Adaptive Scheduling in Real-Time Systems
Through Period Adjustment

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Abstract—Real-time system technology traditionally developed for safety critical systems, has now been extended to support multimedia and virtual reality. A large number of real-time application, related to multimedia and adaptive control system, require more flexibility than classical real-time theory usually permits. This paper proposes an efficient adaptive scheduling framework in real-time systems based on period adjustment. Under this model periodic tasks can change their execution rates based on their importance values to keep the system underloaded. We propose Period_Adjust algorithm, which considers the tasks whose periods are bounded as well as the tasks whose periods are not bounded.

I. INTRODUCTION

The real-time scheduling paradigms, both static such as rate monotonic scheduling [13], and dynamic such as earliest deadline first scheduling, do not fit well the requirements of advanced real-time applications in dynamic environments. Real-time systems are being increasingly designed for complex systems. For these applications, it is sometime impractical or impossible to provide static guarantees to real-time computation. These motivations have led to the emergence of the adaptation and overload management as a major research issue in real-time systems.

An overview of prior art in overload management and adaptive scheduling techniques for real-time systems is given in Lu et al. [14]. Mechanism for detecting and handling timing errors including overloads are discussed in Stewart and Khosla [20], with emphasis on a specific application-oriented operating systems. An interesting technique for overload management in hard real-time control applications is described in Ramanathan et al. [17]. The author presents a scheduling policy deterministically guaranteeing $m$ out of any $k$ periodic task activations, along with a methodology able to minimize the effects of missed control-law updates. This work provides a solid foundation to graceful degradation policies of periodic real-time tasks. However, unless the overload duration is very short, the application could be significantly impaired by the loss of periodic execution for a number of real-time tasks. Dynamic Window Constrained Scheduling algorithm is similar except that the window $k$ is fixed. Mok et al. [16] modified Dynamic Window Constraint Scheduling, which is primarily deadline based by using the concept of Fairness to improve the success rate for tasks with unit size execution time. Other frameworks such as the imprecise computation model and reward based model can be applied in the situation where quality of service is proportional to the amount of workload completed.

The need for adaptive management of the Quality of Service has been widely recognized in the domain of the distributed multimedia systems. A graceful degradation of the communication subsystem is obtained in Abdelzaher and Shin [1] by means of QoS contracts specifying degraded acceptable QoS levels. Significant research has also been devoted to schedulers providing some degree of adaptation to cope with the dynamic overload environment. The need for scheduling systems providing real-time guarantee to a subset of tasks within a general operating system has been emphasized in the Stankovic et al. [19]. In Lu et al. [14] the authors assume a flexibility in timing requirements. To address the dynamics of the environment, they proposed a modified EDF adaptive scheduling framework based on feedback control methods and use feedback control loops to maintain a satisfactory deadline miss ratio when task execution times change.

Many real-time task models have been proposed to extend timing requirements beyond the hard and soft deadlines based on the observation that jobs can be dropped without severely affecting performance [4]. Despite the success of some models in alleviating overload situation, it is sometime more suitable to execute jobs less often instead of dropping them or allocating fewer cycles. The work in Kuo et al. [12] is among the first to address this type of requirement. Load-adjustable algorithms and value-based policies are the main techniques proposed for graceful recovery from overload. A load adjustment mechanism is proposed in [12] in order to handle periodic processes with varying temporal parameters. The aim of this work is to determine feasible time parameter configurations (execution time $C$ and period $T$) and thus modify the real-time computation for collections of tasks. The configuration selection problem is solved by a harmonic approach achieving the maximum exploitation of the computational resources under any time parameter configuration. While appealing, this approach does not lend itself to many real-time systems, where execution times, in spite of their variability, cannot be set or chosen by the designer.

In [18] Seto et al. considered the problem of finding a feasible set of task period as a non-linear programming problem, which seeks to optimize specific form of control
performance measure. Cervin et al. used optimization theory to
solve the period selection problem online by adaptively
adjusting task periods with focus on optimizing specific con-
trol performance [9]. Baruah et al. [2] proposed a scheduling
algorithm maximizing the effective processor during overload,
given a minimum slack factor for all tasks.

