Riverine Operations: Modeling and Simulation

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Abstract. This work presents a riverine environment combat simulation system model, providing a way to evaluate Brazilian Marines behaviors, actions, and decisions made in a military riverine operations.

Keywords: Riverine Operations, Warfare Games, Military Modeling and Simulation.

1 INTRODUCTION

Training a Marine is an extremely complex task. The marine needs to be able to plan and carry out military operations of different kinds. Computer simulations have an important role in this training because they provide a reduced cost way of experiencing several combat situations, since there is no waste of fuel, ammunitions or armament [4].

Besides, operations can be planned and tested as much as necessary without the tire out of the troops in the field. It is also possible to exhaustively test the planning of a specific operation, evaluating several enemy possibilities, for posterior use of the forces either in a real training or a combat situation [6].

Marines usually perform different kinds of operations. Among others, the Riverine Operation stands out because of its complexity. Such complexity is mainly due to the variety of regions that may be included under the concept of riverine region and its characteristics, including reduced visibility, limited ground communications and extensive water surface, which is the main route of local transportation. Besides, both tidal variations and flooding substantially affect the navigation along those waterways [2].

Just as an illustration, we provide below an imaginary situation suitable for a Riverine Operation:

> "A guerrilla group from Country A is positioned in the Region B surmounting the authority of its govern and threatening the local population. Now, they are supplying drugs to other countries in the continent through the River C. International pressures require the local government to halt the guerrilla actions."

This paper aim to specify the modeling of a combat simulation tool in riverine areas, independently of their differences, in such a way that it is possible to evaluate the marines behavior, actions, and decisions taken during a riverine operation.

2 MODELING

In order to have control over a riverine environment navy forces must be able to move efficiently along the terrain and through the rivers, sometimes facing both natural and artificial obstacles, poisonous animals and regional diseases that are characteristics of such environment. In general, this control may include actions as fire support over the enemy, as well as engineering tasks. At the same time as cooperating with the local population it is also duty of the navy forces to inhibit the development of the narcotic and the guerrilla focuses, both internal and external to the country, which are very common in frontier regions [5].

2.1 Terrain

There are two riverine areas in Brazil showing a wide range of contrasting characteristics: the Amazon and the Pantanal.

In the Amazon, the balance between the jungle and its dense and varying forest makes difficult the ground visibility and prevents both the air support and the use of combat and transportation vehicles. The plentiful hydrography, comprehending the denser fluvial basin in the world, requires the riverine operations to concentrate mainly along the rivers, with aircrafts doing just identification flights. Ground incursions may occur only after some anomaly identification in the region (as significant increasing of the number of buildings or illegal airfields, for example) and validated the need of an inspection.

The Pantanal is the largest extension of continuous

Figure 1: Amazon, the denser fluvial basin.

wetland of the globe, constituting a huge plain of flooding areas in the rain season. Contrasting to the Amazon, where the ground conditions are constant along the whole year, the Pantanal changes a lot between the dry and rain seasons. This transformation is drastic that it becomes impossible to navigate in certain rivers and flooded areas become broad dry lands. In the riverine operations in the Pantanal the use of combat and transportation vehicles, as well as aerial support, is substantially greater.

The solution chosen for modeling such varying terrain was quite simple. It was necessary a satellite image, a quantification algorithm, such as median-cut, and to determine the number of different kinds of terrain we want to include in the simulation.

Satellite images will determine the algorithm precision. If a high quality satellite image (in a scale of 1:2000, for instance) is used, the algorithm will show grate results. If a poor quality satellite image (in a scale of 1:50000, for instance) is used, the algorithm will lose precision, but you still get good results for a simulation.

Figure 2: Pantanal, the largest wetland

Figure 3: Satellite image of Amazon

The goal of the quantification algorithm is to reduce colors in the satellite image to a know number of kinds of terrain that are relevant to the simulation. For example, if you are using a satellite image of a region that has three kinds of terrain (forests, rivers and bare areas) that are relevant to your simulation, you will reduce your satellite image colors to three colors. After that, you will notice that the rivers has a color, forests are in another color and bare areas received the last one. Of course, you can't say that if a point on the image has a color of forest, so the exactly same point on the terrain will be a forest, but it's a nice simplification approach.

By kinds of terrain we mean, portions of the main terrain that have common characteristics like vegetation, trafficability, camouflage, noise propagation among others. Amazon, for example, is composed by many kinds of terrain like dense forests, light forests, rivers, river shores, some bare areas, farms, etc.

