Applications of an Automated Stem Measurer for Precision Forestry

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Abstract— Accurate stem measurements are required for the determination of many silvicultural prescriptions, i.e., what are we going to do with a stand of trees. This would only be amplified in a precision forestry context. Many methods have been proposed for optimal ways to evaluate stems for a variety of characteristics. These methods usually involve the acquisition of total stem measurements, which are expensive and difficult to collect. A video rangefinder instrument is presented here as a move toward efficient collection of this total stem data used on a per stem or precision basis for fertilization, thinning, harvesting, and merchandising decision-making.

INTRODUCTION

The goal of precision forestry is to enhance value, assumedly where the benefits gained outweigh the costs of management. This is a complicated task as the many public and private entities which own, manage, and regulate forest operations often have different management objectives and constraints. A common denominator among all of these entities is the need for accurate and thorough information on which to base, prioritize, assess, and defend management decisions. The increase in knowledge about the impacts of forest operations and the increasing demand for forest products are intensifying the level at which we must know and manage this valuable resource. Forest operations from fertilization to thinning to harvesting and merchandising all rely on accurate measurement of individual tree stems.

Tree heights, upper-stem diameters, and lengths and form of bole sections are some of the many variables needed for the more advanced models and assessment procedures available today. The acquisition of many individual tree measurements beyond DBH (diameter at breast height) is a time consuming endeavor. For this reason new instruments are needed to provide this detailed information in a very rapid and accurate manner. Here an instrument for collecting dimensional information very quickly is presented and its potential application for precision forestry is shown. It is only a prototype instrument at this point and more work is needed to make it ready for regular field use, but it provides a very important link to the applications involved in precision forestry.

The TMS Instrument

An instrument has been developed incorporating a standard format video camera, a 3-axis magnetometer (to measure instrument orientation), and a laser-rangefinder (table 1, figure 1). The camera is positioned to record through the heads-up display that indicates the exact location of the laser pulse and the ranging information. Video data is output to a portable video cassette recorder via a standard video cable. The recorder has an IEEE-1394 "i.LINK" interface which would allow additional information (i.e., the range and orientation data) to be written synchronously with the video to the tape, though the camera is not equipped to do this at this time. Currently, the range and orientation data are output to a memory card, which is later read into the processing program "Tree Measurement System" (TMS) as a separate file.

The procedure to extract the desired information from the data currently requires the use of a desktop computer. The TMS program synchronizes the range and orientation data from the memory card with the video data from the videotape. Currently, manual input is required to extract frames and determine stem edges, etc. The frame extraction and image processing components are being developed to allow automation of information output (e.g., point & click diameter/height/volume measurements).

A previous study (Clark et al. 2001) shows that this instrument performs comparably to standard optical methods for determining stem volume and height. This investigation compared diameter, height, and volume measurements for 20 hardwood and 20 softwood trees using optical calipers and aluminum height poles, conventional caliper and tape measurements on the felled tree, and the TMS instrument. The TMS instrument did not perform as well for individual diameters, however investigations are underway to improve performance.

Field data collection time was reduced with the TMS instrument. One person using the TMS instrument captured the required data in approximately the same length of time as 4 crews of 4 people using the optical calipers and alumiheight poles, and one crew of 4 people using the felled tree methods. The time is only given as an approximation as the measurements were taken on the same trees on the same days, so bottlenecks did occur using some methods. For instance, the felled tree method crew had to be last for obvious reasons.

POTENTIAL APPLICATIONS FOR PRECISION FORESTRY

Precision forestry will reduce management units from the stand level to small groups of trees or even individual stems. Directed treatments on these smaller units will aid in meeting multiple objectives and in better utilization. There have been many forest-related analysis tools developed for computers in the last few years for inventory, visualization, modeling, decision support, and simulation.

Volume and Merchandising

Many studies have shown areas where potential improvements can be made for volume estimation. Wiant et al. (1992) state that errors as great as 30% can occur if inappropriate volume tables or functions are used. Goulding (1979) has shown that when using widely spaced upper stem diameter measurements volume estimate errors can still exceed 8%. Importance sampling (Gregoire et al. 1986) and its cousins centroid (Wood et al. 1990) and critical height (Van Deusen 1990) have been underutilized due to difficulty of field implementation. The height-accumulation method (Grosenbaugh 1954) has been found to be reliable, yet time consuming by some based on the need to obtain multiple upper-stem measurements (Ferguson and Baldwin 1995). The TMS instrument can efficiently collect data for the entire stem allowing the implementation of any or all of these methods.

