Reflections on the Development of a Machine Vision Technology for the Forest Products Industry

Richard W. Conners, Director
Spatial Date Analysis Laboratory, Virginia Tech., Blacksburg, VA, 24061-011l, USA
D. Earl Kline, Assistant Professor, Department of Wood Science and Forest Products, Virginia Tech., Blacksburg, VA, 24061-0323, USA
Philip A. Araman, Project Leader, Southeastern Forest Experiment Station, U.S. Forest Service, Brooks Forest Products Center, Virginia Tech. Blacksburg, VA, 24061-0503
Robert L. Brisbin, Project Leader, Northeastern Forest Experiment Station, U.S. Forest Service, 24740

ABSTRACT

The authors have approximately 25 years experience in developing machine vision technology for the forest products industry. Based on this experience this paper will attempt to realistically predict what the future holds for this technology. In particular, this paper will attempt to describe some of the benefits this technology will offer, describe how the technology will probably evolve over the short term of three to five years, and address the issues that must be considered when one thinks of incorporating this technology in a plant. The paper will concentrate on the hardwood forest products industry since the automatic defect detection and identification in hardwoods is a more difficult problem than performing the same functions on softwoods. However, much of the discussion will be applicable to both industries. A purpose of this paper is to have this new, infant machine vision technology for the forest products industry avoid the typical "boom-bust" cycle that many technologies experience when they are first introduced.

INTRODUCTION

During the recent international Woodworking Machinery and Furniture Supply Fair held in Atlanta, Georgia from August 21-24, 1992 at least three companies displayed machine vision systems (MVSs) for automatically locating and identifying defects on hardwood lumber. The MVSs demonstrated were used as the "eyes" for systems that automate the crosscutting of hardwood strips. It is also known that a number of other companies are in the process of attempting to develop MVSs for performing this same function. While automating the crosscutting operation seems to be the thrust of most of most industrially sponsored development, other problems are being addressed by machinery manufactures as well including the automatic grading of hardwood lumber.

The authors' feel that the coming years will see an increasing demand for MVSs to automate various wood processing operations. There are a number of reasons for this. First and foremost is the advantage MVSs seemingly can offer to wood processing plants. Wood is a very heterogeneous material. A board's surface typically has a number of "features." Depending on the product being manufactured some of these "features" are acceptable and can be left in the rough parts used to create whatever product is being manufactured. Yet other "features" are not acceptable. These unacceptable "features" represent removable defects that should not appear in rough parts. Making the decision as to which "features" should be left in and which must be removed requires a good deal of skill. This is especially true in batch processing operations where the definitions of removable features vary from day to day. Studies [Hub87, Hub90] suggest that sawyers may not always make very good judgments about which "features" are the ones management wants removed. Hence, a fully automated cutup system offers the potential for an improvement in either the effective yield of parts produced in secondary remanufacturing or the value of lumber produced in primary manufacturing. While the amount of improvement possible using MVSs is not known, one study [Reg92] suggests that a significant improvement, i.e., an improvement of 20 percent or more in lumber value, is possible in primary manufacturing.

Unfortunately, while the future seems bright for MVSs in automating forest products plant operations, the authors remain concerned about a typical cycle that seemingly accompanies the introduction of many new technologies, the “boom-bust” cycle. Before a new technology demonstrates capability to solve a problem, say problem A, there is little expectation that the technology can be effectively applied to problem A. However, as the infant technology begins to show some capability to solve problem A there is a trend overly excited about these improvements.

Expectations soar! As it becomes known that the technology’s current capabilities is not as great as originally supposed, the euphoria for the technology quickly subsides. This quick loss of faith is called the valley of despair. After the bottom of the valley is reached, confidence and trust is slowly restored but at a pace that is typically much slower than the actual incremental advances that are occurring in the technology’s ability to solve problem A. The result is a most unfortunate set of circumstances where no one benefits. Money and premature investment in equipment is lost. Once faith is lost incremental advances in the technology take longer to achieve since it is difficult to raise money to do the required research. Companies then are slow to embrace the technology even though it has reached a maturity level that makes it clear beneficial. No one wins!

