REAL TIME SCHEDULING FOR AUTONOMOUS MOBILE ROBOTS USING GENETIC ALGORITHM AND CONSTRAINT BASED REASONING

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To my beloved father and mother

ACKNOWLEDGMENTS

In the Name of Allah, Most Gracious, Most Merciful

All praise and thanks are due to Allah, and peace and blessings be upon his messenger, Mohammed (peace be upon him).

Alhamdulillah, it is with Allah S.W.T will that I get to finish this project in the time given. Here, I would like to express my heartfelt gratitude to my supervisor Professor Dr. Safaai Deris, who introduced me to the filed of real-time scheduling and without whose guidance and advice this study would not have been possible. He has been incredibly wise, helpful, understanding, and generous throughout the process. He has truly been a mentor and I owe him my deepest thanks.

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Finally, I would like to thank my wife for her patience, encouragement, support and understanding.

ABSTRACT

In many real-time systems, relative timing constraints are imposed on a set of tasks. Generating a correct ordering for the tasks and deriving their proper start-time assignments is a Nondeterministic Polynomial Problem (NP) hard problem; it subsumes the Non-preemptive Scheduling Problem. Real-time systems are characterized by the presence of timing constraints on the computations carried out by the system. Examples are found in domains such as avionics, process control and robotics, where a computer is used to control and manipulate a physical system. Real-time systems are characterized by computational activities with timing constraints and classified into two categories, hard real-time system and soft real-time system. In hard real-time system, deadline missing can be catastrophic. However, in the case of soft real-time systems, slight violation of deadlines is not so critical. Autonomous mobile robot system is one of typical task scheduling of soft real-time system. In this study we addressed the problem of real-time scheduling in autonomous robot and in particular we compared two different scheduling approaches, hybrid GA and Pre-emptive Rate Monotonic. The results have shown that in this case a hybrid GA approach is preferable because it is more efficient and moreover the disadvantages of such a choice have shown not to be relevant to the overall functioning of a typical autonomous robot application. In fact, the greater efficiency could be exploited to minimize the overall deadline missing among the tasks and therefore robot can work smoothly.

ABSTRAK

Masalah sistem masa nyata adalah umpukan masa yang bergantung kepada set tugasan. Masalah utama bagi *Nondeterministic Polynomial Problem (NP)*; juga masalah *Non-preemptive Scheduling Problem* ialah menghasilkan aturan tugasan dan mendapatkan masa permulaan tugasan yang sesuai. Sistem masa nyata dikategorikan mengikut kewujudan kekangan umpukan masa pada pengiraan yang dilakukan oleh sistem. Contohnya, pada ruang lingkuk seperti *avionics*, kawalan proses dan robotik, di mana komputer digunakan untuk mengawal dan memanipulasikan sistem fizikal. Sistem masa nyata dikategorikan mengikut aktiviti pengiraan dengan kekangan tetapan masa dan dikelaskan kepada dua kategori; sistem masa nyata kritikal dan sistem masa nyata kurang kritikal. Di dalam sistem masa-nyata kritikal, kehilangan tempoh masa tamat boleh menyebabkan kesan buruk. Namun demikian, bagi sistem masa nyata kurang kritikal pula, sedikit gangguan pada tempoh masa tamat tidak terlalu kritikal. Salah satu penjadualan tugasan yang biasa bagi sistem masa-nyata kurang kritikal ialah sesetengah sistem robot autonomi mobil. Di dalam projek ini, kami membentangkan permasalahan penjadualan masa nyata pada robot autonomi mobil dan membandingkan dua pendekatan penjadualan, iaitu GA hibrid dan *Pre-emptive Rate Monotonic* dengan terperinci. Dalam kes ini, keputusan telah menunjukkan pendekatan GA hibrid lebih sesuai dan lebih efisyen kerana kelemahan pada teknik lain kurang seeuai dengan fungsi keseluruhan aplikasi robot autonomi. Sebenarnya teknik yang baik boleh digunakan untuk meminimakan kesemua masa tamat yang hilang pada tugasan dan dengan itu robot dapat berfungsi dengan sempurna.