As long as bias is not present, individual stem errors have minimal impacts in a large-area inventory, when many stems growing in varying environments are grouped together. In a precision forestry context, however, errors of individual sterns are a great concern. Moreover, the parameter of interest may not be only total volume, but volume by product class. Figure 2 demonstrates our limited ability to adequately model a stem with existing profile equations. Generally, stem form is omitted from stand inventories. At most, an individual stem may be categorized into a particular product class. The efficient data collection made possible by the TMS instrument will allow better methods of analysis to be realized. It may also extend the boundaries for new types of evaluation, especially in the area of stem form, product yield, and merchantability to multiple markets.

Stem Form / Products

Current technologies and resource demands are creating the need for more detailed data about individual trees. Goulding (2000) presents an idea of a pre-harvest inventory where stems are evaluated for product yield while' still standing. The information alongwith the locations of these stems are available so that when an order for a certain product arrives, these particular stems can be gathered for delivery.

Figure 1. TMS instrument on monopod with portable DV videocassette recorder.

There have been a number of programs written for predicting local timber product yield and optimizing the utilization of each stein (Olsen et al. 1991). BUCK® (Use of tradenames for informational purposes only and does not constitute endorsement by the USDA Forest Service, http://www.forestyield.com/) is an example of a program that generates local timber product yield tables based on user-defined stem inputs and product specifications. HW-BUCK (Pickens et al. 1993) is a computer simulation program designed to be used as a training tool to increase value recovery and optimal bucking of hardwood logs. There are other similar programs that have been developed for a variety of species and markets that offer these optimization functions (e.g., MARVL (Deadman and Goulding 1979, Firth et al. 2000) available for *Pinus radiata* D. Don). These models require detailed stem data in order to generate beneficial output. The TMS instrument can provide this detailed data.

Stem Mapping

Stein mapping is useful for relocating a particular tree for remeasurement or spatial analysis. Other precision forestry developments such as Radio Frequency Identification (Ringstad et al. 2001) would likely require stem location as an attribute. Obtaining a GPS point at each stem in a stand would be very time intensive. Stem mapping using a tape and compass is quite time consuming and frustrating, especially in thick understory. Sonic devices (Doyle 1994) as well as laser rangefinders (Peet et al. 1997) have been used with varying levels of success to attempt to speed up the process of stem mapping. Although any rangefinder would be adequate for this task, the issue involved in this entire precision forestry endeavor is efficiency. The TMS instrument can capture the distance and azimuth digitally which can then be automatically tied to a coordinate position and individual tree record.