Buttazo et al. [5] proposed a flexible framework known
as elastic task model, where deadline misses are avoided
by increasing task periods until some desirable utilization is
achieved. The work in [14] extends the basic elastic task model
to handle cases where the computation time is unknown. In
elastic task model [6],[7], periodic computations are modeled
as springs with given elastic coefficients and minimum lengths.
Requested variations in task execution rates or overload condi-
tions are managed by changing the rates based on the spring’s
elastic coefficients. Generalized elastic scheduling proposed
by Chantem et al. [10],[11], by generalizing elastic scheduling
approach. Although the Elastic model is nice but it does not
consider the cases where the task periods of soft real-time
systems may be unbounded or loosely bounded. We develop
in this paper an efficient adaptive scheduling scheme in real-
time systems through period adjustment, which consider the
tasks having bounded as well as unbounded periods.

This paper is organized as follows. Section 2 describes
problem definition and motivation. Section 3 presents our
proposed task model and the Period_Adjust algorithm and
its features. In section 4, we present the experimental results.
Finally, section 5 contains conclusion.

II. PROBLEM DEFINITION AND MOTIVATION

Many models have been proposed in real-time scheduling
theory to deal with adaptive scheduling and overload man-
agement. Some of the proposed models are based on the
observation that less important jobs can be dropped without
severely affecting performance. But dropping of jobs may not
always be the best option, because it is sometime more suitable
to execute the jobs less often instead of dropping them even
if they are less important. Elastic task model [6] uses flexible
framework but it do not consider the case where some of
the soft real-time task may be loosely bounded or unbounded.
We propose a novel scheduling framework based on period
adjustment. Our algorithm considers the tasks whose periods
are tightly bounded as well as the tasks whose periods are
loosely bounded. We feel that this is more general model and
this model performs nicely even when all tasks are bounded.

Many soft real-time applications require the execution of
periodic activities, whose rate can usually be defined within
a certain range. The higher the frequency, the better the
performance. Depending on the application domain, some
tasks are rigidly imposed by the environment whereas other
activities can be more flexible, producing significant results
when their rates are within a certain range. For example,
in multimedia systems the activities such as voice sampling,
image acquisition, data compression, and video playing are
performed periodically, but their execution rates are not so
rigid. Depending on the requested quality of service, tasks
may increase or decrease their execution rate to accommodate
the requirements of other concurrent activities. However this
period range may be flexible also. Suppose a soft real-time
task has period range \((a, b)\), then in some application it may
be possible to increase few time units above \(b\) and decrease few
time units below \(a\), if by doing so system become schedulable.

It is sometime counter intuitive that a soft real-time application
which is schedulable in range \((a, b)\) can not be schedulable
for the range \((a, (b + 1))\) or alike. There are many flexible
applications in multimedia and control applications in which
we may be able to vary few time units across bound (upper
or lower) without severely affecting the performance. We
feel that there should be a general scheduling framework
which can consider the flexible applications whose periods
are unbounded alongside with the bounded one.

III. PROPOSED WORK

A. Task Model

We consider the system where each task \(\tau_i\) is periodic and is
characterized by the following tuple: \((C_i, T_{i_{\min}}, T_{i_{\max}}, w_i)\)
for \(i = 1, \ldots, N\). Where \(N\) is the number of tasks in the
system, \(C_i\) is the worst case execution time and \(T_{i_{\min}}\) is
the initial period of \(\tau_i\). \(T_{i_{\min}}\) denotes the minimum possible period
of \(\tau_i\) as specified by the application, and \(T_{i_{\max}}\) represents
the maximum period beyond which the system performance
is no longer acceptable. The weighting factor \(w_i\), represents
importance of task \(\tau_i\), to changing it’s period in face of
changes. The longer the weighting factor of a task, the more
will be it’s contribution towards the overall utilization. Given
a task set \(\Gamma\), tasks are arranged in a nondecreasing order of
deadline.

