Virtual forest stand as a component of sophisticated forestry educational systems

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ABSTRACT: The paper presents the methodology of virtual stand generation. Virtual stand serves for forestry e-learning as a tool for training of forest tending and demonstration of stand structure and some forest mensuration practices. The model can be connected with growth simulator and geographical information system, or integrated into the Internet environment. In the first part of the paper, the methodology of individual tree visualisation, total stand visualisation, terrain and stand environment visualisation and the principle of user's interaction with virtual forest are proposed. The Virtual Reality Model Language (VRML 97) was used for these goals. In the second part of the paper, an example of model usage for the training of forest tending is presented.

Keywords: forest visualisation; forest modelling; e-learning; VRML 97; thinning training tool

In European countries with advanced forestry models and software systems for the forest growth simulation and prognosis (PRETZSCH 1992; HASENAUER 1994; STERBA 1995; NAGEL 1996) are continuously improved. Models keep on achieving a higher level of detail: describe the evolution of single trees, take into account the competition ships, mortality, different forest tending programmes and are closely related to site fertility and climatic characteristics. They are better adapted to forest practice requirements at the same time. Their software resolutions become more developed (SILVA, MOSES, PROGNAUS, BWIN).

An inseparable part of the above-mentioned models and computer programmes seems to be extended modules for forest visualisation. They enable to review simulation results and to record the dynamics of forest stand evolution visually. Some visualisation modules (mainly static ones) are a direct part of growth simulators. Independent programmes that can visualise the forest stand or its part on the basis of determined data formats are also developed. A good example is the well-known Stand Visualisation System (MCGAUGHEY 1997).

A new trend of utilisation of these models is their introduction into the field of training and education of the forestry community. A transition from static visualisation (2D or 3D) to dynamic **virtual forest stand** is connected with this. It is possible to move, i.e. walk (virtual walk-through) or fly (virtual fly-through), without any limits in this type of stand. Except this, the environment is in close interaction with the user. It means that it is possible to mark trees, to cut trees and to change it in this way. The tool serves for presentation, publicity and demonstration aims, for example the presentation of different stand structures and demonstration of different forest mensuration procedures (an estimate of stand density and tree species composition, methodology of sample plot establishment). After the connection with growth simulators it becomes a tool for virtual training of forest tending, i.e. "*thinning training tool*". This sophisticated approach offers an absolute liberty of tree marking for forest cuttings to the forestry community, moreover the impacts can immediately be tested by means of growth simulations. Another tendency is switching these tools to geographical information systems. The actual forest stands situated in a real geographic position and terrain situation of similar stand structure are subsequently used for education and training. It passes from the level of virtual forest stand to the level of virtual district. The latest element of these systems is their introduction into the Internet environment, the transition from the local connection to the remote one. Then these systems become a basis of sophisticated systems for forestry electronic education (**e-learning**).

The purpose of this study is to present the methodology focused on the virtual forest stand generation and to introduce its applied realisation. The designed system will be a part of growth simulator "SIBYLA" and thinning training tool "TREVYL" developed at the Department of Forest Management and Geodesy within an information system for forest users (FABRIKA 2002a). The system for the creation of virtual forest stands arose within the projects of the 5th framework programme of European Union *Implementing Tree Growth Models as Forest Management Tools*, home Research Project VEGA *Biodiversity, Forest State Assessment and Evolution Prognosis* and project from the field of information technologies *Project of IT Utilisation* *as Tool for e-learning at Forestry Faculty* as a product of their bilateral co-operation.

METHODOLOGY

In the development process of the tool for the virtual forest stand generation it is necessary to solve some methodological questions. Primarily it is important to choose the software platform for virtual forest stands. The following possibilities come into consideration:

1. *Utilisation of user-ready applications*. Several solutions exist in the form of computer programmes in the world. A disadvantage is their binding with certain data format, limited number of tree species, language localisation, more complicated integration with other systems, impossible implementation into the Internet environment and finally license conditions. A notable example of this system is a programme TreeView (SEIFERT 1998), experimentally introduced into the Forest Information System in Slovakia (FABRIKA 2002b).
2. *Construction of new applications on graphic library basis*. This method requires a development of new specific application with utilisation of some 3D-graphic libraries (e.g. OpenGL or Direct3D) in the development of programme environment (e.g. Visual C++ or Delphi). An advantage is maximum liberty of adaptation of requirements of the forestry community. But their creation is very difficult and expensive, mainly for the infiltration into the Internet environment. At the same time the mentioned products are limited only to the functions embedded by the development process and any change requires a re-entry into the source code.
3. *Utilisation of language for building of virtual worlds (VRML).* Virtual Reality Model Language – VRML (CAREY, BELL 1997; ŽÁRA 1999) appears as very promising because of its opened architecture (Open-Source principle), severe ISO standardisation and primary determination for the Internet platform. The description of the virtual world is in an external text file and the absolute possibility offers to build virtual worlds (not only forest stands). Number of viewers exists, even as a part of the Internet applications Netscape Communicator and Internet Explorer. Programme libraries for the integration into the own systems are available on ActiveX components basis.