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LIST OF ABBREVIATIONS

AI	-	Artificial Intelligence
AWA	-	Adaptive Weight Approach
B&B	-	Branch and Bound
CBR	-	Constraints-Based Reasoning
CLP	-	Constraints Logic Programming
CP	-	Constraint Programming
CS	-	Constraints Satisfaction Problem
DC	-	Direct Current
DS	-	Deterministic Sampling Selection Method
EDD	-	Earliest Due Date scheduling policy
EDF	-	Earliest Deadline First scheduling policy
FCFS	-	First-Come First-Served scheduling policy
GA	-	Genetic Algorithms
IRIS	-	Increased Reward with Increased Service task completion
KBS	-	Knowledge Base System
LCD	-	Liquid Crystal Display
LLF	-	Least Laxity First scheduling policy
LP	-	Liner Programming
MOD	-	Mandatory/Optional Decomposition task model
MV	-	Multiple Version task completion model
NP	-	Nondeterministic Polynomial Time
OR	-	Operational Research
PD	-	Proportional Derivative
PUX	-	Period Unit Crossover
RMS	-	Rate Monotonic Scheduling
SJF	-	Shortest Job First scheduling policy
SRS	-	Stochastic Remainder Sampling Selection Method

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Scheduling is the allocation of resources over time to perform a collection of tasks. It is a decision making process that has a goal to one or more than one objective functions. The resources and tasks take many different forms. Resources may be machines in a factory, runaway at an airport, operation room at hospital, processing units in a computer, etc. Tasks may be operations in the factory, takeoffs and landing at the airport, operations at the hospital, executions of the computer program, etc. Objective functions are normally related to maximizing the profit, minimizing the cost, minimizing the time related measures such as tardiness, completion time, etc. Traditionally, scheduling problems have been solved by operational research (OR) techniques such as Liner Programming (LP), simulation, heuristics, and Branch and Bound (B&B). Recently, artificial intelligent techniques such as Constraint Base Reasoning (CBR), heuristics, Knowledge Base System (KBS), and Genetic Algorithm (GA) have been used to solve scheduling problems (Deris, 1997).

There are many computational systems that transfer some type of commodity whilst attempting to satisfy a range of strict time (and/or resource) constraints. These are called real-time or time-critical systems. There are a range of consequences for not satisfying the constraints that depend largely on the application. The commodity that is transferred may be physical, such as the transfer of goods through a manufacturing system, or it may be the transfer of a computational instruction in a computer bus or the transmission of a message in a communications system. When the commodity must utilize some limited resource (alternately referred to as processors or machines in the literature) by competing with other commodities there is usually some mechanism to ensure that the flow of commodities are handled in a manner that benefits the system's overall objectives. This mechanism is usually referred to as the scheduler and creates schedules which are precise sequences or timings of the transfer of commodities.

The timing or ordering of a schedule is determined by the *scheduling policy* common system objectives are to minimize waiting time or cost. The commodities are usually referred to as tasks, processes, or jobs in the context of scheduling, depending on the application. We shall refer to our commodities as tasks throughout the project, unless we cite a reference where jobs or processes are the preferred terms. Performance measures, based on system objectives, are usually applied to the schedules that are created to allow performance analysis and comparisons of policies. Examples of performance measures are the number of missed deadlines and the computational complexity of the scheduling algorithm.

Real-time systems are characterized by the presence of timing constraints on the computations carried out by the system. Examples are found in domains such as avionics, process control and robotics, where a computer is used to control and manipulate a physical system. The presence of timing constraints requires that the computations be scheduled in a manner that satisfies the application's timing requirements. Special classes of real-time systems, termed hard real-time systems, require that the timing constraints be guaranteed prior to execution, since the result of a timing failure may lead to unstable or undesirable system behavior.

1.2 Problem Background

In this section three topics will be explain with respect to our problem, these topics are real time scheduling, constraint based reasoning, and genetic algorithms.

1.2.1 Real-Time Systems

A real-time system is defined as a system in which the tasks must meet their deadlines. Then, the scheduling of a task set consists in the determination of all the activation dates for all the tasks, with respect to the constraints imposed by the system (processor workload, dependencies, priorities, deadlines, etc.). The general case of this problem is Nondeterministic Polynomial Problem (NP) hard. The real-time community has studied this for a long time, and has often introduced restrictions to simplify it. Many scheduling algorithms have been developed for special cases like rate monotonic or deadline monotonic (Jean-Francois and Sreng, 2002).

