

The Virtual Forest: Robotics And Simulation Technology As The Basis For New Approaches To The Biological And The Technical Production In The Forest

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Abstract: *In order to support competitiveness on the worldwide market - but also to overcome efficiency problems related to the forest owner structure in North Rhine-Westphalia (NRW), Germany - the "Virtual Forest" is being developed as an intelligent planning and decision support tool for forest growth as well as for wood mobilization. In practice, the heart of the Virtual Forest consists of a database of approx. 240 million single trees in NRW, its major wood resource. In order to identify the trees, latest aerial survey and satellite technology is used and combined with virtual reality and robotics know how in order to efficiently gather and visualize the data. Thus, the Virtual Forest will serve as a reliable and very up-to-date base and framework for new efficient forest planning, wood mobilization and machine logistics methods.*

1. Introduction

The Virtual Forest (Rossmann 2007) is a joint effort of various partners who combine their know-how in the fields of automation/robotics, machine development and forestry to realize a comprehensive framework in order to identify, visualize and optimize biological and technical processes in the forest.

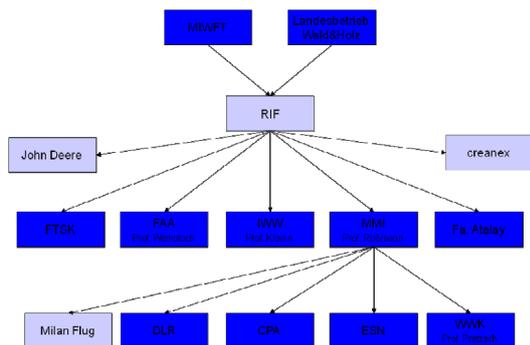


Fig. 1: Partners from science, industry and forest administration who contribute to the "Virtual Forest"

As shown in fig. 2, the developed methods draw from the fields of aerial survey technology, space- and terrestrial robotics, localization and navigation

technology, sensor technology, virtual reality and – of course – latest silvicultural know how.

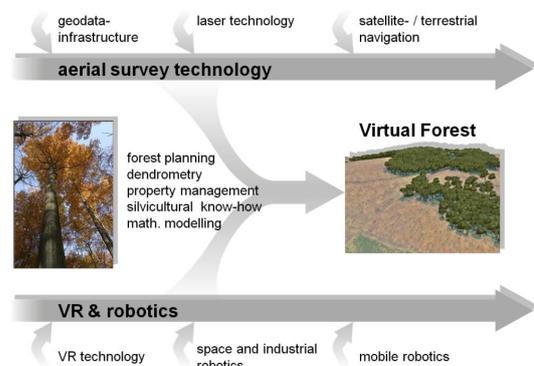


Fig.2: Combining the know-how of various scientific fields makes possible the "Virtual Forest"

The overall goal of the virtual forest is to develop a comprehensive database with a versatile structure which is able to hold all forest relevant data with a very high level of actuality. This database has to be filled in several steps to provide the necessary basic knowledge about the forest. The general idea is to use latest remote sensing technology, i.e. to fly an airplane or a drone to gather photogrammetric and laser based measurements about a forest. The sensed data then undergoes various image processing, object identification and classification

procedures in order to derive tree-wise as well as stand-wise properties of the measured wood resources. The key to the success of this step is that a “multi-sensor-approach” is used which combines the data processing algorithms which have been and are being developed in cooperation with forest experts (see fig. 1) from all over Germany.