The third possibility was chosen for our needs that seemed to be the most convenient from the aspect of establishment difficulty, service properties and a chance of future adaptation. For these purposes we developed a viewing programme "MARKO POLO 3D Explorer" in the Delphi environment. Consequently it was necessary to solve other methodological questions: a method of single tree visualisation, a method of the total stand generation based on commonly available forest information, a method of implementation and terrain visualisation from the digital model in the GIS environment, visualisation of surrounding world for complete virtual experience (background, lighting, visibility, sound extension) and finally to ensure the interaction between the user and the forest environment (tree marking, tree cutting and connection with growth simulator).

Single tree visualisation

The biggest requirements for the forest visualisation are reposed on a 3-dimensional model of single tree. It is necessary that the given kind of tree species will look real to satisfy the purpose of virtual forest stand. This puts great demands on the projection of crown habit and bark texture. Hereby, it is needed that the tree dimensions (tree diameter – $d_{1.3}$, tree height – h, crown diameter – b, crown length – l) will act as variable values. These requirements are really very important, chiefly if we realise that this tool is intended for students whose routine in tree differentiation is forming. Wrong results of tree species visualisation can cause wrong habits of tree species recognition. That is why the specialists in forest dendrology verified the resulting tree species prototypes.

A suitable space model has to be chosen for tree visualisation. Most existing tools use tree generation into the simplest models as frequently as possible. For example, the stem is represented as a cylinder and the crown is a simple body (a ball for broad-leaved trees and a cone for conifers) or the body composed of "lighted part" (a cone, a ball section, paraboloid) and "shaded part" (a cone, a ball section, a cut cone, a cut neiloid, a cut paraboloid). But this visualisation is far from the real look of trees. A different visualisation model was used for our purposes, based on the latest procedures applied to the development of the latest 3D computer games. A principle is shown in Fig. 1.

The tree was divided into three parts: stem, crown and buttress. The stem and the buttress are made up of interlocked cones. The crown consists of four planes rotated at 45°. Bark texture of the particular tree species is built up on the stem and buttress. The bottom of the buttress cone is covered with wood texture in a cross-section (important for cut trees). The illusion of real crown is achieved by texturing the crown habit into the rotated planes. Textures are of transparent background (GIF format was used). Required pictures were scanned and modified according to the drawing of tree crowns in an atlas (COOMBES 1992) and according to photographs of tree bark in atlases (AAS, RIEDMILLER 1987; KREMER 1995; PAGAN, RANDUŠKA 1987, 1988).

To create the tree its following parameters are important: co-ordinates of tree position (*x, y, z*), tree species, serial number of tree, tree status, text description, tree height, tree diameter at breast height and crown parameters (crown diameter in north-south direction, crown length and crown diameter in east-west direction). The syntax is following:

```
Transform {
 translation 30.5 500 20.0
 children[
  TREE_JD {
   tree_number 1
   tree_status 0
   tree_text „“
   tree_height 20
   tree_dbh 26
   crown_parameters 4 10 4
  }
 ]
}
```

These values are necessary for the visualisation of bodies: height and bottom radius of the cone, the crown is defined by the spatial co-ordinates of the corners of planes. The bottom radius of the stem is calculated using the extrapolation of the tree breast height diameter ($d_{1.3}$) and height (h) according to:

$$r_0 = \frac{d_{1.3}.h}{200.(h - 1.3)} \tag{1}$$

The height of the stem cone is equal to tree height.

The bottom radius of the buttress cone is determined by:

$$r'_0 = \frac{2}{1.5}.\, r_0 \tag{2}$$

The cone height of the buttress is determined by:

$$h' = \frac{h}{30} \tag{3}$$

The crown prototype of the size 1 × 1 × 1 m is used for the crown and its real size is obtained by changing the scale in *x, y* and *z*-axis direction.

26 prototypes of tree species were created by the above-mentioned procedure: spruce, fir, pine, Douglas fir, larch, beech, oak, hornbeam, aspen, birch, cherry, willow, poplar, dwarf pine, hedge maple, sycamore, Norway maple, elm, rose acacia, ash, lime, walnut, buttonwood, alder, chestnut and yew tree. Examples of some tree species are in Fig. 2.

Visualisation of forest stand

Another important step in the creation of virtual forest stand is generation of its structure. It becomes problematic when no data on single trees are available (for example, from permanent sample plots). It is necessary to know not only the diameters and heights of the trees, but also their position co-ordinates and crown parameters (diameter and height of the onset). In case these data are not available, it is necessary to generate them. The most common situation is that data on the diameters and heights of trees are missing, i.e. only average stand data are known (e.g. from the stand description in the forest management plan). In this case, it is required to generate the frequency distribution of tree diameters and heights.

