博士論文要旨

Study on Adaptive Scheduling Method based on Anytime Algorithm for Real-time Image Processing

(Anytime Algorithmに基づいたリアルタイム画像処理のための
適応的スケジューリングに関する研究)

大学院情報科学研究科博士後期課程　2006841004　ワイン　ワイン　チュエ
主査　村上和人　教授
副査　奥田隆史　教授
何　立風　教授

Image processing and video processing technologies have been expected to substitute the function of human vision, however there still remains a trade-off problem between image/video processing quality and processing time when these technologies are implemented by several points of view such as hardware and software/algorithm. Although conventional system focused on the function or the result of image processing, and its processing time is not too much considered, recent progress of IT requires a new paradigm based on the processing time and new software/algorithms which work under variety of hardware environment.

In order to solve the time-quality trade-off problem in real-time image processing (RTIP), this thesis described how to construct the adaptive scheduling mechanism for the maximization of overall processing result under time constraint. Anytime algorithm is used as basic tool for the construction of static scheduling method and imprecise computation tool is used for the optimization of overall processing result by modifying the conventional method and using the concept of anytime algorithm. The proposed method is applied to the digital image processing operations as an example in order to solve the time-quality trade-off problem in RTIP. Thus, the objectives of this works are

- Implementation of the adaptive scheduling mechanism,
- Evaluation of the overall processing result for the optimal solution under time constraint,
- Modification of the conventional image processing (CIP) method to anytime algorithmic image processing (AAIP) method.

At first, the problems encountered in real-time systems, related works and basic idea are expressed in chapter 1. Then, about the basic tools i.e., anytime algorithm and imprecise computation used for the implementation of adaptive scheduling and the realization of the overall processing result are briefly explained in chapter 2. The general explanation about scheduling with resource constraint is described in chapter 3. After that, how to apply anytime algorithm to digital image processing operations and the experimental results are explained in chapter 4. Image processing methods are treated as the spatial filtering type, morphological type, and conditional type and concrete methods to implement anytime algorithm to the conventional algorithms are described with experimented results. How to perform the adaptive scheduling method is also explained ([2] W. W. Kywe, D. Fujiwara and K. Murakami, “Scheduling of Image Processing using Anytime

Algorithm", Proc. of ICPR 2006). The experimental results clarify that the possibility of the proposed method for the scheduling of image processing tasks in RTIP. The detailed explanation of how to apply anytime algorithm to the conventional image processing tasks such as noise reduction and edge detection are explained ([4] W. W. Kywe and K. Murakami, "Anytime Noise Reduction and Edge Detection Algorithms for Time-Restricted Image Processing System", Proc. of FCV 2009). Then, the new approach to image processing methods in order to maximize the overall processing result under time restriction is expressed ([5] W. W. Kywe and K. Murakami, "New Approach to Image Processing Methods by Anytime Algorithm for the Overall Result under Time Constraint", Proc. of IWAIT 2010). Presently, 3 types of conventional image processing (CIP) method such as filter type, condition type and morphological type can be applied by anytime algorithm for the construction of anytime algorithmic image processing (AAIP). Thus, the extension of how to apply anytime algorithm to the linear spatial filtering method is described by noise reduction, edge detection, and sharpening operations, and it can be found at the journal paper ([1] W. W. Kywe and K. Murakami, "An Approach to Linear Spatial Filtering Method based on Anytime Algorithm for Real-time Image Processing", Journal of Computing).

The algorithm of task assignment and scheduling by modified imprecise computation method and the concept of anytime algorithm and the experimental results by simulation are explained in chapter 5. Then, how to evaluate the overall processing result and the quality of result are expressed in chapter 6. For the evaluation of the optimal solution, it is evaluated by using the modified imprecise computation method and conditions for the overall processing result. The experimental results of scheduling clarify that the adaptive schedule can be obtained for the optimal solution under time constraint. The possibility of the proposed method is confirmed by ORSJ paper ([6] W. W. Kywe and K. Murakami, "Minimization of the Discarded Optional Sub-tasks and the Realization of the Overall Processing Result for the Task Assignment and Scheduling by Imprecise Computation", Proc. of the central branch of Operations Research Society of Japan) .

In this research work, I also analyzed on the biometric theme, especially for the extraction of contact lens by using thermo vision camera ([3] W.W.Kywe, M.Yoshida and K.Murakami, "Contact Lens Extraction by using Thermo Vision", Proc. of ICPR2006) in the pre-processing of biometrics for the security purpose as an image processing application. The detailed explanation is described in chapter 7. Finally, this thesis is concluded by its contribution, discussion and future works in chapter 8.