The uniprocessor systems are now deeply known. For special cases, formula exists to partially or completely determine the schedulability of set of tasks into these systems. The multiprocessor systems have been more recently studied. The problem is more complex in this case. Indeed a task may be executed on several processors, communications and synchronizations are more difficult (Jean-Francois and Sreng, 2002).

In all the cases the tasks, also called processes, are periodic or sporadic and have a unique entry point. They are modeled by a set of parameters: A periodic task *Ti* is represented by a t-uple (*Ci;Di;Pi*), where *Ci* is the worst-case computation time, *Di* is the relative deadline, *Pi* is the period. The amount of computation time used to process one execution of the task is always lower or equal than *Pi*. Whatever the activation time, execution must be finished before the activation time plus the relative deadline (Jean-Francois and Sreng, 2002).

A sporadic task differ from a periodic one in the activation time: the $(k+1)^{th}$ activation occurs at time $t_{k+1} \geq t_k + T_i$ such a time is randomly activated, only the minimal delay between two activations is known. The activation of a sporadic task is always triggered by the same event.

What is the problem in Real-time System? In Real-Time systems the moment when a result is computed is as important as its logical correctness. One way to meet system's timing constraints is to rely on a real-time scheduler. The scheduler should ensure system predictability, but the restrictions in these systems are so diverse that this guarantee is an NP-hard problem.

1.2.2 Constraint Based Reasoning

The CBR is a reasoning or problem-solving technique used to solve a CSP. The CSP can be defined by the following components:

- A finite set *X* of *n* variables {*X1,...,Xn*}.
- A domain *D* = {*Di, Dj*,.} consisting of possible values for variables *Xi* and *Xj*.
- A set of binary constraints *Rij* between variables *Xi* and *Xj*.

A binary constraint *Rij* between variables *Xi* and *Xj* is a subset of the Cartesian product $Di \times Dj$ that specifies the allowed pairs of values of *Xi* and *Xj*. A solution of the CSP is an instantiation of the variables in ***X*** such that all constraints are satisfied. This instantiation of the variables represents an assignment of a value from domain *Di* to variables *Xi* (Deris, 1997).

Why constraint based reasoning is attractive and important for scheduling?

Constraint-based scheduling is a glass-box framework for solving scheduling problems. It has two major advantages over the existing scheduling approaches: clarity (thus glass-box) and generality of the models. Moreover, it provides generic solution techniques of constraint satisfaction that can be further tuned for scheduling problems by using special filtering algorithms and scheduling strategies. Despite its "young age", constraint-based scheduling proved itself to be an efficient tool for solving real-life scheduling problems.

1.2.3 Genetic Algorithms

The GAs are general purpose optimization algorithms developed by Holland (1975). They are based on principles of natural evolution. In these algorithms, a population of individuals (chromosomes) undergoes a sequence of transformation by means of genetic operators to form a new population. Two operators are mutation and crossover. Mutation creates new individuals by a small change in a single individual and crossover creates new individuals by combining parts of two individuals (Deris, 1997).

Why GA is attractive and important for scheduling? Real-time scheduling of large-scale problems in complex domains presents a number of difficulties for search and optimization techniques, including:

- Large and complex search spaces.
- Dynamically changing problems.
- A variety of problem dependent constraints and preferences.

Genetic algorithms are well suited to such problems due to their adaptability and their effectiveness at searching large spaces. The reason for genetic algorithms success at a wide and ever growing range of scheduling problems is a combination of power and flexibility. The power derives from the empirically proven ability of evolutionary algorithms to efficiently find globally competitive optima in large and complex search spaces. The favorable scaling of evolutionary algorithms as a function of the dimension of the search space makes them particularly effective in comparison with other search algorithms for the large search spaces typical of real world scheduling. The flexibility of genetic algorithms has multiple facets.

