論文 / 著書情報
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題目(和文)	GPGPUによる雪崩流動の高速解析と人体流動連成解析の組合せによる雪崩ハザードマップの高度化
Title(English)	Improvement in snow avalanche map by the combination of runout simulations with a rapid GPGPU-based snow avalanche model and assessment of injury risk with coupled human-flow model
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The title of this doctoral dissertation is “Improvement in snow avalanche map by the combination of runout simulations with a rapid GPGPU-based snow avalanche model and assessment of injury risk with coupled human-flow model”. The summary of each chapter is shown in the following:

Chapter 1 – Introduction
This chapter introduced the importance of snow avalanche mitigation, insufficient information for some target users or overlarge dangerous regions defined by a single topographical parameter in the current official snow avalanche map in Japan, and the studies regarding snow avalanche map generation and its limitations in the computation efficiency and trauma vulnerability assessment.

Chapter 2 - High performance computation for snow avalanche model
This chapter develops a snow avalanche model with the parallel computation technique of GPGPU to reduce the computation time for simulation. The model describes the snow flow motion using shallow water equation and Vollemy-Salm rheology in a Cartesian Global Coordinate. The GPGPU technique is implemented for parallel computation. With many more ALUs, GPU enables achieving high throughout and massive computation when parallel computing. The model reproduces the Mt. Nasu event. The recreated mainstream path and the estimated stopped point of victims reflect the investigation report and rescue point. The calculation cost for each process and the execution time computing on CPU and GPU are discussed. Using the GPGPU technique for computation can be accelerated 80 times faster than CPU computation. The output and data transfer are the slowest processes when computation and are suggested to be reduced to achieve high-performance calculation.

Chapter 3 - Massive computation for snow avalanche map generation
This chapter presents the process of terrain mapping by considering multiple parameters and utilizes the snow avalanche model developed in Chapter 2 to calculate avalanche runouts and determine hazardous areas. The potential release area is identified by parameters of slope, aspect, curvature, ruggedness, fold, and land cover. The total of 123 potential release areas (PRAs) is defined in the target region - Mt. Nasu. The release depth for each PRA is evaluated by 3-day snowfall with elevation correction. The total time for simulation on GPGPU takes about 6.5 hours for 123 cases, reducing the expected computation time of 21.4 days on a CPU. The GPGPU technique reduces calculation time, allowing for quicker updates to conventional maps.

Chapter 4 - Prediction of maximum impact force on a human-shaped object
This chapter simulates a series of human-snow avalanche interactions and proposes an empirical equation for impact force prediction. The study assumes snow and air as an incompressible flow, considers snow as Bingham fluid, and simulates human-snow avalanche interaction by a coupled human fluid model. The mobility decreases the impact force on the movable human-shaped object and obtains kinetic energy from a snow avalanche. This characteristic weakens the hydrostatic force, causing difficulty in evaluating the impact force in a general way. Thus, a new prediction equation for a movable human-shaped object is proposed with energy conception in different depths. This empirical equation enables to estimate maximum impact force on a movable human-shaped object in various flow conditions.

Chapter 5 - Application of injury criteria for snow avalanche map
This chapter correlates the relation between the maximum impact force and trauma and then evaluates the fatality rate for vulnerability mapping. The study utilizes AIS (Abbreviated Injury Scale) to estimate the injury severity for head and thoracic trauma

and identify whether one gets injured via the injury probability curve. The results show that the most severe injury caused by the snow avalanche flow is thoracic trauma. A trauma vulnerability assessment in Mt. Nasu is demonstrated with simulation results and predicted injury severity. The wider dangerous area is covered, while its value is smaller than expected. Ignoring the collision impact with a rock or tree might be the reason for underestimation. These collisions could cause more severe trauma, multiple traumas, or even a fatality. To achieve an entire trauma vulnerability, it suggests collecting more accurate land cover information and considering trauma vulnerability related to other collisions in future work.

Chapter 6 - Conclusion
This chapter gives the conclusions of the research results and suggestions for future work. The contributions are:

- A snow avalanche model with the parallel computation technique of GPGPU is established with 80 times speed up computation.
- Reducing unnecessary output and data transfer is helpful in achieving high-performance calculations.
- When subjected to a snow avalanche impact, the mobility of the human-shaped object weakens the hydrostatic force and obtains the kinetic energy from part of the avalanche energy.
- An empirical equation for predicting impact force based on energy concepts is proposed for different depths.
- The most severe trauma led by a snow avalanche impact is thoracic trauma.
- The trauma vulnerability for collisions with trees or rocks is suggested to be considered in future work.

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