A purpose of this paper is to prevent this typical cycle from occurring to the new, infant MVS technology for the forest products industry. To prevent this from happening the authors would like to take a realistic view of the future of this technology over the next three to five years. The goal is to indicate what the equipment should be able to do over this time interval and also to present some of the many issues management should consider before attempting to incorporate this technology into their operations. The goal is to foster the orderly incorporation of this technology into manufacturing plants so that everyone wins.

ISSUES OF IMPLEMENTATION

The issues of incorporating a MVS based processing system in a plant are basically the same as those involved in the decision to purchase any piece of equipment. These issues include concerns about performance, cost, availability, maintainability, supportability, and fault detectability. Because of the varied nature of the potential reading audience, these concepts will be defined and briefly addressed as they relate to MVS technology. The so-called "ilities" will be discussed first. The issues or performance and cost will be addressed last.

Availability is the probability that a system will be capable of operating at or above a specified level of performance if called upon to do so at a random point in time. Mathematically, availability, A_O is defined by

$$A_o = MTBF/(MTBF+MDT)$$

where MTBF is the "mean time between failures" and MDT is "mean downtime." It should be clear that a system's availability is directly determined by its design.

Reliability is defined to be the probability that an item of equipment will perform its intended mission without failing, assuming that the item is used within the conditions for which it was designed [Jon87]. Mathematically, reliability, Rt is defined by

$$R_t = e^{-k}$$

where Rt=l/MTBF is the failure rate and t is time. Also note that a system's reliability is an inherent characteristic of its design.

Maintainability is also inherent in design. According to Blanchard [Bla90]. it pertains to the ease, accuracy, safety, and economy in the performance of maintenance actions.

Manability deals with such items as personnel requirements, the determination of training requirements, and the test and evaluation of the human being in the system. Obviously, this "ility" is also inherent in system design. Manability embraces the disciplines of human factors engineering and safety engineering.

Supportability defines the degree to which a system when placed in its intended operating environment and already established support system, can be economically supported.

Fault detectability deals with a systems ability to detect its own faulty operation caused by either the need for routine maintenance to be performed or a failure in one of the system's components. Like all the other "ilities" this one is inherent in a systems design.

Please note that since all the above "ilities" represent concepts that are inherent in a system’s design, it is possible and, indeed quite likely that one can find two machine vision systems that have comparable performance but significantly different "ility" characteristics. A system with poor "ility" characteristics will have markedly higher life cycle cost.

Because of this it is important for management to understand some of the factors that affect the "ility" characteristics of an MVS. In what follows the authors will attempt to delineate some of these factors. To begin, it is important to understand the components that make up a typical MVS. These components include:

1. illumination source - tungsten halogen bulbs, a laser, an x-ray tube, etc;
2. a sensing element - a line scan camera or array camera either of which can be black and white or color;
3. a lense or focusing system;
4. imaging electronics - timing components, sample and hold circuitry, and at least one analog-to-digital converter;
5. computer interface - a device that converts the digital signals

coming out of the imaging electronics into a form that can be understood by a computer;

6. a computer for processing the image data;
7. special purpose image processing hardware - hardware that resides in the computer and performs image processing operations must faster than the computers central processing unit can;
8. a materials handling system - for moving lumber or lumber strips through the imaging components over to an automatic processing station;
9. an automatic processing station - a saw or sorter, etc.

In examining issues of the "ilities" it is important to observe that component 8 should not be significantly different from materials handling systems already in manufacturing plants and component 9 should have the same basic design as say an automatic crosscut saw that processes boards based on marking done by employees. Hence, it would seem that most plant management would already have experience with the "ilities" characteristics of devices similar to components 8 and 9. Therefore, this discussion will not include these components.

Rather than directly addressing the issues of availability and reliability, this discussion will focus on the mathematically equivalent concepts of MTBF and MDT.

Of all the components of a typical machine vision system the one that is most prone to failure is the illumination source. Depending on the type of source used the mean time to failure can range from as low as 40 hours to well over 1000 hours. Typically when an illumination source fails, more is involved than simply replacing it, rather, the machine vision system has be recalibrated. If light bulbs are used, there can be a 20 percent difference in the lighting intensity of two bulbs. Hence, part of the recalibration involves adjusting the intensity of the new bulb so that it matches the intensity of the old bulb. This is required to maintain uniform a lighting across the imaging field. Another related part of the recalibration usually involves showing the MVS two targets that will allow it to compute a new shading correction function. Controlled illumination is very important in most MVSs. It allows the analysis algorithms to be markedly simplified, thus, reducing the computational complexity of the analysis process. Even the best illumination systems have a 10 percent variation in lighting across the imaging field of view. Shading correction is used to remove this variation and also to correct for any sensitivity variations that exist across the face of a sensing system.