Modeling

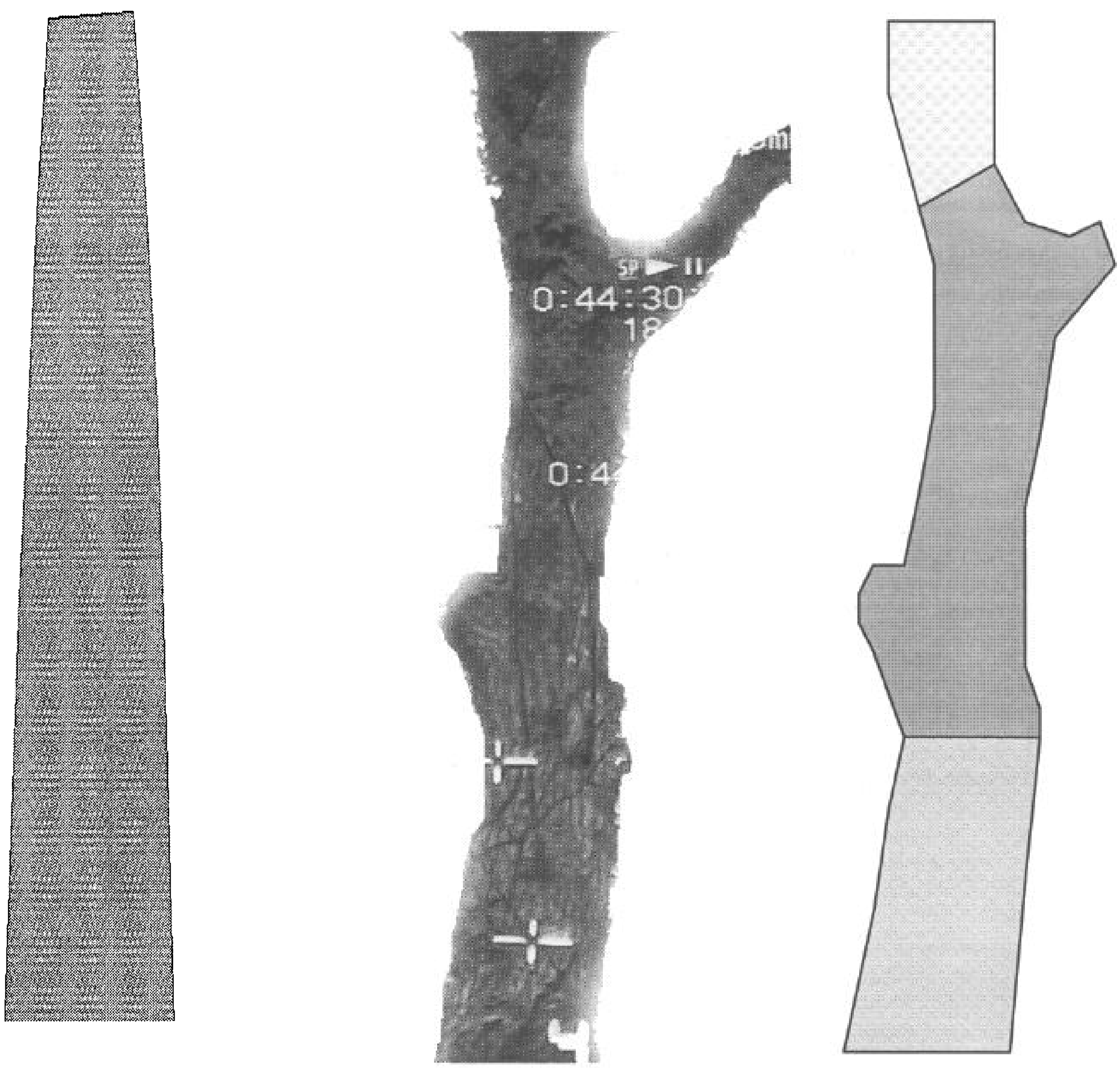
Not only are the data collected with the TMS instrument useful for evaluation of what currently exists, these data can

Table 1. Technical Specifications of the TMS instrument.

Dimensions	21.5 x 11.5 x 19 cm		
Weight	2.1 kg		
Distance (no reflector)	Range 2 – 610 m	Accuracy	±15.3 cm
Azimuth	Range 0.0° – 359.0°	Accuracy	±1.5° RMS
Inclination	Range ±50° *	Accuracy	±0.4°
CCD Camera	480 x 720 RGB color		

*Mounted at a 30° incline to cover a range from -20° to +80° respective to horizontal

Figure 2. The model approximations (left) that are currently used are inadequate to meet the demands for merchandising optimization. Data collected with the video system will provide the stem data needed to optimize product output.



also be inputs for predictive modeling. A survey of growth and yield modeling over the last 17 years (Baldwin & Cao 1999) has revealed that the development and sophistication of these models has closely followed that of computers and software. And while few of these models have been packaged for convenient delivery to users, there has been a progressive step to incorporate some of these models into decision support and expert systems. Surveys of some current systems are presented in Reynolds et al. (1999) and Rauscher (1999).

These predictive models also extend to biomass (Means et al. 1994), fire (Cook 2001), and silvicultural modeling (Dean 1999). Public awareness and integration into decision-making processes have lead to the creation of landscape visualization software. Programs such as the Landscape Management System (McCarter 1997) and Envision (McGaughey 2001) have been developed to assist in stand and landscape-level and forest ecosystem analysis and planning. Multi-resource inventories (Lund 1998) are now being realized in some situations where multiple entities cooperate in data collection efforts to share the labor while meeting the requirements of each group. Nearly all of these models require data from individual stems in the form of location, density, crown ratio, volume, stand structure, etc. An instrument such as the one presented in this paper will be necessary to efficiently collect the massive amount of required data inputs.