Each task \(\tau_i\) in task set \(\Gamma\) is divided in to two parts. \(\Gamma_h\)
for hard real-time tasks and \(\Gamma_s\) for soft real-time tasks such
that \(\Gamma = \{\Gamma_h \cup \Gamma_s\}\). \(N\) is the total number of tasks in the
systems. \(n_h\) is the number of hard real-time tasks such that
\(n_h = |\Gamma_h|\). \(n_s\) is the number of soft real-time tasks such
that \(n_s = |\Gamma_s|\). \(w_i\) is the weighting factor or importance
value of each soft real-time tasks in \(\Gamma_s\). \(w_i\)'s for soft real-
time tasks are arranged in such a way that \(\sum_{i=1}^n w_i = 1\),
in other words \(w_i\) represents fractional importance value or
percentage of importance value of each soft real-time tasks
towards the whole system performance. Furthermore a task
in \(\Gamma_s\) may belongs to \(\Gamma_s_{\text{bound}}\) or \(\Gamma_s_{\text{sp}}\) or \(\Gamma_s_{\text{unbound}}\), i.e.
\(\Gamma_s = \{\Gamma_s_{\text{bound}} \cup \Gamma_s_{\text{sp}} \cup \Gamma_s_{\text{unbound}}\}\) where \(\Gamma_s_{\text{bound}}\) con-
stists of those soft real-time tasks for which an upper bound
or lower bound or both are imposed on tasks periods prior to
execution or during execution, and \(\Gamma_s_{\text{sp}}\) consists of those soft
real-time tasks which have fixed periods or which requests for
fixed periods during run time, whereas task set \(\Gamma_s_{\text{unbound}}\)
consists of those tasks which are unbounded. However as
a matter of fact period \(T_i\) can not be less than worst case
computation time \(C_i\) of a task. Our scheduling algorithm
emphasize such soft real-time application which have more
number of tasks in \(\Gamma_s_{\text{unbound}}\).

In this task model, all the tasks \(\tau_i\), which does not belongs
to \(\Gamma_s_{\text{bound}}\), can have \(T_{i_{\min}}\) or \(T_{i_{\max}}\) equal to \(\Phi\), which means
that they are unbounded. For each \((\tau_i \in \Gamma_h)\), \(w_i = h_{rt} = 1\) which means that all hard real-time tasks must execute provided they are schedulable. \(T_i\) denotes the actual period of task \(\tau_i\), which is constrained to be in the range \([T_{i_{min}}, T_{i_{max}}]\) for the case \((\tau_i \in \Gamma_s\_bound)\), whereas \(C_i\) denotes actual execution time considered to be known a priori. In the case of tasks with variable computation times, \(C_i\) will denote the actual worst case execution time. Any period variation is always subject to an utilization guarantee and is accepted only if there exists a feasible schedule such that tasks are scheduled by earliest deadline first algorithm. Hence if \(\sum(C_i/T_i) \leq 1\), all tasks can be created at the minimum period \(T_{i_{min}}\), otherwise the algorithm is used to adapt the task’s period to \(T_i\) such that \(\sum(C_i/T_i) = U_d \leq 1\), where \(C_i\) is the current online execution estimate and \(U_d\) is some desired utilization factor. System designer can set \(w_i\) statically or dynamically depending upon requirements. In static method, all soft real-time tasks are assigned \(w_i\)’s prior to start of the task execution and these \(w_i\)’s remains fixed up to the end of the task completions. In dynamic method, assignment of \(w_i\) is event based i.e., weighting factor \(w_i\) may be reassigned during the occurrence of any event such as, a new task arrival or completion of a task.

B. Period_Adjust Algorithm

We propose a new scheduling framework namely Period_Adjust algorithm which accepts set of tasks \(\Gamma\) and desired utilization \(U_d\) and return set of periods for soft real-time tasks so as to maximize quality of service. We may set \(U_d\) equal to the maximum schedulable utilization of individual scheduling algorithm. We can set \(U_d = 1\) for dynamic scheduling algorithm like EDF, or we can set \(U_d(n) = n(2^l/n - 1)\) for the static scheduling RM algorithm, where \(n\) is the number of independent, preemptable periodic tasks with relative deadline equal to their respective periods. In this algorithm we assume that deadline is equal to the period. We also assume that the execution time \(C_i\) of all the tasks is given prior alongwith the periods of hard real-time tasks. The total task set \(\Gamma\) is divided in two groups, namely the set of hard real-time tasks \(\Gamma_h\), and the set of soft real-time tasks \(\Gamma_s\). Further the set of soft real-time tasks may consists of \(\Gamma_{sp}\), in which soft real-time task request for fixed period, \(\Gamma_{s\_bound}\) in which tasks are bounded by maximum and minimum periods.