Because of the above, it is important that the MVS

1. use illumination sources with long expected lifetimes - affects MTBF;
2. provide a very easy mechanism for changing the failed illumination source - affects MDT;
3. provide a simple method for performing all the recalibration once a source fails - affects MDT.

Illumination sources typically are hot during their operation and do not cool off very quickly once they are turned off or burn out. Safety seemingly demands a way for an employee to change the source without getting burned. It is also desirable that the illumination sources not be located in the chamber where the imaging system and lense or focusing device is located. An employee during the act of changing a source might inadvertently knock the imaging sensor out of alignment, change the lense/focusing mechanism position, and/or introduce dirt and debris onto the imaging system.

A lense or focusing mechanism should have an extremely long MTBF and as such should not ever have to be replaced under normal operation. However, accidents do happen and therefore the design should provide mechanism for obtaining easy access to these components.

All the rest of the components of the MVS are made up of solid state electronic parts and printed circuit boards. As such, these components typically have very long expected life-times and therefore have very long MTBFs. However, it should be noted that electronic components exhibit very interesting reliability characteristics. Typically, first few hundred hours of operation these components have a relatively high failure rate. After this burn in period they usually exhibit very low failure rates. Finally, at the end of their expected lifetimes they, once again, exhibit a high failure rate. Hence, the electronic components of the system should all carry a warranty for typical one year period. This should easily cover the initial burn in period.

To address the other part of the equation, the MDT, it is important that these components come with some self diagnostics and that the components be designed so that board level replacement is facilitated. The better the self-diagnostics the better the MDT will be for the system. With the aid of these self diagnostics, a problem board should be easily identified. Plant personnel can then easily replace the faulty board with one in stock at the plant. Because of their potential impact on MDT, it is important to look at the diagnostics very carefully when evaluating a system.

As was mentioned above electronic parts typically have very long MTBFs. However, there is something that can markedly shorten these MTBF. It is exposure to electromagnetic noise. This noise can affect the ability of the electronic components, particularly digital electronic noise can affect the ability of the electronic components, particularly digital electronic components from accurately communicating with each other. Forest products manufacturing plants are filled with relatively big electric motors. These motors produce a good deal of electromagnetic waves that are "noise" to the MVS's electronic components. If this noise interrupts communication between components the system is effectively failed. Hence, one must make sure an MVS was designed so that it can operate under such high noise conditions as exist in forest products manufacturing plants. The best way to assure the system will operate under such adverse conditions is to test it. Run the system in a situation where there are a number of large electric motors setting next to it and running during the test.

As for maintainability, many issues with regard to this issue have already been addressed. Important things to look for include the access available to all the system’s components, the system's self diagnostic capabilities, the ability to easily make board level changes of all electronic components, the ease with which the system can be recalibrated after replacing an illumination source, the ease with which an illumination source can be changed, and the present of automatic shutdown devices on all accesses to dangerous operating areas in the system. However, there is one additional point that must be considered. Forest products production facilities are dusty places. It is clear that on a relatively frequent basis any optical lense or focusing mechanism on the system will have to be cleaned. This cleaning will, no doubt, be the most frequently required routine maintenance that has to be performed. Hence, it is an important factor to look at when considering an MVS design. A convenient and easy mechanism must be provided for cleaning these components. Obviously, the less often they have to be cleaned the less routine maintenance that will have to be performed. Therefore, any methods employed for preventing dust build up on these devices should be considered.

Supposedly, the only human interaction with an MVS based automated processing operation occurs during start up, shutdown, maintenance, and manual override situations. Consequently, the manability of the systems depends on how well the designer did his/her job to reduce the skill level of employees that have to perform these functions. Things to look for in accessing system manability include computer menu driven system control, computer menu driven, powerful self diagnostics, ease with which illumination sources can be replaced, menu driven system recalibration, system self checks at start up, ease with which optical components can be cleaned, and ease with which board level replacement of electronic components can be accomplished.