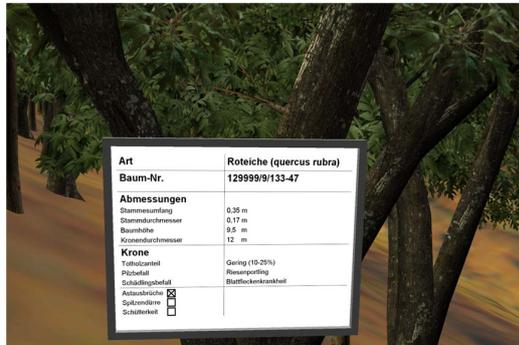


Fig.3: The results of the remote sensing step are “digital business cards” for each single tree

These are currently being integrated into the Virtual Forest framework whose key design issue is to allow the algorithms to evolve. Whenever “ground truth” shows that the currently used algorithm does not provide satisfactory results, it may easily be changed or even replaced with an improved version. Thus the framework makes sure that it can always incorporate the most up-to-date state of science and technology. Fig. 3 show the results of this process for the tree-wise delineation: Every tree receives its “digital business card”, a collection of its properties that are relevant to its health, market value, treatment options etc.

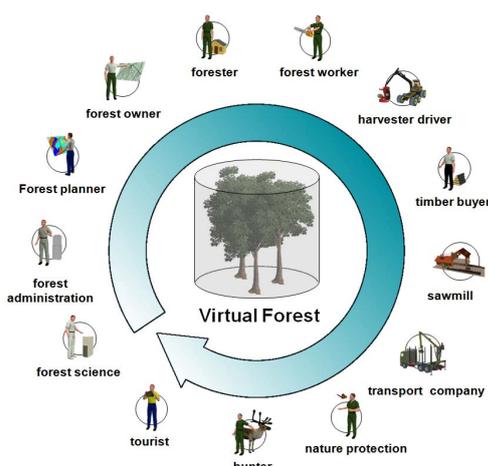


Fig.4: The Virtual Forest is being developed to be beneficial for various parties doing business in the forest

Here, it is important to notice that by Virtual Forest *not the virtual reality representation of the forest* is meant, but *the Virtual Forest is the resulting database of the single trees and the tree stands*

(where single tree data is not available or too expensive to gather). Of course, given the Virtual Forest database, it is rather straight forward to generate a corresponding virtual world of a forest as shown in many of the figures below.

Although *the virtual world is not the key result of the Virtual Forest*, it proved to be an *exciting communication and crystallization point* for the various partners (see fig.4) involved in forest related business models.

2. Application of the Virtual Forest Database in Practice

One of the design issues – and the reason why different automation experts (see fig. 1) are involved – is the practical applicability of the generated tools, methods and data in an foresters daily work. As doing business in the forest is complex and has a manifold of complex decisions to make and complex tasks to perform, the Virtual Forest project is divided into 21 sub-projects, of which the most important will shortly be summarized in this chapter.

2.1 Forest Planning

In order to support forest planning, a new 4D-GIS approach was realized, based on an innovative virtual reality and simulation software. In general, the 4D (i.e. the 4 dimensional) aspect was of utmost importance, because *the fourth dimension - the time - is an important property* of all information saved in the Virtual forest database. Thus, all objects are not only known with their geo-coordinates, but all related information is also time-stamped, so that a user immediately gets an impression, how current the presented information is. Furthermore, the Virtual Forest “never forgets” which means that no information entered will ever be deleted: It may be superseded by more current information, but it will always be kept in a revision history that can be questioned to provide a “look back into the past”.

Being able to look back into the past is important in order to learn from the past, but combining this with capabilities to “look into the future” is the basis for economical success. Thus, the Virtual Forest integrates the tool SILVA (Becker 1999: Becker, L., Bernard, L., Döllner, J., Hammelbeck, S., Hinrichs, K., Krüger, T., Schmidt, B. and Streit, U. "Integration dynamischer Atmosphärenmodelle mit einem (3+1)-dimensionalen objektorientierten GIS-Kern," in 13. Internationales Symposium "Informatik für den Umweltschutz", pp. 429-442, 1999, ed. C. Rautenstrauch, M. Schenk, Publisher Metropolis

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), a single tree based stand simulator, to provide a “look into the future” concerning the development of the stand.

