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主　論　文　の　要　旨

論文題目　**Topology optimization for thermal and flow fields related to lattice Boltzmann method**
(格子ボルツマン法に関連した温度・流れ場のトポロジー最適化)

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論　文　内　容　の　要　旨

This dissertation presents the successful application of the lattice Boltzmann method (LBM) in various fields of topology optimization in fluid mechanics. It shows the applicability in either topology optimization for fluid flow or the structure of material. In the former, the topology optimization for the flow field applied to the various aspects of engineering demands, such as the problem for time-independent and time-dependent fluid flow, as well as concerning the minimization and maximization with various functions of interest. This also presents the topology optimization for a single direction flow and multiple directional flows to fit with the needs in engineering design. The novelty of this part is the application of LBM in time-dependent flow with the function of interest that corresponds to the dissipation kinetic energy, which has an essential impact on designing the fluid devices for improving their performances. In the latter, the topology optimization for the material distribution based on the performance of the heat energy conducts infected by the designated function of interest is performed. The original contribution in this work is the successful uses of the LBM in topology optimization for the heat conduction problem, which has a novel contribution to the literature development of the heat energy device. Its performance is, then, directly compared to the one using a conventional method, i.e. the boundary element method. The significant improvement in computation time as compared to the conventional method based is again evaluated the importance of LBM in the topology optimization problem itself in which the high capability of parallel computation in LBM plays an important role and is generally validated in this work.

The topology optimization methods proposed in this thesis are based on the level-set method to update the optimal configurations that have been intentionally optimized by the effect of the function of interest. It is, however, in the former research for the flow field optimization problem, the design sensitivity – the gradient of the function of interest, is derived using the continuum derivative that is based on the continuous adjoint lattice Boltzmann method (ALBM). As a result, the design sensitivity ends up with the continuous form containing the microscopic variables. Nevertheless, in topology optimization based on the level-set method, the gradient information of the function of interest used in the level-set method is more natural to compute with the macroscopic variables such as macroscopic density, macroscopic pressure, macroscopic velocity, or macroscopic temperature. Therefore, in the latter research, the more rigorous topology optimization based on the level-set method applied to the heat conduction is constructed wherein the gradient information of the function of interest is computed by the topological change. This computation is entitled as the topological derivative. The topological change in this work corresponds to the removing/inserting an infinitesimal solid circular from/to the original domain. As a consequence, the topological derivative only consists of the macroscopic variables such as macroscopic temperature and the adjoint temperature. The validation of this proposed methodology is done through several numerical demonstrations consisting of direct comparisons with one found in literature wherein the conventional method is used. The performance of this method is also compared to the previous research wherein the conventional method is used instead of the LBM in the current work. The significant improvement in computation time is, thus, sufficiently certified.

This thesis also covers several theoretical concepts in fluid mechanics, especially, for the theories of Navier-Stokes flow and the heat conduction. The theoretical chapters used for references in the proposed methodologies for the topology optimizations. The fundamental theory of the continuum fluid mechanics in this thesis is not comprehensively covered with the insight contains since it is not necessarily used for the main scopes of this thesis, but for the relation in developing the topology optimization problem in the following chapters. Additionally, the brief introduction of the adjoint method and the methods of computation the sensitivity provides in this thesis will guide the readers to a better understanding of the mainly constructed optimizations for thermal and flow fields in this study. They are also given in the theoretical parts. The mathematical differences in the methods of sensitivity computation given in this part are, moreover, a reference to explain the main differences in deriving the sensitivity in the topology optimization for flow field and in the topology optimization for the thermal field, i.e. the former is generally named as the design sensitivity and the latter is entitled as the topological derivative.

Since the uses of LBM is one of the main contributions in this work, this thesis gives a whole chapter to clarify the applications of the constructed LBMs in this research. The theoretical foundation of the LBM which is originally developed from the kinetic theory to the microscopic-scale time-evolution equation in LBM is sufficiently summarized in order. The LBMs used to govern the behavior of the macroscopic properties in this study are essentially confirmed with the analytical solutions and the conventional method – finite difference method, through numerical examples for the fluid flow and the heat diffusion problems, respectively. Thus, their applications in the topology optimization problems in this study will be necessarily guaranteed.

The novel contribution of this work has been shown in the authors' publications. It is, however, reorganized in this thesis for a more comprehensive study. Due to the limitation in the published journals, more details could not be fully presented in the published articles. Those are, therefore, given in this thesis. Thus, this thesis contains some unpublished research on the topics that have been published recently. The contribution of the published works opens a potential paradigm for the studies of the evolution of the topology optimization for fluid flow and heat transfer, as well as the potential applicability in other structure and fluid topology optimizations. Therefore, some new findings and recognized issues in the use of LBM in topology optimization are sufficiently presented in the last chapter for a better improvement in the future development of the current work.