1.3 Problem Statement

Military vehicles, robotic systems, aircraft, and automobiles are among the many applications that rely on complex embedded computer systems to perform critical operations. The real-time tasks of these systems execute have specific time constraints and a wide range of values. Failure to meet a task's time constraints can result in degraded performance. Some tasks (for example, vehicle braking and weapons control) are critical in that failure to meet their time constraints can lead to costly damage or serious injury.

Autonomous robots and, in particular, service mobile robots, for example vehicles with the task of carrying food and drugs inside hospitals or automated wheelchairs for the elderly and disabled have to deal with an uncertain, dynamic, not-predictable environments where it is often more important to take a fast decision rather than trying to find an optimal one. Each robot has different movement and tasks, so each of them need different scheduling for their tasks. Therefore when we design new robot, we have to determine schedulability of the tasks generate by that architecture, so the robot can function as we design.

1.4 Objectives

This study aims to find optimal schedule of real-time task for autonomous mobile robot using CBR and GA.

The project objectives are:-

a) Identify the characteristics of Real-Time Scheduling problem.
b) Study and choose the suitable techniques for the problem.
c) Formulate the model using the selected techniques.
d) Implement, test and improve the model to find optimal schedule.

1.5 Project Scope

Below defined the scope of the study, which involved several areas:

- The project focuses on scheduling of Real-Time Systems.
- The project focuses on Constraint Base Reasoning.
- The project focuses on Genetic Algorithms.
- The project focuses on data for embedded Real-Time of Mobile Robots.
- The project focuses on performance measures, processor utilization and miss rate.

1.6 Organization of the Report

This report consists of seven chapters. The first chapter presents introduction to the project and the background of problem on why is the study is being conducted. It also gives the objectives and scope of the study. Chapter 2 reviews on real time scheduling, constraint based reasoning and GA. Chapter 3 discusses on the project methodology used in the project. Chapter 4 and 5 shows the general and specific model of scheduling using hybrid GA. Chapter 6 is experimental result and analysis. Chapter 7 is conclusion and suggestions for future work.

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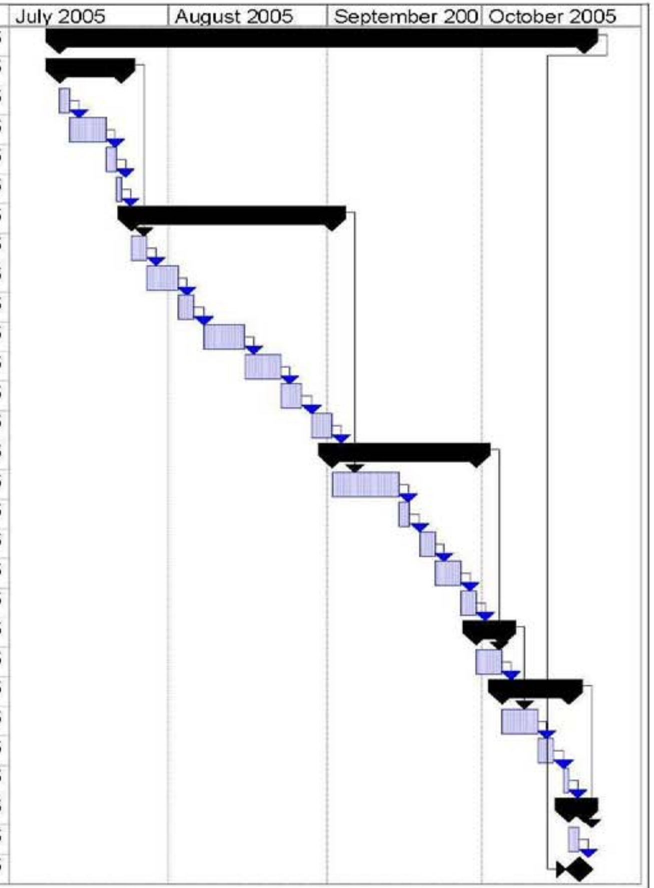
APPENDIX A

