NEW INSTRUMENT EXPANDING INDIVIDUAL TREE STEM ANALYSES

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Abstract--Forest health, vitality, and productivity are interrelated and are maintained by using sound forest management. There are some standard indicators that are measured to assess the extent and severity of damage inflicted by biotic and abiotic agents. Assessment of these indicators using affordable methods is a subjective process. A video rangefinder instrument is presented here as an advance toward efficient collection of objective components of these indicators. This paper describes how rapidly collected quantitative variables such as lengths, diameters, light penetration, etc. can be useful for applying some existing sampling methods and allowing the exploration of new methods that were previously considered intractable.

INTRODUCTION

The concern for forest health, vitality and sustainable productivity has escalated since the Santiago Declaration (Anonymous 1995). Many projects have collected this information on a project or forest stand basis. The Forest Health Monitoring (FHM) program within the USDA Forest Service has been given the charge to collect, analyze, and compile these data on national and regional scopes.

The Tree Measurement System (TMS) instrument is presented here as an aid to accurately appraise selected indicators of forest health. The TMS instrument is a multisensor device, which allows rapid collection of angle, distance, and video data. These data are entirely in digital form and are easily processed by computer programs for further analyses. The TMS instrument can improve the accuracy and expediency of data collection for current indicators as well as making the assessment of other indicators feasible.

THE TREE MEASUREMENT SYSTEM INSTRUMENT

The TMS instrument consists of a standard format CCD camera, a 3-axis magnetometer (to measure instrument orientation), and a laser-rangefinder (Figure 1 inset). The camera records through the heads-up display that is used to sight the exact location of the laser pulse. Video is recorded on a portable video cassette recorder (VCR) via a standard video cable. The VCR has an IEEE-1394 “i.LINK” interface that can allow the video as well as the range and orientation information to be written to the tape simultaneously. This coordinated data stream is not currently implemented necessitating the range and orientation data to be written to a memory card. A custom-written computer program later accesses the range and orientation information from this card to drive a video frame extraction algorithm. These two data streams are then synchronized.

Clark and others (in press) show that this instrument performs comparably to standard optical methods for determining stem volume and height. In this study, diameter, height, and volume measurements were compared to measurements obtained using optical calipers and aluminum height poles. Conventional caliper and tape measurements on a felled tree were used as the true measurements. Diameters were collected in 4-foot increments from 8 feet to total tree height in addition to ground level, 1, 2, 4.5 and 17.3-foot heights. Field data collection time was tremendously reduced using the TMS instrument. It did not perform as well for individual diameters, however modifications are being made to improve results.