Apply the quantification algorithm on the image (Figure 3) reducing the number of colors to the number of terrain types chosen (dense forest, fields, roads, for example). Each color in the new palette is associated to a kind of terrain (Figure 4) and its characteristics (permissibility, mobility and noise propagation, among others) through a configuration file in such a way that these characteristics could be tested and changed in the next simulation without problems, adjusting its values to the real world.

With this simple approach we were able to model complex effects such as the influence of the vegetation over the visibility of a combat element, the difficult of moving in flooded ground, among others.

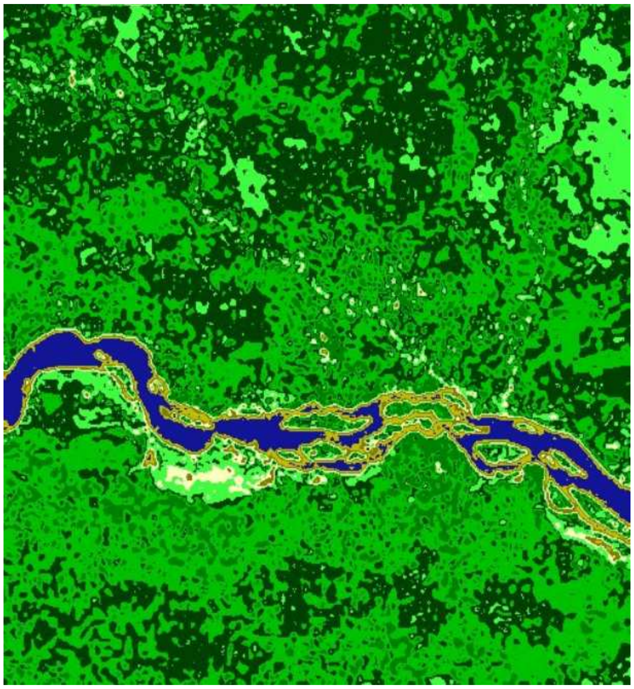

Figure 4: Quantized satellite image of Amazon

2.2 Rivers

The rivers play a crucial role in a riverine operation and are easily identified using the terrain classification technique described above, due to the predominance of the blue color in the image. However, in order to the rivers play correctly their role in the simulation it is necessary to model the streams. To accomplish this task it was necessary to create oriented line segments along the riverbed and attribute a stream velocity to each segment. When an element moves along the river its velocity is affected, positively or negatively, according to the segment he is moving over.

2.3 Movement

A movement is formed by a set of one or more path-segments (straight line segments that possess initial and final coordinates). When an element moves, we determine the amount of time it will need to move and the direction of the movement is set to the same direction as the path-segment. A traversal path algorithm is then used to determine which *pixels* of the quantized satellite image representing the terrain will be used along the path the element will take. Each *pixel* determines the velocity of the element in that position and, if at some moment the velocity reaches zero it means that the movement was halted by the terrain. In other words, it means that the element has reached a terrain obstacle, as a riverbank or a foothill, for instance. When an element reaches the end of a path-segment, its position is set to be the initial coordinates of the next path-segment, eliminating any possible approximation errors, and the finished path-segment is removed.

2.4 Detecting combat elements

A probabilistic model was used for detecting combat elements. For each pair of enemy combat elements (the detection of a friendly element by other is not relevant to the game) we verify the *pixels* existent between the combat elements using the same path algorithm used for moving. Now, each *pixel* controls the probability of detecting an element through the vegetation. The product of detection probabilities determines the probability of a combat element been detected (P prob.). As the probability of one element see other is not the same for both elements, we must multiply one of then by a factor. Let's suppose two different elements A and B. If the probability of see a element over the kind of terrain of A (A prob.) is lower than the probability of see a element over the kind of terrain of B (B prob.), A has more camouflage possibilities than B, the factor is the reason between A prob. and B prob. and will reduce the probability of B see A. If B has more camouflage possibilities than A, then the factor is the reason between B prob. and A prob. and will reduce the probability of A see B.

For example, if A is inside a dense forest with a probability of be detected of 0.25 and B is over a bare area with a probability of be detected of 0.75. Suppose that the P prob. is 0.5. i The factor of correction will be:

$$\frac{0.25}{0.75} = 0.33$$

Then, applying the factor over P prob. results that the probability of B see A is:

$$0.33 \times 0.5 = 0.16$$

and probability of A see B remains P prob.