With regard to supportability there are at least two important considerations. Both involve the fact that any MVS based automated processing system for the forest products industry is going to be a complicated device consisting of quite a large number of components, components which themselves can be quite complicated, e.g., the image processing computer. Given this situation, there are going to be maintenance situations where the down time is going to be on the order of a few days. This delay may result due to the fact that parts are not available and/or because difficulties in diagnosing the problem. (Note items like the mother board of the image processing computer, will, not only be expensive but will also have a very long MTBF and hence will probably be stocked as a spare part. It is this type of item that may not be readily available.) In such situations it is very important that the plant continue to operate. Therefore the system design should allow for some type of manual override situation where at least the materials handling system and the processing station can be used in a manual operations mods. Secondly, it is fairly important that the system have a modem hookup capability so that outside experts that are physically remote from the plant sight can get access to the electronic components of the system. If this capability is present these outside experts can start looking for the failure once it is determined that the failure cannot be found using the system's built in diagnostic capabilities. Some computer companies provide this type of maintenance service and it is a very effective way of reducing down time and minimizing cost since travel cost are not required.

Finally, it is felt that any automated manufacturing system be very fault detectable to prevent expensive raw materials from being wasted because of bad processing resulting from a system fault. Admittedly, adding extensive fault detection capabilities to any system can markedly increase initial system cost and one can get carried away in attempting to provide such capability for even very infrequently occurring problems. But, with respect to any MVS it is felt that at least four fault detection capabilities must be provided. The first is the capability to detect that an illumination source has failed. The second is the capability to detect when the optics need to be cleaned to assure proper operation. The third is the capability to determine that the camera is operating correctly. The final capability required is one that allows the system to determine that a board or strip is stuck and not moving through the system as it should. All of these faults can occur frequently and therefore represent problems management must be concerned about preventing. It is also worth noting providing these four fault detection capabilities can be done at very little expense.

DETAILS OF IMPLEMENTATION

While a number of companies have or are in the process of attempting to develop MVSs for automating various processing tasks, one thing is fairly clear. These early systems have limited capabilities. Therefore, one must carefully examine whether they will solve the problem that actually needs to be solved to make them a good investment. To this end, there are again some rules that can be used to make a preliminary assessment of whether the current technology might be of use. Since most of the MVS based automated processing systems currently being developed by machinery manufacturers are aimed at completely automatic cutup in the rough mill, this discussion will focus on this use of MVS technology.

The first decision point comes from an examination of the company's rough mill operation. The important points to be addressed include the number of hardwood species processed, the frequency with which the species processed changes, the frequency with which the definition of a removable defect varies, and the detail required to determine whether a surface feature is a removable defeet. If the above frequencies change on a daily, weekly, or monthly basis current MVS based processing systems are probably not for your company. If, on the other hand, one processes only one species, making products whose removable defects include only visually obvious surface defects, then the company might want to investigate an MVS based automatic cutup system. Between these two extremes it is advisable to talk to machinery manufacturers about the systems they have available and perform some tests to see if their products are applicable.

In performing the test it is very important that company management understand that no MVS will ever be 100 percent correct in its location and identification of defects. This is true of today's systems and it will be true of tomorrow's systems. Hopefully, as MVS technology matures accuracies will increase but the obtainable accuracy will never be 100 percent. There is a very good reason for this. As one attempts to drive the error rate to zero the design problem starts going up exponentially and, hence, so does the cost of the resulting system. The important design issue in the design of these systems is achieving the best possible accuracies at the lowest possible cost to produce a commercially viable product.

Given that a machine vision system will never be perfect, management must have some criteria for judging whether the investment in the automation technology is worthwhile. To create such a criteria requires a very good quantitative understanding of how well the manual system is working. This quantitative criteria then becomes the basis upon which the automatic system can be judged during the testing phase. This criteria should obviously include how much raw material is processed per unit time and what the average effective yield is. The effective yield figure should include the number of sawn parts that must be thrown away because they contain unacceptable surface "features."