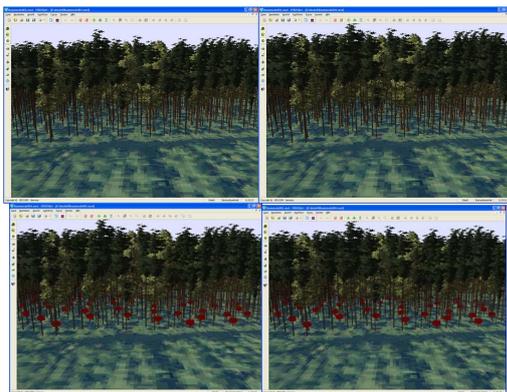


Fig. 5: From top left to bottom right – Results of the tree stand simulation with SILVA: The initial state of the stand, its state after 5 years of undisturbed growth, elite trees are chosen, support of elite trees through thinning

Fig. 5 shows a sequence of pictures which resulted from the stand simulation with SILVA predicting the development of a stand within the next 5 years – including the thinning recommended to support elite trees. The sequence of images in Fig. 5 is way more convincing if viewed directly in the virtual world of the Virtual Forest, because one can “see the trees grow” in time-lapse mode and feels like being inside a “time-machine”.

Whereas the single tree view is still a matter of science and research and is only just about to be introduced into a forester’s daily work, the stand-wise view is well known and accepted. Thus, the Virtual Forest also incorporates important aspects of today’s forest planning tools. By collaborating with Atalay Consult, Balve, Germany, renowned forest planning know how could also be integrated into the unifying framework of the Virtual Forest. As part of the cooperation, the existing forest planning software was made compatible to Virtual Forest data sources. On the one hand, this allows us to further use the proven prediction and forest planning tools of Atalay Consult based on the latest data sources. And on the other hand, the well understood forest planning methods serve as a

reference to the new single-tree methods. An experienced forest planner can thus easily compare the results of the new approaches with the proven approach under one simple to operate user-interface.

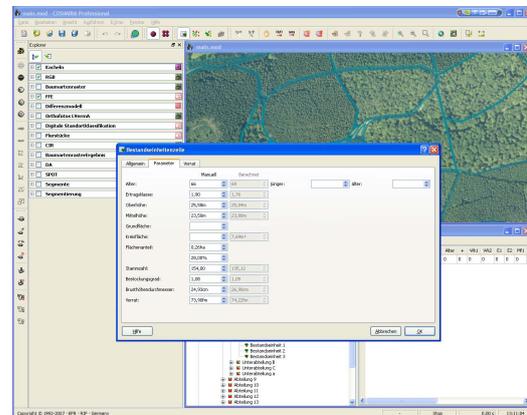


Fig. 6: State-of-the-art forest planning parameters and results may also be used in the Virtual Forest framework and are made available under a user-friendly user-interface

The 4D-Geo Information System (GIS) depicted in fig. 6 is a major, immediately usable outcome of the Virtual Forest for forest planning tasks. The user-interface has especially been designed for ease of operation and user-friendliness, and it is provided to support the daily work of the forester related to forest planning, environment protection, machine deployment and overall forest logistics and in-situ information collection.

It has to be stated here, that the knowledgeable forester is an important part of the Virtual Forest, because he/she has to verify the generated information against “ground truth” and has to add information that cannot be gathered by remote sensing technology, i.e. tree diseases, multi-level tree stands etc. On the other hand, the developed technologies relieve the forester from routine tasks like the measuring of tree heights and other tree properties that can well be derived from the gathered data.

2.2 Technical production

Another important aspect of the virtual forest is the support of the "technical production", i.e. the use of advanced mobile robotics technology in order to make the work of forest machines more efficient - e.g. by the introduction of a "automatic navigation to the next tree to fell"- feature - and also more environment friendly - e.g. by the support of automatic tire pressure control systems.

