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著者(和文)	MASTIYAGEDON SUDEERA HASARANGA GUNATHILAKA
Author(English)	Sudeera Hasaranga Gunathilaka Mastiyage Don
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論 文 要 旨

THESIS SUMMARY

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学生氏名： Student's Name	MASTIYAGE DON SUDEERA HASARANGA GUNATHILAKA	審査員主査： Chief Examiner	Masahiro TAKINOUE

要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Combinatorial optimisation problems (COPs) are present in a wide range of fields. These problems often exhibit exponential growth in computational time as the problem size increases linearly, making them computationally demanding for classical systems. Non-von Neumann architectures, such as quantum annealers, Coherent Ising Machines (CIMs), and simulated bifurcation machines, have emerged as promising solutions for this. These systems approach COPs by mapping them onto a Hamiltonian, specifically the Ising Hamiltonian, often with a Zeeman term.

A key challenge in solving a COP using a CIM lies in amplitude inhomogeneity and the implementation of Zeeman terms. These problems arise due to the use of soft spins, which are continuous variables representing the CIM amplitudes. Here the quadratic interaction term and the linear Zeeman term scale differently with respect to the spin amplitude. This mismatch can lead to frustration in the system, causing significant variability in the ground state (GS) as the spin amplitude changes. To address this issue, interaction and Zeeman terms must be carefully adjusted to maintain balance and consistency with the Ising model. These challenges are particularly relevant for quadratic unconstrained binary optimisation (QUBO) problems, which can also be mapped to Ising Hamiltonians and are frequently encountered in real-world applications.

To overcome these issues, Inui et al. (2022) introduced the Inui model (IM CIM), using a technique called Chaotic Amplitude Control (CAC). CAC homogenises the amplitudes of CIM by forcefully equalising them to a given target value. If the squared amplitude deviates from the target, CAC feedback mechanisms forcefully try to adjust the amplitudes to the desired value. This approach induces chaotic behaviour, which can help escape local minima in the energy landscape. Additionally, CAC adjusts the size mismatch between the coupling and Zeeman terms using the target information, improving the system's accuracy. However, IM CIM models have not yet been applied to solving real-world QUBO problems and have only been tested with Ising Sherrington-Kirkpatrick (SK) problem instances.

Building on IM CIM, this dissertation extends the IM CIM models to solve QUBO problems directly using soft spins in the 2nd chapter. This is the first time CIM soft spins have been employed to directly tackle QUBO problems. The QUBO-extended models, called CAC-CIM-CDP (Wigner) and CAC-CIM-CDP (Positive-P), were tested on both artificial random data and sparse magnetic resonance imaging (MRI)

data for L0-regularised compressed sensing (L0RCS). These models demonstrated improved accuracy compared to existing methods such as open-loop CIMs, least absolute shrinkage and selection operator (LASSO), and simulated annealing. However, IM CIM has a high computational cost.

To address the computational cost issue in IM CIMs, a simplified IM CIM model, named as MFZ-CIM, is proposed in the 3rd chapter. This model neglects fluctuation and noise components, significantly reducing computational cost while maintaining performance similar to the IM CIM (Wigner) for Ising SK problem instances. Among various techniques for realising Zeeman terms, CAC proved to be the most effective for the MFZ-CIM, outperforming other methods like absolute mean amplitude and auxiliary spin for effective Zeeman term realisation.

Combining the results of the QUBO-extended IM CIM (chapter 2) and MFZ-CIM (chapter 3) models, chapter 4 introduces a QUBO-extension to MFZ-CIM, called CAC-MFZ-CDP. This model includes two injection field variations, binarised and continuous. Despite its simplicity, the CAC-MFZ-CDP achieves similar performance to the computationally expensive CAC-CIM-CDP models in solving the QUBO problem of L0RCS. Notably, no significant performance differences were observed between the binarised and continuous variations.

In conclusion, this dissertation enhances the applicability of IM CIMs. Key contributions include the proposal of QUBO-extended IM CIM models, CAC-CIM-CDP (Wigner) and CAC-CIM-CDP (Positive-P) for solving L0RCS problem instances; the development of a simplified, less computationally expensive alternative to IM CIM, MFZ-CIM; and the CAC-MFZ-CDP model by combining the results of CAC-CIM-CDP and MFZ-CIM.