For these objects the stand structure generator was used (STRUGEN) that is a part of growth simulator SILVA 2.2 (PRETZSCH 1993). An algorithm was applied and an independent module was created that can generate particular tree characteristics on the basis of stand data (mean diameter d_m, mean height h_m, average basal area per hectare G_{ha} and average number of trees per hectare N_{ha} with regard to tree species in different storeys). These data are normally available from stand description. The principle of generation is as follows:

1. Generation of diameter frequency distribution (n) on the basis of Weibull function ($F(d_{1.3})$), as modified by NAGEL and BIGING (1995):

$$F(d_{1.3}) = 1 - e^{\left(\frac{7}{a_0}\right)^{a1}} .\, e^{\left(\frac{d_{1.3}}{a_0}\right)^{a1}} \tag{4}$$

2. Generation of single tree heights (h) on unit height curves (ŠMELKO et al. 1987):

$$h = 1.3 + (h_m - 1.3).e^{[(a_0 + a_1.h_m + a_2.d_m)\,.\left(\frac{1}{d_{1.3}} - \frac{1}{d_m}\right)]} \tag{5}$$

3. Generation of crown diameters (b) and crown onsets (h_l) according to the relations (PRETZSCH, KAHN 1998):

$$b = e^{a_0 + a_1\,.\,\ln(d_{1.3}) + a_2\,.\,h + a_3\,.\,\ln(\frac{h}{d_{1.3}})} \tag{6}$$

$$h_l = h\,.\left[1 - e^{\left(a_0 + a_1.\frac{h}{d_{1.3}} + a_2\,.\,d_{1.3}\right)}\right] \tag{7}$$

4. Generation of position co-ordinates of single trees on the basis of Poisson's homogeneous process (PRETZSCH 1993). The algorithm enables to simulate a random tree distribution or group (alternatively strip) addition of one tree species into the random distribution of other species. The principle of group mixture is designed in Fig. 3. The generation is carried out on the basis of filters. In the first step the positions of a mixture tree species are generated. In the second step other species fill up the stand. A stand macrostructure (i.e. groups or strips) is created by the first grade filter (filter 1). It means that the points of different probability decreasing from the middle of the groups or strips are accepted. The filter has the same probability through the entire area in the case of random tree distribution. The second filter (filter 2) regulates the stand microstructure. It means that only the points at a distance greater than the permitted minimum distance to the created trees are accepted. Minimum distances depend on tree species and their crown diameters. The process of occupation the stand area realises till all the trees generated at point 1 are placed.

Detailed algorithm description and coefficient values are in appropriate publications.