As the visibility in an riverine operation is reduced, the detection becomes a crucial factor for the possibility of occurrence of confrontation between two combat elements. This happen because when an element detects an enemy this enemy has already been in the range of its weapons for a long time. So, we can identify a possible engagement for any detected combat element.

2.5 Engagement

The engagement routine is, for sure, one of the most complex routines in the system. During an engagement, it is necessary to know which weapons are been used, the amount of ammunition to be used, the lethality of each weapon when using specific ammunition (some ammunition, like smoke grenades, present zero lethality), which shots have reached the target and the fatalities imposed to the enemy.

This modeling is characterized by a large lack of information. In addition, it was not possible to find a mathematical model that satisfactorily represent the results of a combat between a conventional force correctly trained (marines) and a non- conventional force (guerrilla or drug dealers, for instance), determining the fatalities in both sides.

Frederick Lanchester has established a system of differential equations that intends to quantify the fatalities in a battle. The system is based on the principle of that the losses imposed to one of the forces is proportional to the number of elements in the other side.

$$\frac{dx}{dt} = -aY$$
$$\frac{dy}{dt} = -bX$$

where a and b are the efficacy coefficients of the forces Y and X, respectively.

The main drawback in Lanchester's model is the fact that the correct values of a and b are unknown because they depend on the characteristics of the weapons, on the capacity of reaction of the elements and also on the degree of efficiency of the command, coordination, control and communications [1].

A good way of starting an engagement model is to determine how the combat power (PCA), the firepower of each combat element, will be calculated. In order to perform such calculation we choose the following equation

$$PCA = \sum_{i=1}^{allweapons} (qtde(i) \times cad(i) \times let(i))$$

where $qtde$ is the amount of weapons, cad is the cadence of the weapon and let is the lethality of the weapon when using specific ammunition.

It is known that the ratio between the combat power of a conventional force and that of a guerrilla must be $10:1$, which means, it is necessary to the conventional force to have a combat power ten times greater than the guerrilla [3].

Adapting Lanchester's equations we obtain to the calculation of the fatalities, in both guerrilla and conventional force, the following equations

$$\frac{dx}{dt} = -gxy$$
$$\frac{dy}{dt} = -cx$$

Combining the above equations, we get

$$\frac{dy}{dx} = \frac{c}{gy}$$

after integrating it becomes

$$gy^2(t) = 2cx(t) + M$$

or yet

$$M = gy_0^2 - 2cx_0$$

where x and y are, respectively, the number of combat elements in the guerrilla and the conventional forces, while g and c are, respectively, constants that define the guerrillas and conventional forces efficiency.

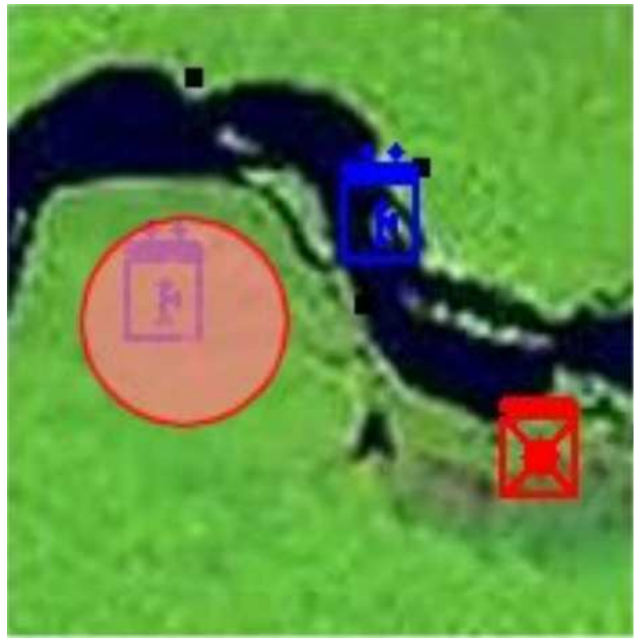

Figure 5: Aerial fire visualization.

If $M < 0$ then the guerrilla wins. If $M > 0$ the marines win. If $M = 0$ there is a tie between the opposite forces.

For usual values of c and g, one can conclude that

$$\frac{y}{x} \approx \sqrt{\frac{2c}{gx}}$$
$$y \approx 10x$$

Solving the equations correctly will produce the amount of fatalities and material losses occurred during the engagement of the conventional and guerrilla forces.