Our Period_Adjust algorithm works as follows: The first for loop computes the utilization of hard real-time tasks, then algorithm computes the summation of all utilization of task set \(\Gamma_h\) to check for its feasibility. In the second for loop it computes the utilization of those tasks which request for period change, if there is no such task \(U_{sp}\) is set to zero, after that it again checks for the feasibility of the schedulable utilization. The third for loop computes the tasks periods of all soft real time tasks in accordance with their weighting factor or importance value. Next the algorithm checks whether the periods of unbounded tasks are less than their computation time. If period is less than computation time, it replaces period by computation time. Finally it checks whether these periods exceeds their bounds for the bounded tasks, if this is the case it replaces periods with their bounds.

Algorithm 1 : Period_Adjust(\(\Gamma, U_d\))

```plaintext
for each \((\tau_i \in \Gamma_h)\) do
    \(U_i = C_i / T_i\)
end for
\(U_h = \sum U_i\)
\(U_s = U_d - U_h\)
if \((U_s \leq 0)\) then
    return infeasible
end if
for each \((\tau_i \in \Gamma_{sp})\) do
    \(U_i = C_i / T_{isp}\)
end for
\(U_{sp} = \sum U_i\)
\(U_s = U_d - U_h - U_{sp}\)
if \((U_s \leq 0)\) then
    return infeasible
end if
for each \((\tau_i \in (\Gamma_s - \Gamma_{sp} - \Gamma_{s\_bound}))\) do
    if \((T_i < C_i)\) then
        \(T_i = C_i\)
    end if
end for

for each \((\tau_i \in \Gamma_{s\_bound})\) do
    if \((T_i < T_{i_{min}})\) then
        \(T_i = T_{i_{min}}\)
    else
        if \((T_i > T_{i_{max}})\) then
            \(T_i = T_{i_{max}}\)
            \(\Gamma_{s\_bound} = \Gamma_{s\_bound} - \tau_i\)
            \(\Gamma_{sp} = \Gamma_{sp} + \tau_i\)
        end if
    end if
end for
if \((mod == 1)\) then
    return Period_Adjust(\(\Gamma, U_d\))
else
    return feasible
end if
```

If computed period \(T_i\) for a bounded task is less than the minimum period \(T_{i_{min}}\), we can simply replace \(T_i\) by \(T_{i_{min}}\) because increasing the period leads to less overall utilization. However, if the computed period \(T_i\) is greater than the maximum period \(T_{i_{max}}\), we can not simply replace \(T_i\) by \(T_{i_{max}}\), because decreasing the period leads to increased
utilization, which may exceed the schedulable utilization. Therefore corresponding task is removed from bounded task set \( \Gamma_{s,bound} \) to fixed period task set \( \Gamma_{sp} \) and Period_Adjust algorithm is re-invoked. In this algorithm we assume that in soft real-time application there are many cases where either no bounds are available or no bounds are required for soft real-time tasks.

IV. EXPERIMENTAL RESULTS

In this section we present the experimental results performed on our task model. We consider period selection with deadlines equal to periods. In all the following tables here onwards periods \((T_{i0}, T_{imin}, T_{imax})\) and computation times \((C_i)\) are expressed in milliseconds (ms).

| Task | \( C_i \) | \( T_{i0} \) | \( T_{imin} \) | \( T_{imax} \) | \( w_i \) |
|------|---------|---------|---------|---------|-------|
| \( \tau_1 \) | 18 | 100 | 50 | 150 | 0.30 |
| \( \tau_2 \) | 18 | 100 | 50 | 150 | 0.30 |
| \( \tau_3 \) | 18 | 100 | 50 | 150 | 0.18 |
| \( \tau_4 \) | 18 | 100 | 50 | 150 | 0.12 |
| \( \tau_5 \) | 18 | 100 | 50 | 150 | 0.10 |