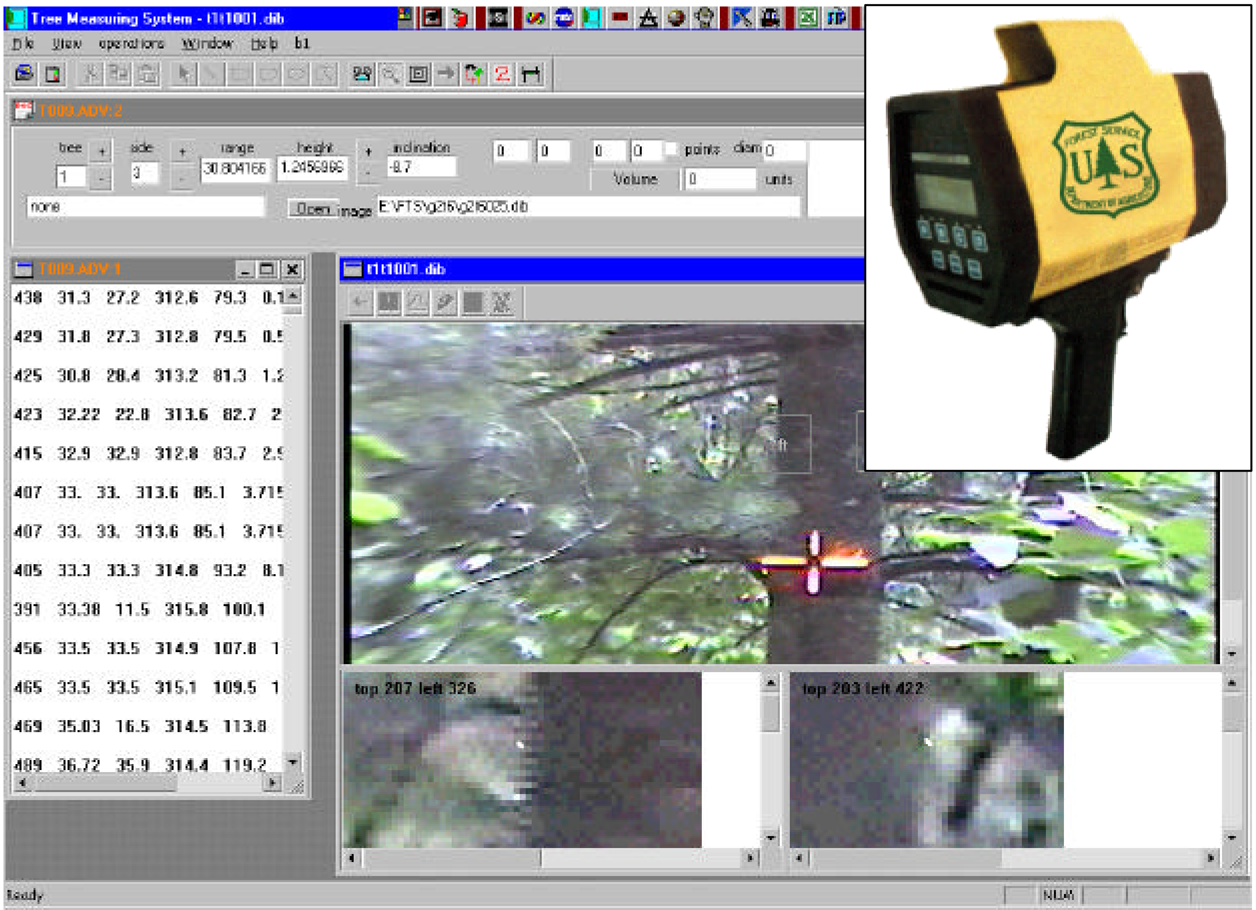

Figure 1. Screenshot of the Tree Measurement System program. The inset in the top right shows the Tree Measurement System instrument.

FOREST HEALTH INDICATORS

Various indicators have been identified in the Santiago Declaration (Stolte 1997) to assess the productivity, vitality, and health of the forest. Some of these indicators include damage from agents such as insects, disease, exotic species, fire, storm, land clearance, permanent flooding, salinisation, and animals. Some defined air pollutants are also considered. Soil factors, nutrient cycling, pollination, seed dispersion, and the monitoring of organisms critical to the ecology of forest ecosystems are other items considered in the assessment of forest health, vitality, and production. These indicators and the sampling protocols for each vary widely. Irrespective of the exact causal factor of forest health decline, reduced foliage and change in crown architecture are early warning signs of decline.

Crown Metrics

Aside from roots, foliage and branches are temporary structures in the allometry of trees. Roots may provide good information about tree vigor, however this sampling must be performed by destructive means and is extremely expensive (Schreuder and others 1993). This is why crown metrics are favored as indicators of tree health and vitality. Optical estimation has been the primary mode of collection for these data due to the difficult, time consuming, or destructive physical methods. Of course, destructive sampling is prohibited for plots that are subject to monitoring by repeated measurements.

Optical estimation of crown ratio has been shown to be highly variable (McRoberts and others 1994). Given that this metric is simply a ratio of two lengths, which could be easily measured, it can be assumed that the other crown metrics would be susceptible to an even greater level of variability and subjectivity. Variability causes problems when performing trend analyses, but it is not as serious as subjectivity, which may cause considerable bias. Variability is reduced in the FHM protocol by using a two-person agreement method. In this method two persons assess these metrics from different vantage points. They both make and compare their estimates. If the estimates differ more than an agreed upon range they discuss their reasoning, or move to different vantage points until they reach an agreeable estimate.

Some variables such as crown density, foliage transparency, light exposure, and crown position require more human judgement than many of the other variables. The TMS instrument works by optical means as well, so it is vulnerable to some of the same issues of lighting and obscurity as a human observer. The advantage of the TMS instrument is the ability to objectively measure distances, angles, and coverage. As such, it is helpful for the indicators mentioned below and will allow them to be assessed with greater consistency.

Crown Diameter—-Points on the ground plumb from the edges of the widest distance across the crown and the distance perpendicular to this are measured using a tape. These distances are used to determine a measure of crown diameter. Error can enter in determining the widest distance and in determining points normal to the crown edge. With the TMS instrument, the operator can stand in one position near the tree length position of the stem and measure the distances to several apexes, provided that there is a clear line of sight. With the combination of a few vantage points a “circumference” or a surface area can be determined that is more informative than a diameter measurement. In either case, the relative size of the crown will give some indication of crown competition, a measure of localized stand density.

Live Crown Ratio--The length of the live crown is measured from a horizontal line at the bottom of the lowest portion of live foliage to the top of the stem not interrupted by more than a 5 foot gap. The proportion of this length to the entire stem length is the live crown ratio. This provides a third dimension to the crown diameter estimate, thus some estimation about the “volume” and shape of the crown can be made. Error can enter in determining the location of the horizontal line of the lowest foliage, the determination of the stem top, and poor estimation of the proportion. Using the TMS instrument the lengths can be measured rapidly rather than estimated.

Compacted Crown Ratio--This is similar to live crown ratio except all of the gaps are removed from the length measurement. This requires a bit more judgment, thus the addition of more places where subjectivity and error may appear. This metric is thought to be less noisy than the live crown ratio as it gives a more precise estimate of the productive structure of the tree. The lengths between the top and bottom of the crown as well as the lengths of the gaps can be measured with the TMS instrument and an algorithm can be written to perform the compaction.

