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Applying domain decomposition to wind field calculation

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ABSTRACT

Forest fire are natural hazards that every year cause significant looses. Predicting the evolution of a forest fire is a critical issue in mitigating its effects. Such predictions must accomplish strict real time constraints to be effective. Wind field calculation is a key issue in providing accurate forest fire propagation predictions. However, it implies solving large linear systems with 10^5 to 10^8 variables that takes too long using conventional methods. Therefore, the domain decomposition Schur method has been applied to accelerate wind field calculation. Using the Schur method, the linear system is significantly reduced and several phases can be parallelised exploiting cluster computing capabilities. Results show that the execution time for the wind field calculation of a map of 800 × 800 cells has been reduced from 400 s to 90 s using 10 nodes.

1. Introduction

Forest fire is a natural disaster that burns thousands of hectares around the world every year, destroying ecosystems and prolific areas and causing significant economic and social losses. Therefore, it is necessary to provide extinction services with the best means of mitigating the effects of such hazards. In this context, forest fire propagation prediction appears as a very significant contribution to allow extinction services to use the available resources in the best possible way. Several models have been developed and integrated in computer simulators (FARSITE[7], FireStation[12], Wildfireanalyst [14] or CARDIN [13]) to estimate forest fire propagation.

These propagation models, and the consequent simulators, need a large set of input parameters describing the actual scenario in which the fire is taking place. These parameters include a terrain elevation map, a vegetation map and the features of said vegetation, an initial fire perimeter, and meteorological conditions. Therefore, running simulations to predict forest fire propagation requires the integration of different data acquisition methods and several adapters to transform data to the required format. The input parameters can be classified, according to their features, into four different classes:

1. Digital elevation maps can be obtained from different sources at different resolution degrees (100 by 100 m, 30 by 30 m or even 10 by 10 m). Elevation maps can be considered constant since they do not change over time. The higher the resolution, the more accurate the map is, but for forest fire prediction purposes 30 × 30 m appears to be an adequate resolution.
2. Vegetation maps can be obtained from soil use maps available from different sources, but, in this case, there are different issues to be considered. Several vegetation types have been identified depending on the vegetation species

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and the amount, mass and height of the vegetation. However, in some cases, there is a very slight difference between two vegetation types and soil use maps are sporadically updated. This means that the vegetation evolves dynamically between the two map soil estimation. Moreover, there are certain features, such as the moisture content of the vegetation that change quickly depending on weather conditions (precipitation, clouds, temperatures, wind,...) and modify fire behaviour. So, the vegetation parameters can only, in the best case, be approximately estimated and present a certain degree of uncertainty that introduces uncertainty in forest fire propagation prediction.

3. The initial perimeter can be obtained from satellite images, airborne images or located by the direct observation of extinction services. In the case of airborne images or extinction services observation, it is very important to provide an accurate geo-reference of the fire front.
4. Meteorological conditions change dynamically over time, and certain meteorological parameters can be obtained from predictions of meteorological services at a low resolution (2500 by 2500 m).

Each input parameter of forest fire propagation simulators requires its own treatment and careful analysis, but, in general terms, it can be concluded that there is a lack of accuracy in input parameter estimations. This lack of accuracy in the values of the input parameters provokes a mismatch between forest fire propagation predictions and real fire propagation. It is clear that the accuracy of the prediction provided by forest fire propagation simulators depends largely on the accuracy, acquisition frequency and resolution of all of these input parameters. So, it is necessary to introduce new estimation methodologies and to couple complementary models in order to improve data accuracy, acquisition frequency and resolution.

It is well known [1,16] that two of the input parameters that most significantly affect fire propagation are wind speed and wind direction. So, it is critical to provide the best possible value for such parameters to provide the best possible propagation prediction. However, wind speed and direction are parameters that present two significant features that make them difficult to estimate precisely:

1. Dynamic wind variation: Wind does not present a constant speed and direction, but it varies significantly from one time interval to the next. Meteorological models [19] can provide wind prediction, but the time step (output) of the meteorological model is provided, at maximum, every hour (usually every 3 or even 6 h). So, concerning forest fire propagation prediction, wind speed and direction are considered to be constant during this time interval. So, it would be necessary to obtain more frequent meteorological estimations, but reducing the meteorological model time step increases execution time dramatically.
2. Topographic wind distribution: Meteorological wind is modified by terrain topography. Wind parameters provided by a meteorological model (such as WRF) at a 2500 by 2500 m resolution do not consider the effect of the topography of the terrain on wind parameters and introduce inaccuracy in forest fire propagation models. Therefore, it is necessary to couple complementary wind field models that, given a meteorological wind at a low resolution, can provide a complete wind field at higher resolution (100 by 100 m or even 30 by 30 m). The wind fields generated by such wind field simulators take into account the effect of the topography of the terrain on meteorological wind. Coupling a wind field model with forest fire simulators provides more accurate forest fire propagation prediction [4]. But, wind field simulators are also time consuming applications that must be parallelised to become useful in real time operation.

So, this work focuses on applying domain decomposition to accelerate wind field calculation and coupling the wind field simulator to a forest fire propagation simulator. The forest fire simulator selected is FARSITE [7] because it is extensively validated and is widely used throughout the firefighting community. Taking into account that the forest fire simulator used is FARSITE, the wind field simulator chosen is WindNinja [8,10] because it can accept the same input files as FARSITE and can generate wind field files that can be directly used by FARSITE. So, it is very easy to couple WindNinja and FARSITE [3]. This coupled scheme is shown in Fig. 1.

In Section 2 the main features and limitations of the WindNinja wind field simulator are described. Section 3 presents the domain decomposition Schur method. Section 4 shows the application of the Schur method to wind field calculation and presents the results of the experimental study that has been carried out. Finally, Section 5 summarises the conclusions of this work.

2. WindNinja

WindNinja [9] is a wind field simulator based on mass conservation equations that determines the wind at each point of the terrain, given the meteorological wind speed and direction.

WindNinja is based on the equations that describe air flow variation in the atmosphere. Specifically, it is based on a mass conservation model initialised by boundary conditions. The function to minimise is constructed using the square of the difference between the adjusted and observed values as is shown in Eq. (1), where u, v, w are the velocity components in the x (positive to East), y (positive to North), and z (positive upward) directions, respectively. The initial values of velocity are u^0, v^0, w^0. Furthermore, $\lambda(x, y, z)$ is a Lagrange multiplier and α_1 is the Gauss precision moduli.

$$E(u, v, w, \lambda) = \int \left[(\alpha_1)^2 (u - u^0)^2 - (\alpha_1)^2 (v - v^0)^2 - (\alpha_1)^2 (w - w^0)^2 + \lambda \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) \right] dvol \qquad (1)$$