PROJECT TIME MANAGEMENT

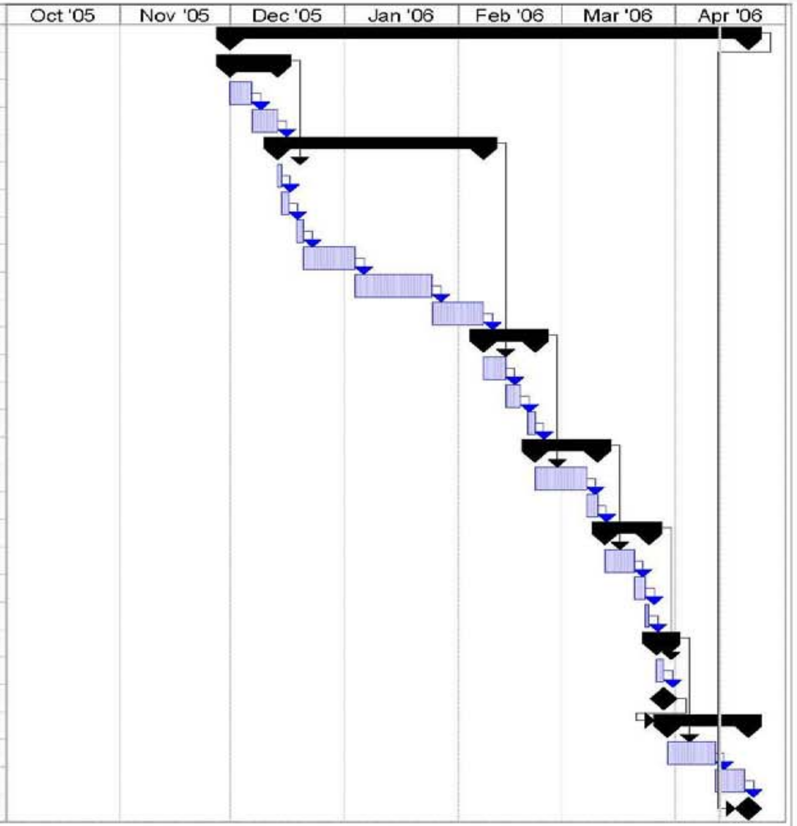
ID	Task Name	Duration	Start	Finish
1	MASTER PROJECT PLAN - PROJECT 1	74 days	Mon 11/07/05	Thu 20/10/05
2	IDENTIFYING PROJECT REQUIERMENTS	10 days	Mon 11/07/05	Fri 22/07/05
3	Identify Project Filed and Title	2 days	Mon 11/07/05	Tue 12/07/05
4	Identify Problem Background, Objectives & Scopes	5 days	Wed 13/07/05	Tue 19/07/05
5	Prepare Project Proposal	2 days	Wed 20/07/05	Thu 21/07/05
6	Submit Project Proposal	1 day	Fri 22/07/05	Fri 22/07/05
7	RESEARCH & ANALYSIS	29 days	Mon 25/07/05	Thu 01/09/05
8	Gathering Information On Topics Related	3 days	Mon 25/07/05	Wed 27/07/05
9	Research On Scheduling Theory	4 days	Thu 28/07/05	Tue 02/08/05
10	Research On Real-Time System	3 days	Wed 03/08/05	Fri 05/08/05
11	Research On Real-Time Scheduling Approaches	6 days	Mon 08/08/05	Mon 15/08/05
12	Research On Constraint Based Reasoning	5 days	Tue 16/08/05	Mon 22/08/05
13	Research On Genetic Algorithm	4 days	Tue 23/08/05	Fri 26/08/05
14	Writing Up Chapter II - Literature Review	4 days	Mon 29/08/05	Thu 01/09/05
15	METHODOLOGY	20 days	Fri 02/09/05	Thu 29/09/05
16	Research and Selecting Appropriate Methodology	9 days	Fri 02/09/05	Wed 14/09/05
17	Identify System Requirements	2 days	Thu 15/09/05	Fri 16/09/05
18	Writing Up Chapter III - Methodology	3 days	Mon 19/09/05	Wed 21/09/05
19	Writing Up Chapter IV - Model for General Scheduling	3 days	Thu 22/09/05	Mon 26/09/05
20	Writing Up Chapter V - Model for Real-Time Scheduling	3 days	Tue 27/09/05	Thu 29/09/05
21	CONCLUSION	3 days	Fri 30/09/05	Tue 04/10/05
22	Conclusion & Results Expectation	3 days	Fri 30/09/05	Tue 04/10/05
23	HAND IN DRAFT & DRAFT CORRECTIONS	9 days	Wed 05/10/05	Mon 17/10/05
24	Hand in Draft to Supervisor	5 days	Wed 05/10/05	Tue 11/10/05
25	Draft Corrections	3 days	Wed 12/10/05	Fri 14/10/05
26	Hand in 3 Copies Final Draft	1 day	Mon 17/10/05	Mon 17/10/05
27	PROJECT PRESENTATION	3 days	Tue 18/10/05	Thu 20/10/05
28	Preparing Presentation Materials	2 days	Tue 18/10/05	Wed 19/10/05
29	Project Presentation	1 day	Thu 20/10/05	Thu 20/10/05