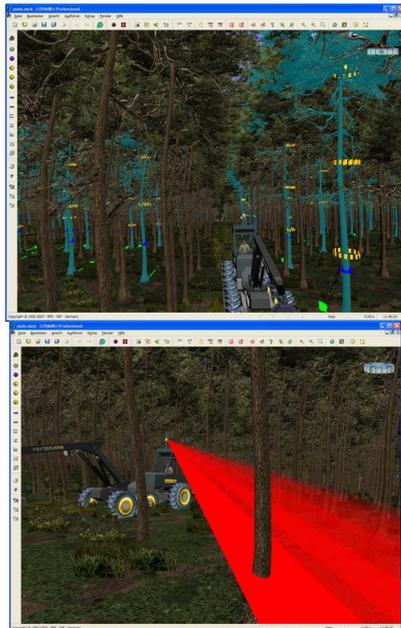


Fig. 7: Machine logistics, -deployment and -chaining in the Virtual Forest: The forest machines are equipped with new sensors to enhance effectiveness and

In order to be able to fully exploit the new capabilities of the Virtual Forest to support the technical production, i.e. the mobilization of wood resources, it is important that especially a harvester knows its exact location. If this is the case, the Virtual Forest's single-tree data, gained by the described remote sensing step, can be updated by incorporating the geo-referenced harvested trees: The harvester just has to "find out and remember" which tree was just cut and provide this information to back to the Virtual Forest. In the Virtual Forest database, those tree are then treated as "cut" and so the calculation of the available wood volume can incorporate the latest state without waiting for the next remote sensing flight.

Furthermore, this approach resolves a problem typical of the state of North Rhine-Westphalia (NRW) with its huge number of forest owners with only small parcels. About two thirds of the privately owned forest in NRW consists of parcels of a size between 0.5 and 1,5 ha per owner. Having this new single-tree based bookkeeping available, the felled trees can exactly be assigned to the parcel where they were felled – and thus to the owner. Various experiments showed that the GPS accuracy under the tree canopy is not sufficient to be able to identify and distinguish between single trees. Thus, the Virtual Forest supports the equipment of harvesters with "optical GPS", a new technology that uses laser range finders (see fig. 7) in order to get a measurement of the trees close to its position. It then *uses the single tree positions, previously generated for the Virtual Forest through remote sensing as a map to localize itself.*

This is pretty much similar to human behavior: Look for landmarks, compare their configuration to a map, determine your position in the map.

First tests of this approach really provided amazingly good results. In a tree stand of spruce, age 80 to 100, the harvester was able to localize itself with an accuracy of approx. 30 cm, which is way sufficient for the bookkeeping as planned.

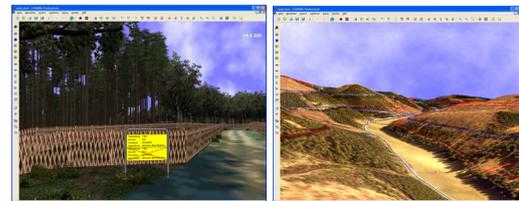


Fig. 8: "Virtual fences" are metaphors for parcel boundaries, working paths can be projected onto the terrain in order to evaluate potentially difficult working conditions

In order to facilitate the work for the harvester driver, metaphors are provided. Fig. 7 shows that the trees to fell are highlighted in light blue, so that the drivers can find the trees to cut easily. Fig. 8 shows "virtual fences" and virtual owner signs as metaphors of parcel boundaries, so that the driver can immediately see when he/she is crossing boundaries. The right part of fig. 8 shows that in the Virtual Forest, the working paths of the forest machines can be projected onto the terrain. Terrain slopes can be viewed this way – or even better with the help of metaphors as shown in fig. 9. When preparing a forest machine operation, one can slide a "virtual spinning top" around in the terrain and watch its color. As soon as it changes from green to red, caution is advised, because the terrain might be too steep.

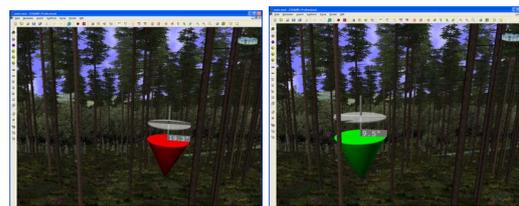


Fig. 9: Virtual "spinning tops" as metaphors provide information about the slope to expect and thus the difficulty of the terrain. A harvester probably would not want to enter a terrain where the color changed from green to red.