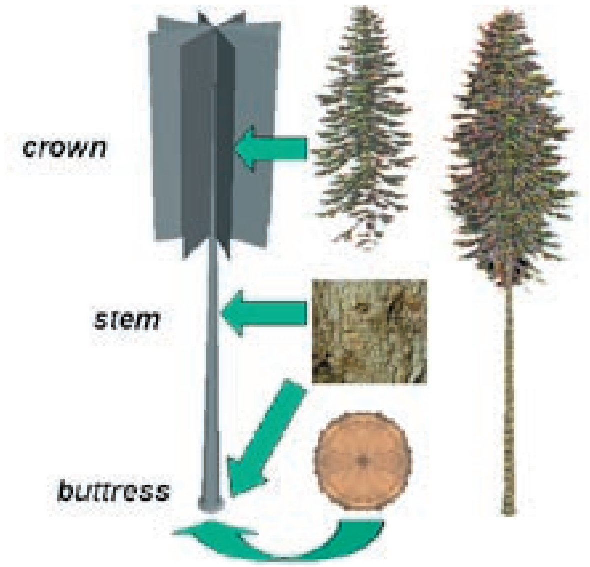

Fig. 1. The principle of single tree visualisation

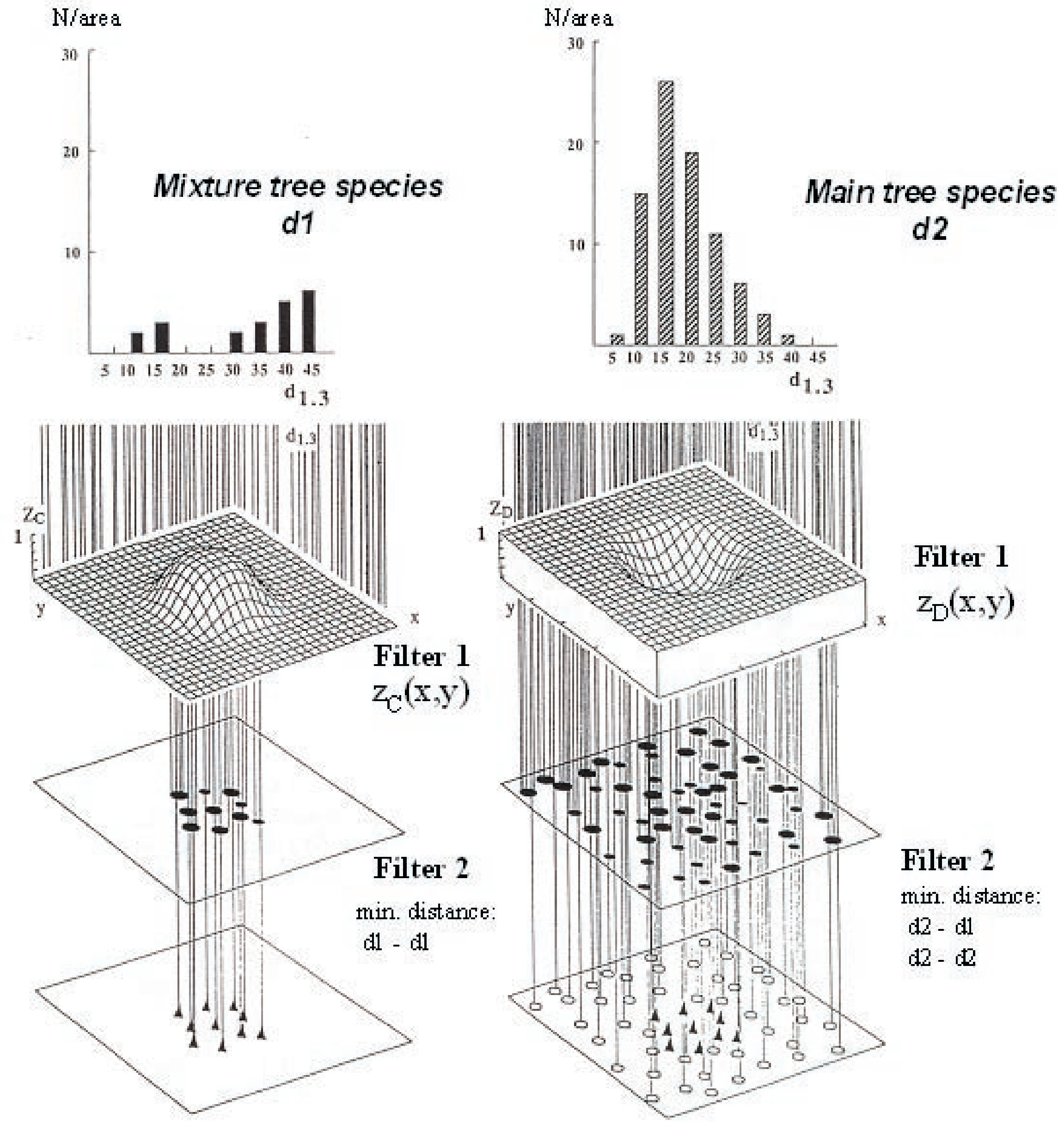

Fig. 3. The principle of tree position generation (PRETZSCH 1993)