2.6 Fire Support

The fire support consists in realizing a sequence of fire in a region defined by its coordinates. Those fires can be provided by vessels, aircrafts or even terrestrial elements. When the fire support is provided by aircrafts it is named Approximated Aerial Support.

For calculation it is necessary to verify if the target is inside of the weapons range. In the affirmative case, a normal distribution of shots in terms of the target is calculated. Then, the percentage of the target reached is calculated and consequently we obtain the amount of fatalities and material losses (Figure 5).

2.7 Aerial Support

The aerial support consists in using aircrafts (helicopters or aircrafts) to perform supporting tasks for the mission. Those tasks may include either logistics and reconnaissance operations or even attack to previously determined targets. Although in the Amazon the dense vegetation makes almost impossible the use of aerial support, but its use in the

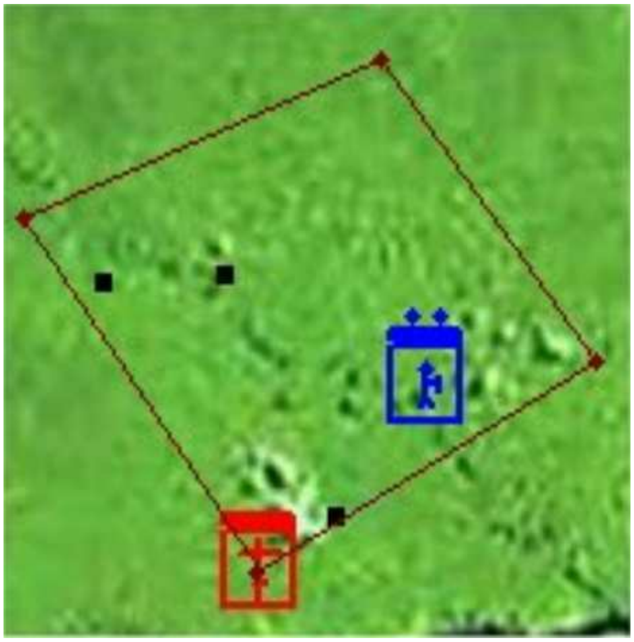

Figure 6: Aerial reconnaissance path-segments

Pantanal region is quite feasible. In order to perform an aerial support, the user must determine the type of aircraft that will be used, the path to be followed (Figure 6) and the type of aerial support he desires.

In the case of a logistic aerial support, the required supplies are deducted from the supply vessels and added to the transporting aircraft. Then a movement is set to the aircraft according to the path determined by the user. Reaching the destination, the supplies are deducted from the aircraft and added to the terrain. When a combat element approaches the terrain containing the supplies, these are deducted from the terrain and added to the combat element.

The case of aerial attack, supporting either terrestrial or marine unities, is quite similar to the previous case. However, when reaching the destination (target) a fire support (see 2.6) is started.

If the aerial support is for reconnaissance, the detection algorithm (see 2.4) performs the necessary calculations for identifying the elements seen by the aircraft.

2.8 Patrol

Patrolling is a widely used activity in riverine operations. There are two different types of patrolling: reconnaissance and combat. These are quite distinct behaviors.

A reconnaissance patrol travels around a previously defined area in the terrain, informing the enemy's position every time it detects one. The patrol does not take any offensive action and avoids confrontation at all costs. A combat patrol also travels around the terrain, however, every time it sees the enemy, it follows them until they have been eliminated or the pursuit is not possible anymore. A pursuit may be interrupted when the enemy is not visible or the patrols cannot move due to the terrain conditions.

When the enemy is previously detected it is possible to the patrol to set up an ambush, camouflaging it the bushes and waiting for the enemy. Ambushes are widely used by guerrillas and increase the combat power of an element, since it uses the surprise factor. The guerrilla fighter is characterized by avoiding the direct confrontation with conventional forces and, usually, they set up ambushes causing some fatalities in the enemy's force and quickly escaping. Such fatalities delay troops' progress and reduce its moral and motivation.

At every movement the patrolling combat element tests if any enemy was seen and assumes the corresponding behavior, which depends on the type of patrol. The agent model has proved to be very efficient for such implementation [7].

2.9 Engineering Tasks and Obstacles in the Terrain

The engineering tasks and the obstacles in the terrain play an important role in the riverine operation because it is common to find, in a riverine combat setting, mines, pitfalls and improvised bridges.