Crown Density--Crown density is an estimation of the amount of light blocked by the branches, fruits, and foliage of a tree. The crown silhouette is visualized and the amount of illumination through this space is determined. This delineation of the crown silhouette and estimation of illumination provide opportunities for errors. Isolating the stem being considered from background stems in a dense canopy is an additional difficulty. The TMS instrument can do a very accurate job determining the amount of unobstructed light. However, determination of the crown silhouette and distinction of background crowns may pose challenges. An alternate sampling strategy can use the TMS instrument pointed skyward from a location below the canopy. This reduces the likelihood of overlapping crowns.

Foliage Transparency--Similar to crown density, foliage transparency is an estimation of the amount of light blocked. However, only the foliage is considered in this analysis. This indicator should be more sensitive to short-term stressors (i.e., insect attack) than perhaps the crown density measurement alone. This indicator is particularly difficult to estimate due to the large amount of imaginary delineation required.

Crown Dieback--Crown dieback is recorded in the FHM program as the percent mortality, by 5 percent classes, of the terminal portion of branches in the sun-exposed portion of the crown. This is an indicator of the severity of recent stresses on the tree. The measurement is the percentage of the dieback area in the live crown. Again, judgment and visualization are necessary components for the evaluation of this variable. In the previously mentioned metrics percentage estimates tend to be large. Since crown dieback is usually a small percentage, analysis of a trend over time may be difficult. For instance, at sample cycle 1 crown dieback is estimated to be 10 percent on a crown that has a live crown ratio of 60 percent. If there is no change in dieback by cycle 2, but the live crown ratio is reduced to 50 percent due to natural necrosis of the lower limbs, crown dieback may be disproportionately increased due to reduction of the live crown. The TMS instrument allows a permanent record to be kept, which allows for the examination of the specific amount of recession of live matter from the top.

Non-Crown Indicators

There are other indicators, such as growth rate, productivity, and understory, which may exhibit a level of correlation with crown measurements, and are valuable to be considered in their own context. For instance, growth rate may continue to increase despite a major defoliation caused by a temporary outbreak of insects. These variables help to make the overall analysis of forest health more thorough and robust.

Growth Rate--Repeated measurements, collected over time, can be used to examine growth rates. Diameter at breast height is commonly the chosen measurement used to evaluate the growth rate because of high assurance of repeatable measurements, especially when the location is marked. The TMS instrument is suitable for repeat measurements as the bearing and distance are automatically recorded in addition to the ability to use the image to determine exact locations. In this way measurements on other portions of the stem can be assessed for growth as well. This may be more critical for larger trees where annual growth adds only small changes to DBH.

Forest Productivity--Productivity, as viewed in the Santiago Declaration, is concerned with the productive capacity of the forest ecosystem. Of course this concept may have a very wide interpretation and indicators may vary greatly. This criterion can also be taken to involve the growth and removal of forest products. Techniques for deriving growth are well developed. However, there are still some improvements to be made in expanding and validating the accuracy of these models in certain populations. The TMS instrument can be used to measure stem volumes rapidly in order to check and calibrate existing volume equations for underrepresented populations. Stem form information obtained using the instrument can also be useful in classifying the growing stock into potential product classes.

Understory--In addition to evaluation of large stems, the understory vegetation is also important for determining overall forest health. The amount and type of understory vegetation provides valuable information about other stressors (e.g., animals, disease, soil properties, etc.) and about regeneration potential. Understory components are also considered for biomass estimation and fire fuel loading and structure.

Understory sampling is typically done using very small plot sizes. For many biomass studies a square meter quadrat is used to estimate the amount of herbaceous material(MacDicken 1997). This sampling method is statistically valid and provides crucial information on the types and amount of vegetation. This system faces inefficiencies due to spatial correlations often found in natural systems (Parresol 1999). Understandably, every sampling problem cannot be solved given time and budget limitations, however the rapidity of data collection should allow the TMS instrument to provide an ancillary source of information about the amount and structure of understory vegetation.

HOW THE TMS INSTRUMENT ADDRESSES THESE MENSURATIONAL CHALLENGES

The TMS instrument has the capability of capturing large amounts of data in a short period of time. For variables that can be quantitatively assessed (e.g., lengths, upper-stem diameters, light penetration, etc.) the TMS instrument provides objective measurements very rapidly. Additionally, the TMS instrument can be applied from the same location over measurement cycles. If the image data is archived, conditions can be reliably monitored over time. This may also lend to the reasonable application of more robust sampling procedures (e.g., randomized branch sampling (Gregoire and others 1995)) to assess foliar change on particular branches over time. The capabilities of the TMS instrument introduces much anticipated potential for extending the amount and reliability of sampling for forest health, vitality, and productivity assessment.

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