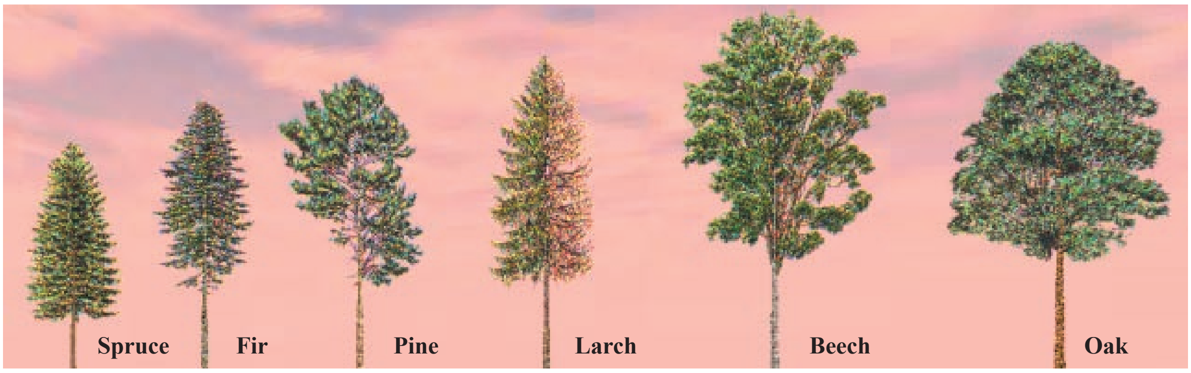

Fig. 2. An example of visualisation of some tree species

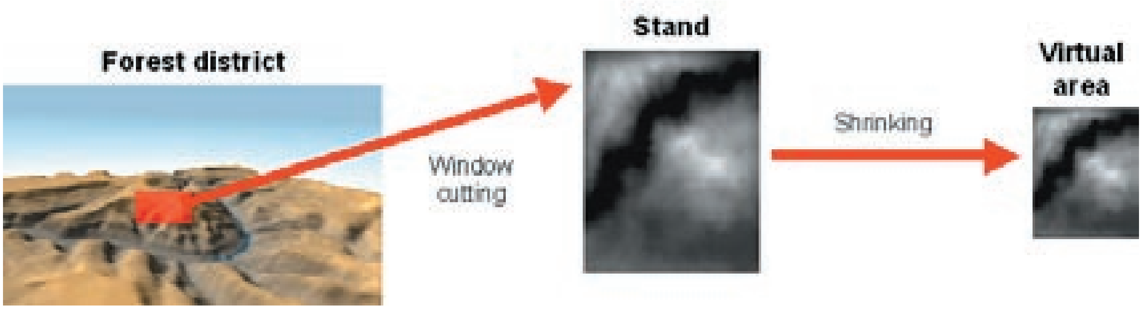

Fig. 4. The method of virtual area selection

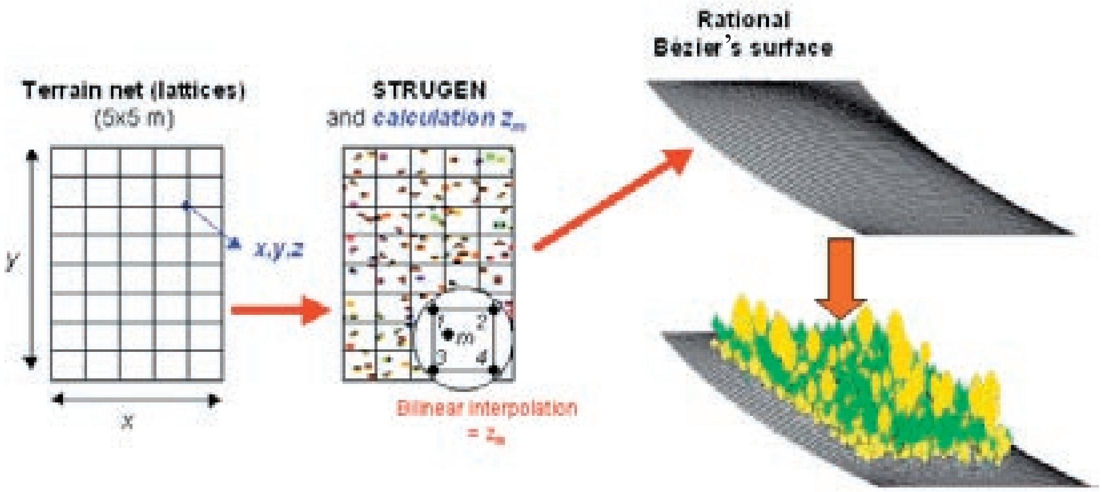

Fig. 5. The method of stand visualisation in the terrain


Fig. 6. Comparison of view into the stand at midday and by night

Terrain visualisation

It is not possible to create a real model of virtual stand without a terrain model. This simultaneously affects competition relationships among the tree species because the competition situation is different between the lowland and the dissected slope. This factor determines the mutual tree position (shading and straitening) and thus a computation of competition indications (BACHMANN 1998). By the terrain generation for the virtual forest stand it is necessary to solve some methodological problems: representative terrain sample and its extraction from the data sources, derivation of the height position co-ordinate for each tree and at last the method of final visualisation together with the forest stand.

For the selection of a representative sample it is necessary to choose a suitable size of the area, its shape and this shape to extract from the original terrain model. From the aspect of calculation speed it is not favourable to choose the size of the whole stand. For the purposes of the virtual area and consecutive growth simulations the size that results from the optimisation among the representativeness of stand structure and calculation and user's suitability is sufficient. An optimal compromise seems to be the area of 25 ares. In dependence on stand density it consists of approximately 50 trees (200 trees per hectare) to 2,500 trees (10,000 trees per hectare).

Another question is the selection of an area part to extract it from the original terrain. It is possible to choose the system for a location of this part into the stand centre. But this approach implies some methodological problems and at the same time it does not represent the entire stand well, especially when terrain conditions are markedly different from the area centre. For our purposes, the approach of shrinking the stand area into the required virtual area was chosen (Fig. 4). In the first step a rectangle (alternatively square) is selected from the digital terrain model coming from the forest district. The geometrical figure out-rounds the chosen forest stand. A given terrain section is consequently reduced into the required size by scaling the raster. This approach will ensure better representation of the area from the aspect of competition situation in the stand.

The method of derivation of the height position of single trees and final visualisation is illustrated in Fig. 5. A net of 5 × 5 m points is derived from the virtual area (i.e. lattices). Single trees are placed into this net according to the approach in the preceding chapter. A bilinear interpolation of horizontal tree co-ordinates (x_m, y_m) and height co-ordinates of the appropriate cell corners (z_1, z_2, z_3, z_4) is used for the derivation of height co-ordinate for each tree:

$$z^1_m = z_1 + (z_3 - z_1) \cdot \frac{(y_m - y_1)}{(y_3 - y_1)} \tag{8}$$

$$z^2_m = z_2 + (z_4 - z_2) \cdot \frac{(y_m - y_2)}{(y_4 - y_2)} \tag{9}$$

$$z_m = z^1_m + (z^2_m - z^1_m) \cdot \frac{(x_m - x_1)}{(x_2 - x_1)} \tag{10}$$

The derived terrain net is used for the creation of a surface model on the basis of rational Bézier's surface (BÉZIER 1972). The algorithm description is in the paper by ŽÁRA et al. (1992). The individual trees are located onto the presented area.

