgraduate courses for remote access students. Studying a course via the Internet means that the student can communicate with their tutors and fellow classmates via e-mail, electronic conferencing and a host of WWW tools, submit assignments via e-mail, and participate in electronic tutorials from home. This educational method requires a high degree of motivation and maturity on the student's behalf. Therefore it is most suitable for postgraduate and senior undergraduate courses. This is emphasised by the fact that, on average, a third of those who enrol in distance education, on any subject, never complete the course.

A key element of the strategy for the use of the WWW for remote access teaching is the high degree of interaction between the course tutor and the students. The technical difficulties in implementing any strategy must also be addressed. Other important design factors include the educational benefits of remote access teaching, maintenance of material, running examinations and course-work assignments, the use of automated course review questions, practical implementation issues, legal and intellectual property control concerns. The cost structure of the proposed solution, both to the end user and the course provider, should also be considered.

Significant opportunities and difficulties exist with the development and introduction of online postgraduate courses for remote access students. One of the author's (PFW) experiences is based on the successful running of such a course, namely *Computer and Machine Vision*. This course ran as part of a pilot phase of the *Remote Access to Continuing Engineering Education (RACeE)* initiative at Dublin City University (DCU). A key motivation behind the RACeE programme, is the need for key research laboratories within the School of Electronic Engineering, DCU, to transfer specialised skills to industry and to educate students in these respective research areas. This phase of the RACeE initiative has had students undertaking the course on a 100% remote-access basis. The majority of these students are drawn from multinational organisations based throughout Ireland. There is no fundamental reason imposed by the WWW technology, or course structure, limiting its expansion to a wider, international, audience. It is expected that remote access students from a range of countries, including the USA and Singapore, will take this course during 1997/8.

The DCU remote access *Computer and Machine Vision* course provides all of the information needed for this particular module within the M.Eng./Graduate Diploma in Electronic Systems programme, including a number of automated self assessments. These review tests, which are automatically administered and marked, allow each student's progress to be measured individually, without any direct intervention by a tutor. Since the students are assessed by a conventional written examination at the end of the course, it is possible to assess its effectiveness, compared to a lecturer. Preliminary indications are very positive, although we must emphasise that this observation is based on a small sample of students.

All course material is password protected, and therefore requires either registration on the M.Eng. course, or payment of suitable fees (i.e. the skill-based course material only option), to gain access. The course introduces the student to the theory, applications and techniques of Machine Vision and provides detailed explanations of many practical aspects of the subject. It is intended for people with a wide range of backgrounds, including engineering, manufacturing, automation, computer, mathematical and the physical sciences. The student gains familiarity with the fundamentals of Machine Vision systems and learns how to design and implement image processing, analysis and classification algorithms. In addition, the course teaches the student how to assess commercial vision systems and evaluate emerging machine vision technologies. The following topics are included in this course, which makes use of a *Windows*

based interactive algorithm development system, called *MvT*, developed by one of the authors [PFW] at DCU:

- Introduction
- Sensors
- Optics
- Lighting
- Image representation
- External devices
- Point operations
- Neighbourhood operations
- Feature extraction and image analysis
- Image classification
- Image transforms
- Morphology
- Texture analysis
- Colour analysis
- 3D imaging
- Intelligent vision
- Systems engineering
- Case studies & review

There are two options for remote access students wishing to take this course. Under the *Full Course* option, the student will fully participate in the course (including course-work and examinations) and would partially fulfil the requirements for the M.Eng. offered by DCU. The second option, *Course Material Only*, excludes course-work and examinations, and is suitable for those people who wish to update or expand their skill base, without adding to their qualifications. This course was designed from an educational perspective to meet specific niche educational demands. It should not be confused with note presentation on the WWW. The key to this approach is the development of means of educational interaction via the WWW. Further outline and registration information can be found at [8,9].