To execute the Period_Adjust algorithm, we first use the task set parameters given in Table 1. In this experiment, all tasks start at time 0 with an initial period of 100 time units and the task set is schedulable under EDF. Here the required maximum utilization of the overall system is \( \frac{18}{100} + \frac{18}{200} + \frac{18}{150} + \frac{18}{750} + \frac{18}{150} = 1.8 \), whereas the required minimum utilization of the overall system is \( \frac{18}{150} + \frac{18}{150} + \frac{18}{150} + \frac{18}{150} = 0.6 \). Since the current utilization is \( \frac{18}{100} + \frac{18}{100} + \frac{18}{100} + \frac{18}{100} + \frac{18}{100} = 0.90 \), the task set is schedulable under EDF. Assume that, at the 10sec, \( \tau_1 \) needs to reduce its period to 50 time units, due to some changes in system dynamics not experienced by other tasks. Since the new required utilization of the system is \( \frac{18}{100} + \frac{18}{100} + \frac{18}{100} + \frac{18}{100} + \frac{18}{100} = 1.08 \), which is greater than 1, and therefore as such it is not schedulable under EDF. We can observe that the required minimum utilization of the system is \( \frac{18}{100} + \frac{18}{150} + \frac{18}{150} + \frac{18}{150} + \frac{18}{150} = 0.84 \), which is less than 1. Therefore to allow for \( \tau_1 \) to change its period, the period of tasks \( \tau_2, \tau_3, \tau_4 \) and \( \tau_5 \) must increase for the system to remain schedulable. At time 20sec, \( \tau_1 \) goes back to its original period state. Fig. 1 shows the cumulative number of executed instances for each task as its period changes over time. When we execute Period_Adjust algorithm on the above task sets, it will return the feasible set of task periods \((T_1 = 50, T_2 = 80, T_3 = 110, T_4 = 138, T_5 = 150)\).

Now we consider the same task set parameters with some change. Here we assume that soft real-time tasks \( \tau_4 \) and \( \tau_5 \) are not bounded, i.e. although the preferable maximum period is 150, some flexibility is provided by the application to increase or decrease the bound. In this case assume that at 10sec \( \tau_1 \) needs to reduce the its period to 50 time units and \( \tau_2 \) needs to reduce the its period to 60 time units, as shown in Table 2.

For these task set parameters Task_compress algorithm [5] is infeasible, whereas Period_Adjust algorithm is feasible. In fact when we execute the Period_Adjust algorithm on the above task sets, the corresponding periods obtained for the tasks are shown in Fig. 2 \((T_1 = 60, T_2 = 60, T_3 = 147, T_4 = 155, T_5 = 175)\).

Now, we consider the task set parameters given in Table 3 for the case of admission control policy during dynamic task activation. In this experiment \( \tau_1, \tau_2 \) and \( \tau_3 \) starts at time 0. They have the current utilization \( \frac{30}{100} + \frac{50}{200} + \frac{70}{300} = 0.78 \) and therefore schedulable by EDF. At time 10sec two tasks \( \tau_4 \) and \( \tau_5 \) arrives which makes the total utilization \( \frac{30}{100} + \frac{50}{200} + \frac{70}{300} + \frac{10}{100} + \frac{10}{100} + \frac{10}{100} + \frac{10}{100} = 1.03 \). In order to allow the tasks \( \tau_4 \) and \( \tau_5 \) for execution, the tasks \( \tau_1, \tau_2 \) and \( \tau_3 \) can increase their period. Since both tasks \( \tau_4 \) and \( \tau_5 \) are of 10 sec duration, after 20sec tasks \( \tau_1, \tau_2 \) and \( \tau_3 \) returns to their previous periods, as shown in the Fig. 3(Period_Adjust activation). Now we consider the above task set parameters with some modification. In this case \( \tau_4 \) and \( \tau_5 \) arrives at 10 sec having the computation times 30ms and 20ms respectively as shown in Table 4. Here task \( \tau_3 \) is loosely bounded (period of task \( \tau_3 \) should be preferably between 50 and 350 but not necessarily). In this case total utilization is \( U = \frac{30}{100} + \frac{50}{200} + \frac{70}{300} + \frac{30}{100} + \frac{20}{100} = 1.37 \). Obviously task sets are not schedulable. Task set parameters alongwith importance values are given in the following table. In this case also Task_compress algorithm is infeasible. While Period_Adjust algorithm is feasible. On execution periods returned by the Period_Adjust algorithm are \((T_1 = 150, T_2 = 250, T_3 = 355, T_4 = 150, T_5 = 200)\).