The implementation of these obstacles must be done in such a way that changes the mobility of the combat element in the terrain. We have chosen that a combat element must have its velocity reduced to zero and suffer some fatalities in case of finding a mine. A combat element crossing the river using a bridge built as an engineering task keeps its velocity in despite off been over the water. A suitable way of implementing such obstacles is to change the satellite image. If we desire to build a bridge over a river, it is only necessary to change the colors of the *pixels* related to the bridge to the same color as the terrain (Figure 7). However, is we want to launch a bridge over a mined field it is only required to set the bridge's *pixels* with a color that corresponds to a zero velocity.

2.10 Fluvial Blockage and Passage

The fluvial blockage is the closure for transit of a specific portion of the river, allowing inspections of the boats looking for smuggling and guaranteeing the security of military installation (aerial and ground operation bases) and vessels localized in that region. A passage is set along the river's margin where the blockage is localized (Figure 8). A passage is an area of the fluvial blockage where the transit of vessels is allowed.

2.11 Regional Diseases

The riverine environment is quite favorable to concentration of dangerous bugs, poison animals and regional diseases. It is important to consider such agents during the simulation because they push the simulation closer to the reality, developing the sense of care.

An efficient modeling technique is the use of a probability model for troops contamination and fatalities, caused by such agents, in a previously defined area. Contamination probabilities must be low since the number of combat elements in a riverine operation is small and fatalities caused by those agents would make operations unfeasible.

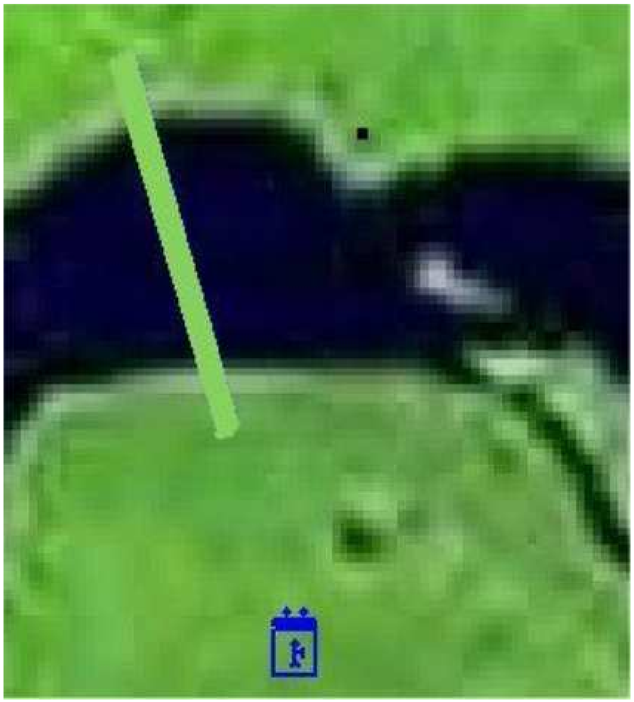

Figure 7: Representing a bridge over a river.

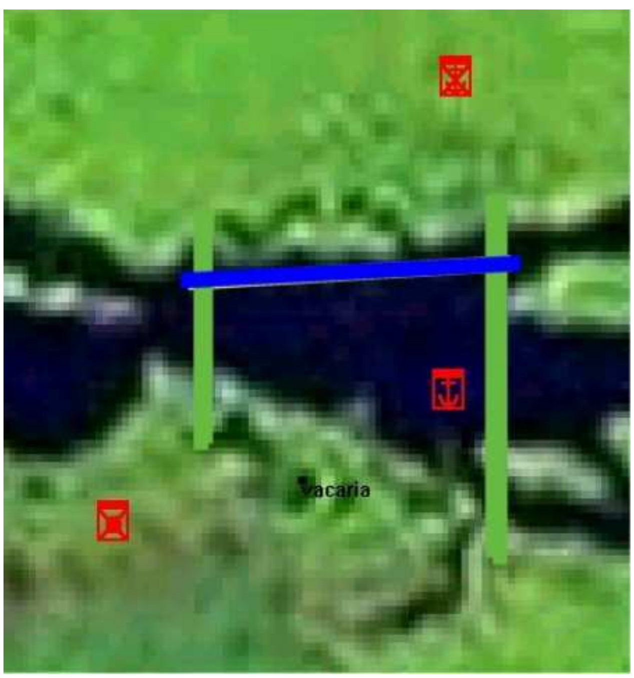

Figure 8: Fluvial blockage visualization.