DISCUSSION

Though there are some really exciting possibilities in the integration of all of these tools and technologies for more timely and cost-efficient analysis, there are some potential challenges as well. Any time that new methods are developed and introduced there are always some new obstacles that are often not anticipated. This is generally the cause of the queasy feeling that the production manager gets when attempting a "better" way to accomplish the task at hand. One solution is to stick with the tried-and-true. There is a higher confidence of success, yet the return is not likely to satisfy the expectations of the investor. Here are a few issues that can be foreseen with this camera system.

Field Issues

Currently the TMS instrument is ruggedized, however the video cassette recorder used to store the camera data may not withstand much abuse. Once resolved, on-board processing and data reduction can eliminate the need for this external storage. The need for portable electric power is also inconvenient. The present configuration allows 1.5 hours of use per recharge for the instrument. The video cassette recorder has a separate rechargeable battery that has 1 to 3 times that duration. And finally, the camera records incident radiation within the visible range so light conditions and occlusions can have unpredictable effects on the results. A forester will usually confirm that visual contact is sufficient when using some other optical dendrometer. Developing this visual context and verification for the TMS instrument may be difficult. These obstacles need to be addressed before the instrument is truly deemed field-ready.

Data Distribution

It is great to have large amounts of data and a suite of analysis tools available, but if they are not organized and accessible, they won't be used (Martin et al. 2000). A big effort in this area is web-based data distribution for custom user analysis. This may present more problems in assuring that metadata are also reported and warning the user of the validity of the data for their analysis. This issue trickles down through the entire sampling design. An issue to consider with the TMS instrument is the lowest level of data or information to retain and make accessible to the overall system. In the usual case, individual diameters or height measurements are the lowest level of individual stem data recorded. These data are processed and aggregated into informational units (e.g., volume of pine sawtimber by county) deemed to be the finest level of detail desired or statistically viable to present to users. The lowest level of data collected with the TMS instrument is a matrix of brightness values, time (intrinsic with data streaming), range, and orientation. This massive amount of data requires storage and an organized mode of access. For each project, a data model considering the lowest level of data (frames, range and orientation data, or a compressed mosaic of the entire stem) or information (derived diameters and heights) and its organizational structure would need to be determined to avoid being overloaded with data.

Tackling the Precision Issue

Sampling has been developed and used to estimate a parameter that is impossible to measure directly. Usually there is a compromise between sampling and measurement error. Foresters have been accustomed to being very concerned about measurement error for a number of sample elements (i.e., DBH) and tolerating a huge model error when predicting the population parameter (i.e., volume). What digital devices lose to analogue instruments in measurement precision, they make up for in number of measurements collected. So an assessment should be made to evaluate the performance of more precise element measurements used with a less precise model, versus a greater number of less precise observations used with a more precise model.

Automation

The great advantage of the system being digital from start to finish is capability for the automation of results. Just by pulling a trigger and scanning a tree, the volume can be estimated and made available for analysis. This will eliminate blunder errors caused by transcription. Verification is an issue with automated processes. Unless the system is robust to the point of being foolproof, a verification step should be introduced to safeguard against collection blunder errors. If this can be accomplished, the time savings presented by rapid collection and automation of information extraction should greatly facilitate the usefulness of improved models and analysis tools.

CONCLUSION

The future of forest management is going to increase in complexity as the land base decreases, values diversify, and regulations increase. Fortunately, many useful tools, such as merchandising optimization programs and decision sup port systems, are becoming available to assist managers in dealing with this complexity. In order for these tools to be useful in a precision forestry context, large quantities of detailed data will be required at rapid rates. The TMS system, presented here, can currently be used to rapidly acquire heights and diameters for an entire tree bole. Furthermore, the imaging nature of the collected data allows more intensive variables such as stem form and some defect information to be assessed. With some additional work to make this instrument field-ready, adding some verification procedures, and smoothing the data flow, these data can be used in many applications for precision forestry.

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