Project: Project I
Date: Thu 20/10/05

Task | Progress | Milestone | Summary
Rolled Up Task | Rolled Up Milestone | Rolled Up Progress | Split
External Tasks | Project Summary | Group By Summary | Deadline

ID	Task Name	Duration	Start	Finish
1	MASTER PROJECT PLAN - PROJECT II	101 days	Thu 01/12/05	Thu 20/04/06
2	REQUIREMENT ANALYSIS	9 days	Thu 01/12/05	Tue 13/12/05
3	Identify Problems	4 days	Thu 01/12/05	Tue 06/12/05
4	Requirement Analysis	5 days	Wed 07/12/05	Tue 13/12/05
5	DEVELOPMENET PHASE	40 days	Wed 14/12/05	Tue 07/02/06
6	Installing C++	1 day	Wed 14/12/05	Wed 14/12/05
7	Installing GALIB Library	2 days	Thu 15/12/05	Fri 16/12/05
8	Installing Timestool Software	2 days	Mon 19/12/05	Tue 20/12/05
9	Gathering Data	10 days	Wed 21/12/05	Tue 03/01/06
10	Applying GA with Constraints Architecture	15 days	Wed 04/01/06	Tue 24/01/06
11	Testing Data using GA	10 days	Wed 25/01/06	Tue 07/02/06
12	IMPLEMENTATION AND TESTING	10 days	Wed 08/02/06	Tue 21/02/06
13	Testing Data using Hybrid GA	4 days	Wed 08/02/06	Mon 13/02/06
14	Testing Data using Timestool Software	4 days	Tue 14/02/06	Fri 17/02/06
15	Analyze Results	2 days	Mon 20/02/06	Tue 21/02/06
16	DOCUMENTATION	13 days	Wed 22/02/06	Fri 10/03/06
17	Writing Up Report	10 days	Wed 22/02/06	Tue 07/03/06
18	Update and Edit Report	3 days	Wed 08/03/06	Fri 10/03/06
19	HAND IN DRAFT & DRAFT CORRECTIONS	10 days	Mon 13/03/06	Fri 24/03/06
20	Hand in Draft to Supervisor	6 days	Mon 13/03/06	Mon 20/03/06
21	Draft Corrections	3 days	Tue 21/03/06	Thu 23/03/06
22	Hand in Complete Report to Evaluators	1 day	Fri 24/03/06	Fri 24/03/06
23	PROJECT PRESENTATION	3 days	Mon 27/03/06	Wed 29/03/06
24	Preparing Presentation Materials	2 days	Mon 27/03/06	Tue 28/03/06
25	Project Presentation	1 day	Wed 29/03/06	Wed 29/03/06
26	HAND IN FINAL REPORT	16 days	Thu 30/03/06	Thu 20/04/06
27	Hand in Draft after Corrections	9 days	Thu 30/03/06	Tue 11/04/06
28	Report Binding	6 days	Wed 12/04/06	Wed 19/04/06
29	Hand in Final Report	1 day	Fri 21/04/06	Fri 21/04/06



Project: Project II
Date: Thu 13/04/06

Task | Progress | Milestone | Summary
Rolled Up Task | Rolled Up Milestone | Rolled Up Progress | Split
External Tasks | Project Summary | Group By Summary | Deadline