For the comparison purpose, here we use the task set
parameters in [7], and we show that Period_Adjust works nicely in these cases also.

Table IV: Task Set Parameters

| Task | C_i | T_0 | T_{min} | T_{max} | w_i |
|------|-----|-----|---------|---------|-----|
| τ_1  | 30  | 100 | 50      | 350     | 0.20|
| τ_2  | 50  | 200 | 50      | 350     | 0.20|
| τ_3  | 70  | 300 | Φ       | Φ       | 0.20|
| τ_4  | 30  | 100 | 50      | 350     | 0.20|
| τ_5  | 20  | 70  | 50      | 350     | 0.20|

Table V: Task Set Parameters

| Task | C_i | T_0 | T_{min} | E_i | w_i |
|------|-----|-----|---------|-----|-----|
| τ_1  | 24  | 100 | 30      | 1   | 0.30|
| τ_2  | 24  | 100 | 30      | 1   | 0.30|
| τ_3  | 24  | 100 | 30      | 1.5 | 0.25|
| τ_4  | 24  | 50  | 30      | 1   | 0.25|

Task set parameters are shown in Table 5. In this experiment four periodic tasks are created at time t = 0. All the tasks start executing at their initial period, at t = 10 sec τ_1 decreases its period from 100 ms to 33 ms. At t = 20 ms τ_1 returns to its initial period. The result of the application of Period_Adjust algorithm and Task_compress algorithm on the above task sets is shown in the Fig. 4. It shows the actual number of instances executed by each task as a function of time. Next experiment consider the case of admission control policy during dynamic task activation (Table 6). Three tasks starts executing at the time t = 0 at their initial period. An other task τ_4 arrives at time t = 10 sec. Since tasks are not schedulable when τ_4 is started, Period_Adjust algorithm is invoked which increases the periods of other tasks to make the request of task τ_4 fulfilled.

Table VI: Task Set Parameters

| Task | C_i | T_0 | T_{min} | T_{max} | E_i | w_i |
|------|-----|-----|---------|---------|-----|-----|
| τ_1  | 30  | 100 | 30      | 500     | 1   | 0.25|
| τ_2  | 60  | 200 | 30      | 500     | 1   | 0.25|
| τ_3  | 90  | 300 | 30      | 500     | 1   | 0.25|
| τ_4  | 24  | 50  | 30      | 500     | 1   | 0.25|

Fig. 5 shows the actual number of instances executed by each task as a function of time during the execution of the Period_Adjust algorithm and Task_compress Algorithm.

V. CONCLUSIONS AND FUTURE WORK

In this paper we have suggested Period_Adjust algorithm for scheduling of tasks in which periods of soft real-time tasks are flexible. In this framework, periodic tasks can change their importance value to provide different quality of service. Importance value or weighting factor of soft real-time tasks are arranged in such a manner to keep the system underloaded.
Fig. 2. Dynamic period change which is feasible by Period_Adjust only

What makes Period_Adjust more interesting is that it considers those soft real-time tasks whose periods are unbounded. The Period_Adjust model is useful for supporting both multimedia systems and control applications in which the execution rates of some computational activities cannot be properly predicted and they have to be dynamically tuned as a function of the current system state.

We feel that Period_Adjust model is a general model which can be applied in many applications. This framework can be extended to support the cases where deadline is less than period and computation time is variable.

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Fig. 3. Dynamic Task Activation using Period_Adjust

Fig. 4. Period_Adjust vs Task_compress
Fig. 5. Period_Adjust vs Task_compress