Visualisation of the surrounding environment

The environment visualisation does not have any direct impact on the function of stand model, but it has an immense significance for the perception quality and virtual experience. These are the questions of the image background, light, visibility and sound effects.

The background was resolved by projection of panoramic pictures onto the inside walls of a cube surrounding the virtual forest stand. Four backgrounds were made: morning (sunrise), midday, evening (sunset) and night (full moon). For the ground cover 16 textures (i.e. phytocenology tapestries) were prepared and their utilisation depends on the forest and stand type (FABRIKA 2002b). For the light a universal model suited for all the introduced day periods was used. The best seemed to be the spot light projected from the sun or moon side on the panorama background:

```
PointLight {
  on TRUE
  location 167.04 668.16 167.04
  radius 1336.32
  intensity 1.0
  ambientIntensity 1.0
  color 1.0, 1.0, 1.0
  attenuation 1.0 0.0 0.0
}
```

The visibility (Fig. 6) was variantly resolved with regard to the time periods of the day. The effect was guarded by changing the visibility distance (*visibilityRange*), colouring the fog (*color R/G/B*) and by a process of mixing the object colours with the colours of the fog (*fogType*). Selected parameters are in Table 1.

Table 1. Parameters of visibility for time periods during the day

Period	*color R/G/B*	*fogType*	*visibilityRange*
Morning	0.2/0.3/0.1	exponential	25
Midday	0.6/0.6/0.6	linear	100
Evening	0.3/0.2/0.1	exponential	25
Night	0.1/0.1/0.1	exponential	10

Sound extension was executed by means of sounds directly recorded in the forest and converted into the audio files WAV.

Interaction with the surrounding environment

The interaction is a basic condition in the field of e-learning (training of the forest measures). It can be ensured by perception of the real size of the surrounding objects and their precise identification and simultaneously by a possibility of changing the surrounding stand. Anyhow, the communication with growth simulator for a change of the forest state is also important. Perception of the real sizes of trees (diameters and heights) was achieved by entering a 3D figure (i.e. *Avatar*) into the stand model, who "moves in the forest instead of the user". This principle is the same as in computer games of "THIRD-PERSON" type. The user gains a real imagination of tree dimensions on the basis of a relative comparison of the figure "*Avatar"* and trees around. Imaging the attendant information of trees on which the cursor was placed (*tree_text* from input data structure) supports their identification. The process is guarded by the creation of a touch zone (i.e. *TouchSensor*) on the part of the stem (from height of 0.8 m to height of 1.8 m) and by sending information on tree to the *console* through the JavaScript (text on event *isOver*). The arbitrary data on tree (e.g. tree species, diameter, height, quality) is possible to insert into the item *tree_text*. An immediate interaction between the user and the stand culminates by a chance of marking the trees with repeated clicking on the stem in its touch zone. Marking represents a green strip (target tree) or red strip (cut tree) whipped around the stem at the breast height 1.3 m. This event is again activated by JavaScript (reaction on *isActive*). Information on tree marking is saved to the variable (*tree_status* from input data structure). The model of virtual stand also provides a possibility to cut a tree by clicking on his buttress touch zone. An action enables to take measure on releasing the stand canopy after the removal of competitors.

The final communication with the growth simulator (we utilised simulator SILVA) is carried out through the transmission of resultant file containing the information on all the tree status to the *console*:

–1 ..... tree marked for harvesting
0 ..... unmarked tree
1 ..... target tree.

RESULTS AND DISCUSSION

The methodology of virtual forest stand was examined as a tool for the training of stand tending: "*thinning training tool"*. For these purposes stand No. 802 from University Forest School Enterprise Zvolen was chosen, a mixed stand composed of these tree species: beech (53%), spruce (27%), maple (11%) and hornbeam (9%) at the age of 45 on the area of 0.37 ha. "The virtual thinning treatment" was carried out in this stand. A quality crown thinning was applied although the stand tending was divided into two phases: selective and release ones. The selective phase focused on future crop (CT) and target trees (TT). Its quantitative description is in Table 2. The release phase began at the age of 85 years and aimed to support the target trees (first the beech) in order to enlarge the growth increment (i.e. light increment supply) by effective releasing their crowns.

A comparison of the stand at the beginning (45 years) and at the end (85 years) of the thinning treatment is shown in Table 3. The thinning treatment increased the proportion of spruce and maple to the detriment of beech and mainly hornbeam, whose abundance was reduced to a minimum. The number of trees per hectare was reduced from 1,497 to 215 although the volume per hectare increased from 251 m^3/ha to 317 m^3/ha. Average stem volume increased from 0.14 m^3 to 1.26 m^3. In Table 2 the yield from all thinning interventions in the