2.12 Divers

Combat Divers are extremely dangerous elements in a riverine operation. A unique combat diver is able to be infiltrated close to his target by aircrafts, ground vehicles, boats or vessels. The combat diver approaches its target without being noticed using extremely quiet scuba gears, which makes no bubbles (closed circuit). This characteristic allows them to start the actions and surprise the enemy, causing damages in vessels, placing explosives and even performing rescue operations.

The explosives are modeled by engineering tasks that insert fire support on that specific position after a chosen time interval, simulating a timer.

2.13 Riverine Population

As the rivers are the main communication way in riverine environments, the transit of local population using different types of boats is quite intense. It is also common the flux of people along tracks connecting several types of settlements (farms, plantations, harbors). The interaction with this people is the major advantage of the riverine operation simulator. The locals constitute the best camouflage to the guerrilla because they can be easily confused. In addition, the locals can be convinced to work to the guerrilla or even join them, considering the poor life conditions in the region.

Local boats can transport weapons, narcotics or even guerrilla from on settlement to others. During a riverine operation, the marines try to perform social aid jobs to the local people in order to minimize the influence of the guerrilla. A suitable modeling of riverine transit is a consistence step toward an efficient simulation.

A way to simulate the riverine transit is to require that neutral elements be constantly created during the simulation and move from place to place. A place can be occupied by guerrilla, marines or simply be unoccupied. If a local reaches a place being occupied by guerrilla, its tendency to the guerrilla side increases. On the other hand, its tendency to guerrilla reduces in the case of the place be occupied by marines. A neutral element (a local) becomes a guerrilla if its tendency to guerrilla reaches 100%.

2.14 Residues in the River

It is quite common to find residues, such as rest of plants, following the river's currents. Such residues constitute an amazing opportunity of camouflage for combat elements, as well as for drugs and weapons.

The residues must be created by the system from time to time during the simulation, and must have a movement related with the river's current. It must be possible to hide combat elements, drugs and weapons in the residue.

3 ARCHITECTURE AND IMPLEMENTATION

The Riverine Operation Simulation System is a program that simulates, in real time, a conflict situation. The system is composed basically by 3 modules:

- Execution module - the core (engine) of the system.
- Interface module - how the user interacts with the system.
- Persistence module - how the information will be stored, recovered and consulted synchronously by user logged in different workstations.

The execution module was developed in C++ using the DBGraf [8] library and it is where all calculations needed by the simulation (like movements, engagements and detections, for instance) are executed through cycles of actions. For each action there is a cycle where the data from the persistence module is stored in tables of objects needed to the action, modified and placed back into the persistence module.

The interface module was developed in Lua [11] using IUP [10] and DBLua [9] libraries for interface implementation and communication with persistence module, respectively. There are 3 distinct types of files in this module: interface files, action files and database communication files.

The interface files contain just the statement of the elements composing the interface and its links with related actions. The action files contain the actions related to each interface elements (the action to be executed when click a specific key). The database communication files present the functions that get the data and return it stored in Lua tables.

The interface module tells the user how to input the data required by the actions and how to visualize the system's answers and the simulation progress.

The persistence module is where all information is stored. All actions input by the interface module are kept in this module, as well as changes in the data calculated by the execution module. So, the persistence module works not only as a data keeper (its original function), but also as a connecting layer between the execution and interface modules. The persistence module has a completely passive role in the program. It is only used for consults, actualizations and data input, which is the role of the majority of existing databases.

4 CONCLUSION

Computer simulations are important teaching tools for knowledge evaluation, specially the ones who aim to simulate the real conditions of a military operation, training officers to take the right decisions in complex situations.

The described modeling offers, in a unique system, the mapping of the real characteristics of two types of terrain, like Amazon and Pantanal, which besides their differences are classified as riverine, increasing the realism of the simulation.

The main advantage of the proposed architecture is that the system is divided into 3 independent modules. Therefore, the development, maintenance and use of a specific module does not implies in changes in the others, making easier the evolution of the system.

In pacific countries, like Brazil, didactic military simulations constitutes fundamental part in the formation of both officers and privates from Marines, providing a way to evaluate and improve their training. The computers have enlarged the possibilities of military simulations and have been successfully used along several years in Brazilian Marines.

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