The test that need be conducted on the MVS based automated processing system are of three different types. The first test that is conducted is a laboratory test. This involves the company supplying lumber or strips to the equipment manufacturer. This lumber is used to "train" the MVS. It should be carefully selected to represent a reasonable cross section of the variety of material that is processed by the plant where the automated equipment would be placed. The MVS training to be done typically involves setting a number of software parameter values. These parameters are used to "optimize" system performance to the characteristics the plant uses in defining which surface features are removable defects. This step is usually performed at the machinery manufacturers facility by the machinery manufacturers personnel.

The second type of testing that should be conducted involves semi -real testing of the MVS based automated processing system. The goal here is to determine whether the machine is capable to reach the performance level set by management. This test will also require the lumber be supplied from the plant in which the equipment would be placed. Again, careful selection of the material is very important. A good deal of lumber should be provided. It is possible that on some types of lumber sawyers may be able to out perform the automated system but that overall the automated system may perform better.

Examining the automated system's performance on a good deal of material makes sure the test is fair. This test, again, should be conducted at the machinery manufacturers facility. There are two reasons for this. First it is a lot less expensive to transport lumber than expensive machinery. Second if the equipment fails the first semi-real test, the machinery manufacturer can use the lumber provided to do further "training" of the MVS. Note it may take a couple of tries for the equipment to reach the desired performance level. Also note that after the equipment has clearly reached the desired level of performance, it should be checked for its ability to withstand the effects of electromagnetic noise. The method for doing this was briefly outlined above.

The final test is an in plant test to verify the actual performance of the system on-site. This is an extremely important test to conduct. The machinery might perform well in the semi-real test but the ultimate gauge of its utility to the company comes from its ability to perform day after day in the plant. This test should begin immediately after the equipment is pronounced ready to run and last for some number of weeks, perhaps months, until everyone feels comfortable with its ability to do the job.

Clearly, the purchasing company is the one that must exercise the most caution but the machinery manufacturer must also be careful. In private conversations with a number of companies they continually complain that purchasers expect 100 percent accuracies and that they provide material that is unrepresentative of the material actually being processed at the plant where the equipment is to be located. In defense of the machinery manufacturer 100 percent accuracies just will never happen. Employees make mistakes so will the equipment. As long as its performance makes the company money its mistakes should be forgivable. However, the purchasing company MUST know when the equipment is actually making them money. That is the reason for going through the analysis suggested above. The need for representative material should be obvious from the statements made above. Both companies have something to lose. The purchasing company needs to make sure the investment is a wise one. The machinery manufacturer has his her reputation on the line. Hence, it is important that all concerned make every effort to make the tests as fair as possible.

WHAT THE FUTURE HOLDS

At this particular stage of development, all existing MVSs, whether they be the product of industrial development or the product of university research, are inflexible. Some have difficulty in handing more than one species of material. All have trouble recognizing the spectrum of hardwood lumber defects and/or processing induced defects. All have difficulty in adjusting from one set of definitions as to what constitutes a removable defect to another set of definitions. Consequently, there is still a good deal of work that needs to be done. A last point to be made is that all existing MVS based automated processing systems are designed to act like "islands of automation." This is most unfortunate as will be pointed out below.

To attempt to look into the future is always a very dangerous thing to try to do. Unforeseen leaps in technology are always possible. The level of spending on research and development can always change, sometimes quite abruptly going either up or down. All of these things represent hazards when attempting to look into the future. To reduce the hazards somewhat the authors are going to limit the time frame of this forecast to the three to five year range with full knowledge that some of what is described might take longer.

This forecast is based on the idea that most of what will happen will be market driven. Hence, in looking into the future concentrate will be placed on capabilities that seemingly should be of interest to end users. To this end the following will concentrate on features the end users should want if not demand over the next few years.

One trend is obvious. The next few years must see an imporvement in both the number of features that can be located and identified as well as the accuracy with which both these functions can be accomplished. The next few years will also almost assuredly have to see a swing away from very specially tailored computer vision software packages where each package only addresses one small problem to computer vision system that have a basic general core and with only small add ons required to tailor the system to individual applications. This seemingly demands that the core vision technology be able to operate in a species independent manner with special add ons provided to tailor the system to red oak, cherry, yellow poplar and the like. These special add ons will have to allow for obvious species dependencies, e.g., the existence of gum pockets in cherry and the wild color variations in yellow poplar. This swing away from very special purpose systems would seem to demand a less statistical pattern recognition approach to the computer vision problem and a more rule oriented expert systems approach be taken.
Finally, it is felt that to achieve all of the above is going to require the use of multiple sensing systems to inspect lumber. Possibilities in color cameras (believer to be essential for most applications), slope of grain finders, moisture detectors (important in the processing of green lumber), x-ray scanners, and laser based ranging camera systems (structured light systems). A description of one possible combination is given in [Con92].