Table 2. Selected thinning concept in a selective phase for stand 802

Age	Future exploitable trees			Species	Secondary stand		
	categ.	quantification			*V*/ha	SKK	SKK
45	CT	number of CT (per ha)	404	beech	27.59	28,198	43,262
		degree of support	1	hornbeam	14.13	5,563	
		mean distance	4.98	maple	2.29	2,317	
				spruce	3.74	7,184	
55	CT	number of CT (per ha)	296	beech	58.09	71,980	162,734
		degree of support	2	hornbeam	14.13	12,610	
		mean distance	5.81	maple	9.91	13,450	
				spruce	31.17	64,694	
65	TT	number of TT (per ha)	204	beech	90.34	135,107	253,420
		degree of support	2	hornbeam	13.76	13,133	
		mean distance	7.00	maple	11.98	22,344	
				spruce	37.45	82,836	
75	TT	number of TT (per ha)	204	beech	53.59	87,686	105,639
		degree of support	1	hornbeam	6.51	6,055	
		mean distance	7.00	maple	7.59	11,898	
					382.27	565,055	565,055

Table 3. Comparison of the stand between the start and end of thinning concept

Species	%	d_m	h_m	*N*/ha	*G*/ha	*V*/ha	%	d_m	h_m	*N*/ha	*G*/ha	*V*/ha
Beech	53	15	16	1,018	18.79	134	47	34.7	27.7	124	11.74	149
Hornbeam	9	15	15	202	3.53	21	1	20.7	22.1	5	0.19	2
Maple	11	15	20	180	3.18	28	14	30.9	29.7	43	3.88	43
Spruce	27	30	24	97	6.92	68	38	51.1	35.8	43	8.83	123
Together	100	16.2	16.9	1,497	32.43	251	100	36.9	29.6	215	24.64	317
Age 45 years							Age 85 years					

selective phase is evaluated on the basis of stand sorting and current wood prices (Ponukový cenník 2000). Total yield of thinnings is 565,055 SKK.

The methodology of virtual forest stand generation is a significant contribution to building the sophisticated systems of modern forest electronic education (e-learning). In Slovakia it is especially important because no similar model has been developed until now. The assumed contributions can be summarised in the following points:

– The model solves some methodological problems that have not been resolved in an adequate way by other systems. It mainly applies to the real looking model of individual trees with real looking crown habit and bark textures for 26 tree species, to the original solution to terrain model implementation on the principle of representativeness for the competitive model, real looking surrounding environment and finally to a high level of interaction between the user and the forest stand environment.
– The connection with the growth simulator SILVA forms a suitable medium for the training of forest tending and in its present version it is ready to be used for forest education purposes. That is why this system has been experimentally introduced into the education process for subjects such as Silviculture and Forest Management at Forestry High School in Banská Štiavnica.
– This system is built on VRML 97 language basis and thus it is possible to integrate it into the Internet environment. Its connection with forest management information system **LesHIS** (FABRIKA 2002a) and with the general Slovak forest information system **GOLEM** is assumed (FABRIKA 2002c). In the years to come the system can be a modern tool not only for e-learning but also for decision support and prognostic purposes.
– The model of virtual forest stand will be a part of the Slovak simulator for forest biodynamics "**SIBYLA**" developed on the basis of growth model SILVA SK and a part of the envisaged thinning training tool "**TREVYL**".

The designed methodology is a considerable contribution to the three-dimensional modelling of virtual forest stands and forestry e-learning. For its wider application in the education process and forest information systems it will be necessary to resolve several methodological and applied questions as automated connection with forest data bank (forest management plan, geographic information system), completion of extension modules, development of methodological instructions in the field of education, completion of virtual reality in the field of forest mensuration (methodology of sample plot establishment for stand forest inventory), promotion of this system into the Internet environment for "remote access" and so on. The new problems of standards for improving the virtual reality will be researched in a longer time span: flow data transmission, multiuser environment, direct support of programming languages and others (ŽÁRA 1999).

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Virtuálny lesný porast ako súčasť sofistikovaných lesníckych vzdelávacích systémov

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ABSTRAKT: Príspevok prezentuje metodiku generovania virtuálnych lesných porastov. Virtuálny porast slúži pre lesnícke elektronické vzdelávanie (e-learning) ako nástroj pre tréning výchovy lesa a demonštráciu rôznych porastových štruktúr a rôznych dendrometrických postupov. Model je možné prepojiť s rastovým simulátorom a integrovať do prostredia geografického informačného systému, prípadne do prostredia Internetu. V prvej časti príspevku je predstavená metodológia vizualizácie jednotlivých stromov, celých porastov, terénu a okolitého prostredia, ako aj princíp interakcie užívateľa s virtuálnym lesom. Pre účely tvorby virtuálneho porastu bol použitý jazyk VRML 97. V druhej časti je predstavený príklad použitia modelu pre tréning výchovy lesných porastov.