Therefore, this research work contributed to the model of the quality functions offers a methodological contribution to the field of system planning and scheduling in operation research in general. The modification of CIP to AAIP methods offers a methodological and practical contribution to the construction of image processing library by the concept of anytime algorithm. The adaptive scheduling method can schedule the combination of tasks of a system under time constraint by distributing the time allocation for each task. It can reduce the idle/rest processing time and it can optimize the overall performance under time restriction. The utilization of this method can apply to solve the problem of optimal decision making by scheduling with limit resources (processing time) in artificial intelligence, and in engineering.

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大学院情報科学研究科博士後期課程　2006841004　ワイン　ワイン　チュエ
主査　村上和人　教授
副査　奥田隆史　教授
何　立風　教授

人の視覚を代替するシステムとして画像処理や映像処理の利用が期待される中、有用な情報の品質（画像処理結果）と処理時間の間にはトレードオフ問題が存在し、実装上の課題となっている。従来は機能面に重点が置かれ、処理時間については後回しにされてきたが、多様なハードウェア環境の下で画像・映像処理技術の利用を促進するためには、処理時間をベースにした新たなパラダイムの導入と、具体的にそれらを実現するためのソフトウェア、アルゴリズムが必要とされる。

この時間―品質のトレードオフ問題を解決するため、本論文では、ある時間制限の下で総合的な画像処理結果（品質）を最大化する適応的な画像処理スケジューリング手法について論じる。具体的には、画像処理へのAnytime Algorithmの導入を試み、以下について述べる。

・最適解を導出するためのスケジューリング手法
・時間制限のある中で画像処理品質を最大化するための画像処理結果の評価手法
・従来型画像処理手法をAnytime Algorithm型画像処理手法に変えるための構成方法

第1章ではリアルタイムシステムに関連する諸課題と基本アイディアについて述べる。第2章ではAnytime Algorithmの諸特性を整理し、画像処理への適用可能性について論じる。第3章では画像処理にAnytime Algorithmを適用する基本コンセプトを説明し、資源に制約がある場合（例えば、処理時間が限られる場合）の最適化手法について論じる。これらのアイディアに基づき、第4章では具体的なAnytime Algorithm型画像処理アルゴリズムの構築方法について説明する。ここでは、まず、雑音除去等の空間フィルタータイプの画像処理、膨張・収縮等の形態的な画像処理、細線化等の条件判断タイプの画像処理など、代表的な手法についてAnytime Algorithmを組み込む方法を提案し、時間とともに処理結果が改善されていく様子を実験結果を交えて示す。次に、適応的なスケジューリング手法について述べる（[2] W. W. Kywe and K. Murakami, “Scheduling of Image Processing using Anytime Algorithm”, Proc. of ICPR 2006）。また、Anytime Algorithmの具体的な適用例として、雑音除去、エッジ検出などの手法を実験結果を交えて示す（[4] W. W. Kywe and K. Murakami, “Anytime Noise Reduction and Edge Detection Algorithms for Time-Restricted Image Processing System”, Proc. of FCV 2009）。さらに、総合的な画像処理品質を最大化する新たな手法について説明する（[5] W. W. Kywe and K. Murakami, “New Approach to Image Processing Methods by Anytime Algorithm for the Overall Result under Time Constraint”, Proc. of IWAIT 2010）とともに、ここで例示した手法が線形空間フィルタ型にも展開可能であることを示す（[1] W. W. Kywe and K. Murakami, “An Approach to Linear Spatial Filtering Method based on Anytime Algorithm for Real-time Image Processing”, Journal of Computing）。

第5章では分割した各々の処理に対して割り当てる時間を最適化するスケジューリング手法を導き出し、その結果が最適化されていることをシミュレーション実験を通して確認する。第6章ではAnytime Algorithm型の画像処理結果を総合的に評価する方法を論じている。特に、複数の画像処理を組み合わせた場合における前の処理結果への依存性について検討し、依存する場合と依存しない場合のそれぞれについて評価方法を定式化している（[6] W. W. Kywe and K. Murakami, “Minimization of the Discarded Optional Sub-tasks and the Realization of the Overall Processing Result for the Task Assignment and Scheduling by Imprecise Computation”, Proc. of the central branch of Operations Research Society of Japan）。第7章ではコンタクトレンズ検出を例として画像処理応用について説明し（[3] W.W.Kywe, M.Yoshida and K.Murakami, “Contact Lens Extraction by using Thermo Vision”, Proc. of ICPR2006）、第8章でまとめと今後の課題について述べる。

本研究で得られた知見は、一般的なシステム設計やスケジューリング分野に対して一つの方法論を与えるものと考えられる。また、従来型のアルゴリズムをAnytime型の画像処理アルゴリズムに変換しライブラリ化する方法は画像処理の実利用に大きく貢献し得るものである。適応的なスケジューリング手法は、時間制限の下での効率的なタスク処理を実現し、無用の待ち時間を減らした上で総合的性能の最大化を実現するものであり、今後、資源（時間）が制限される環境下における人工知能や工学分野にも貢献できると考えられる。