Along with the increase in the types of surface wood features the systems will be able to recognize there will also be an increase in the number of characteristics that are computed from each of the entities. This trend will result from the obvious demand to be very specific about when a surface feature is actually a removable defect. For example when the system identifies an area as being a knot it will have to determine the knot's diameter, whether it is a sound or unsound knot, whether it is loose or tight, and where it is located in regard to the boundaries of the piece. All of these characteristics need be computed for the system to be tailored to meet the variety of specifications companies use to characterize removable defects. To understand the benefits that are possible, consider the pallet industry. It is highly probable that given very specific descriptions of features that affect part strength, raw material costs could be reduced without affecting the overall durability of the pallets produced.

Adding this degree of specificity offers the possibility of reducing the raw material cost needed to cut a given volume of rough parts. Experienced sawyers have a limited memory. They cannotremember a long list of characteristics for specifying when a given surface feature is a removable defect. The more specific a manufacturer can be the greater the probability of getting improved yield. If a sawyer makes an error in a cutting decision, the error will favor the removal of something that "might" be a defect. This very conservative cutting strategy sawyers usually use can, on a day in and day out basis, cost a company money and waste good material.

All of the above has assumed that MVS bases automatic cutup equipment are islands of automation. However, the real power of these systems comes into play when they are all hooked together in a plant wide information network. This is where some real money savings can occur. Consider for the problem of minimizing raw material cost. As indicated above, each of these cutup systems will increasingly get better at getting the optimum out of every board. However, when they are all hooked together, the total amount of raw material being used can be monitored together with the instantaneous part count and effective yield. Since the grade of lumber used is typically dictated by the longest and widest parts, as sufficient quantities of these parts are accumulated a lower lumber grade can then be processed. Statistics can be kept on the yield obtainable from lumber obtained from the various suppliers. Management can then determine which supplier is providing the “best” lumber.

These systems can be used to create a large database representing the lumber processed by a plant. This data base should include board outline information as well as the locations and identities of the various surface features present. Using this data base, management can play "what if" games. What if the specifications for a removable defect is changed for this part? How will this the raw material cost needed to manufacture the product?

Within the primary manufacturing industry, MVS based automatic cutup systems could be used to optimize the edging and trimming operation so that the highest "value" of product is produced. MVSs could be used to automatically grade lumber. Used in an information network, these systems would allow the sawmiller to keep very precise records about inventory and warn when a saw needs to be sharpened. Used to create a date base of board information the sawmiller could also play the "what if" games.

Another important problem MVSs could be used is the problem of uncovering an internal defect during a processing operation. High profitability demands that defective parts be discovered as soon as possible. If MVSs were to use x-ray imaging technology many undesirable internal features could be removed during the initial cutup operation. This should markedly impact the number of processed parts that have to be discarded.

In a similar vein, MVSs should find their way into other machining operations other than the initial saw up. Using these systems to monitor router and molder operations are an obvious applications.

SUMMARY

MVSs would seem to have a very bright future in the forest products manufacturing industries. They seem to offer the potential for significant gains in profitability. Some of these opportunities have been addressed in this paper. Other are sure to be thought of and implemented in the years ahead.

A concern that an early acceptance of this technology by manufacturers before the technology has had the time to mature to the extent that it is really useful. Existing systems are limited in their range of applicability. Criteria for determining the applicability of these systems to manufacturing operations were given.

The robust inspection of particularly hardwood lumber is a difficult problem. In the next few years robust systems for performing this task should become available. Along with the development of these systems will be introduction of a series of completely automated processing systems based on this technology. However, the real power of MVSs will only be obtained when they are combined in full plant information networks. Examples of the utility of such networks were presented.

Hopefully, by the year 2003 the contents of this paper will have been forgotten so that the authors will not have to bear the brunt of these predictions.

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H. H. Wang
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