Kľúčové slová: vizualizácia lesa; modelovanie lesa; e-learning; VRML 97; prebierkový trenažér

V lesnícky vyspelých európskych krajinách sa neustále zdokonaľujú modely a softwarové systémy pre simuláciu a prognózovanie rastu lesa (PRETZSCH 1992; HASENAUER 1994; STERBA 1995; NAGEL 1996). Neoddeliteľnou súčasťou uvedených modelov a počítačových programov sú nadstavbové moduly pre vizualizáciu lesa. Umožňujú sprehľadniť výsledky simulácií a vizuálne zachytiť dynamiku vývoja lesných porastov. Novým trendom využitia týchto modelov je prienik do oblasti výchovy a vzdelávania lesníckej verejnosti. S tým súvisí prechod od statickej vizualizácie lesa k dynamickému virtuálnemu lesnému porastu. Cieľom príspevku je predložiť metodiku na generovanie virtuálnych lesných porastov a predstaviť jej praktickú realizáciu. Navrhovaný systém bude súčasťou rastového simulátora „SIBYLA“ a prebierkového trenažéra „TREVYL“ budovaného na Katedre hospodárskej úpravy lesov a geodézie Technickej univerzity vo Zvolene v rámci informačného systému pre užívateľa lesa (FABRIKA 2002a).

Pri vývoji nástroja pre generovanie virtuálnych lesných porastov bolo vyriešených niekoľko metodických otázok: voľba softwarovej platformy pre virtuálne lesné porasty, spôsob vizualizácie jednotlivých stromov, spôsob pre generovanie celého porastu na báze bežne dostupných porastových informácií, spôsob implementácie a vizualizácie terénu z digitálneho modelu v prostredí GIS, vizualizácia okolitého prostredia pre dokonalý virtuálny zážitok a napokon zabezpečenie interaktivity užívateľa s prostredím virtuálneho lesa.

Pre účely tvorby virtuálnych lesných porastov sme zvolili platformu jazyka VRML 97 (CAREY, BELL 1997; ŽÁRA 1999). Pre vizualizáciu jednotlivých stromov sme využili model vizualizácie, ktorý vychádza z najmodernejších postupov používaných pri vývoji najnovších 3D počítačových hier. Princíp je zobrazený na obr. 1. Strom bol rozdelený do troch častí: kmeň, koruna a koreňový nábeh. Kmeň a koreňový nábeh sú tvorené do seba zapadajúcimi kužeľmi. Koruna je vytvorená štyrmi rovinami, ktoré sú pootočené o 45°. Reálny vzhľad stromov bol zabezpečený kvalitnými textúrami. Parametre geometrických objektov sa vypočítajú na základe vzťahov (1)–(3). Celkovo bolo vytvorených 26 prototypov drevín. Príklad niektorých je na obr. 2.

Na generovanie štruktúry porastu z bežne dostupných informácií o lese (napríklad lesného hospodárskeho plánu) bol použitý generátor štruktúry porastu. Model vychádza z generátora STRUGEN (PRETZSCH 1993), ktorý bol prispôsobený pre slovenské podmienky. Na generovanie hrúbkových početností bol použitý vzťah (4), výšky stromov sú odvodené z jednotnej výškovej krivky (5), parametre korún sa dopočítajú podľa rovníc (6)–(7). Princíp generovania polohových súradníc je znázornený na obr. 3.

Model terénu pre virtuálnu plochu porastu sa extrahuje z vrstvy GIS podľa obr. 4. Z extrahovanej plochy sa odvodí sieť 5 × 5 m (lattices). Sieť sa použije na odvodenie výškových súradníc stromov na základe bilineárnej interpolácie (8)–(10). Terén sa vizualizuje pomocou racionálnej Bézierovej plochy (obr. 5).

Metodika tvorby virtuálneho lesného porastu rieši aj otázky pozadia, osvetlenia, viditeľnosti a ozvučenia. Rovnako je zabezpečená aj interaktivita užívateľa s prostredím virtuálneho lesa (identifikácia parametrov stromov, vyznačovanie stromov a ich ťažba, komunikácia s rastovým simulátorom).

Metodika virtuálneho lesného porastu bola vyskúšaná ako nástroj pre tréning výchovy porastov „prebierkový trenažér“ na poraste Vysokoškolského lesného podniku Zvolen č. 802. Popis jednotlivých zásahov pokusnej prebierky je v tab. 2. V tab. 3 je zobrazené porovnanie stavu porastu na začiatku (45 rokov) a na konci (85 rokov) prebierkového režimu.

Navrhovaná metodika je významným prínosom k problematike trojdimenzionálneho modelovania virtuálnych lesných porastov a lesníckeho elektronického vzdelávania. Pre rozsiahlejšie zavedenie do vzdelávacieho procesu a lesníckych informačných systémov bude potrebné vyriešiť niekoľko ďalších metodických a praktických otázok ako je automatizované prepojenie na banku lesníckych údajov (lesný hospodársky plán, geografický informačný systém), dokončenie rozširujúcich programových modulov, vypracovanie systému metodických pokynov pre oblasť vzdelávania, dopracovanie virtuálnej reality pre oblasť dendrometrie (metodika zakladania skusných plôch pre maloplošnú inventarizáciu lesa), nasadenie systému do prostredia Internetu pre „vzdialený prístup“ a podobne. V dlhšom časovom horizonte sú otvorené aj otázky nových štandardov pre zdokonaľovanie virtuálnej reality, a to: prúdového prenosu dát, viac užívateľského prostredia, priamej podpory programovacích jazykov a ďalších.

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