The next step is close: *A navigation system for harvesters which guide the harvester to the next tree to fell.* It is already possible today, to use computer software to automatically determine the trees to cut e.g. in a thinning operation. With the harvester navigation system, the chosen trees don't have to be marked with paint any more, their

positions will just have to be downloaded into the navigation system.



Fig. 10: “Harvester navigation to the next tree”: Is this the coming generation of harvester navigation systems which directly guide the driver to the next tree to cut. Look at the left onboard display!

Beyond the advantages described above, equipping a harvester with the laser sensors also provides important feedback for the remote sensing procedure: The remote sensing procedure derives e.g. the breast height diameter from the “visible, measurable or known” parameters of the tree like its height, crown diameter, age, water and nutrient supply etc. This estimated breast height diameter can now be compared to the breast height diameters the laser sensor “sees” and thus serve as a basis to further improve the derivation model. Thus, **“ground truth” for the Virtual Forest is provided for free**, as soon as the first thinning takes place.

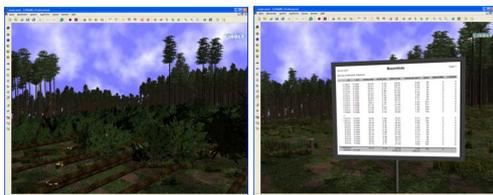


Fig. 11: The Virtual Forest does not only provide methods to quicker estimate the damages caused by windblow, it also provides the simulation methods to calculate the costs to cope with the damages

2.3 Advanced simulation technology

The Virtual Forest also drives forest machine simulation technologies to new heights – and to new application fields. A group of Virtual Forest partners around Prof. Warkotsch are currently developing a forest machine simulator that can not only be used for machine driver training, but also serves as the basis for the economical simulation of forest machine operation (Pausch 2005).



Fig. 12: Advanced forest machine simulation technology is becoming more powerful but cheaper because the systems are now multi-use capable

The system allows to calculate the expected net profit by determining the logging cost with the help of an advanced simulation system. The determination of the logging cost can be performed very accurately today, because the approach carries out the logging **in the virtual world as a simulation first** and thus can calculate very precisely the logging cost to expect with respect to fuel, driving speeds, driver skills, machine capabilities etc. As a side effect, this has opened a new application niche for the underlying simulator which originally was developed and marketed mainly for driver training. This new application opened new fields of application and lowered the introductory price for the driver training simulator to around 10.000€ which is almost an order of magnitude below current market prices and should further help to introduce latest virtual reality technology into the forest.

3. Conclusion

The Virtual Forest is about to become one of the most comprehensive and most current collections of knowledge about the forest and its wood resources available today. Thus, it has the potential to serve as the basis for economical success in the forest as well as for new scientific results related to the forest environment. The results gained so far are already promising and are currently being put to practical tests. It is important to the project not to develop another prototype, but to develop components that are readily available to foresters to alleviate their job.

Ranging from “biological production” to “technical production”, the Virtual Forest is comparable to “Product Lifecycle Management” tools in e.g. the car industry. The complete lifecycle of the product “wood” is covered – but with a big emphasis on the

biological production, i.e. tree growth. Thus, the implemented methods are equally well usable for nature protection purposes as for the evaluation of the efficiency of wood mobilization measures.

Integrating climate change effects together with new models to determine the effects and to evaluate countermeasures could be one of the next great challenges. The developed comprehensive database for such investigations related to the forest is available now through the Virtual Forest project.

Last but not least, the virtual worlds that can be generated from the Virtual Forest database will further help to understand the complex natural mechanisms. The generated virtual worlds – e.g. as shown below – can never substitute a real walk in the woods, but they can help to better understand how to sensibly use, preserve and protect it.



Fig.13: The Virtual Forest “at sunrise”

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