4. Interactive Image Processing Tutorial

A freely accessible tutorial on Machine Vision is held on a server at the University of Wales Cardiff. [10]. This WWW publication does not contain any automated assessment facilities. It covers the following topics:

- Machine Vision, a subset of systems engineering
- Lighting Advisor [3]
- Sample vision tasks
- Ethical, environmental and social issues
- Multi-disciplinary nature of Machine Vision
- Images representation
- Notation
- Monadic point-by-point operators
- Dyadic operators
- Local operators, linear & non-linear
- N-tuple and morphological operators
- Binary images
- Colour recognition & symbolic image analysis
- PIP (Prolog Image Processing) language
- Applications, sample tasks
- Inspecting food products using a 2-beam x-ray
- References and publications

This site also contains an interactive image processing tutorial, as well as a database of lighting and viewing techniques. Both of these are described below, since they represent important developments in WWW teaching material.

5. Additional On-line Software Tools

The *Lighting Advisor* is a pictorial database, giving information about a wide range of lighting and viewing techniques for Machine Vision [1] It was originally written using the *HyperCard* programming facility and runs on the Macintosh family of computers. A version was written in the 1980s using the AI language Prolog, although for later versions, the authors reverted to HyperCard again. The latest stand-alone version can be downloaded across the Internet, using FTP [1]. Another interactive version can be viewed directly on the WWW. [1]

Interactive Image processing is a well-established tool for analysing Machine Vision applications. A package called *PIP*, which combines image processing functions with the AI language Prolog, can be downloaded, via FTP, for a nominal fee, as can the *MvT* package mentioned earlier. Both of these packages are well suited to training. The *Image* package, developed by the National Institutes of Health (USA) is free but this lacks the many of image analysis operators needed for Machine Vision. [1] (In its present form, *Image* is better suited for those applications, such as science and medicine, where image enhancement, followed by simple measurement and counting, will suffice.) It should be understood that all three of these packages are free standing and cannot be run over the WWW. However, such a facility has been developed in several research centres. For example, a version of PIP has been interfaced to provide direct control by users via the WWW. (See Appendix). [1]

6. Conclusion

It is the author's hope that this paper will guide readers to the use the wide range of resources indexed on our *Machine Vision Resources* home page. [1] But for such an initiative to work will require the collaboration of our colleagues working in Machine Vision. Readers are encouraged to submit articles, links to themselves or their research groups, demonstrations, tutorials and design aids. The authors of such material will retain the copyright and the maintenance responsibility for material supplied.

7. References

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Appendix

Downloading PIP: PIP for the Macintosh family of computers can be downloaded from a server based at the University of Wales Cardiff (UWC) on the WWW. [1] The PIP package comprises an image processing toolbox and interactive hypertext documentation, which can viewed with the *Hypercard* application. As a small charge is made for the software, the package is obtained via an interactive request form which requires the user to provide such details as name and address. The user action is logged automatically.

Interactive PIP: In addition to the stand-alone version of PIP described above, there is an interactive version of PIP on the World Wide Web (WWW-PIP) which simulates the stand-alone *Hypercard* PIP documentation. [1] This allows users to view the PIP documentation and carry out image processing operations on demand on the UWC server. Users are able select one of a set of standard images available to PIP and request it to carry out image processing operation sequences. Both the graphic and textual output is returned to the user. The system uses a slightly modified version of the stand alone PIP package described above, enabling it to operate in conjunction with the WWW server application, MacHTTP.

The images within PIP are stored in Macintosh PICT format. WWW browsers require images either GIF or JPEG formats. This requires a code resource to extend Prolog, written in C, containing a predicate to generate a compressed GIF image file from a PIP image.

P.F. Whelan, Bruce G. Batchelor , Melanie R.F. Lewis and Ralf Hack (1997), "Machine Vision and the World Wide Web: Design & Training Aids", in Machine Vision Applications, Architectures, and Systems Integration VI, Proc. SPIE 3205, 14 - 17 October, Pittsburgh, Pennsylvania USA, pp -.