Analysis of Scheduling Algorithm under Task Dependencies in a Networked System

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Abstract: The industrial networked system combines both event and time driven and hence more complex to design. Industrial communication networks are generally have limited bandwidth and occurrence of any unpredictable events increases network traffic. Also, the data transmitted over the network have dependency with the other data and demands a dynamic scheduling algorithm which considers task dependencies. In this paper, an analysis of dynamic scheduling algorithm is suggested which considers task dependencies, without affecting the system performance.

Keywords: Networked control systems, Feedback control real-time scheduling, Task dependencies and distributed systems.

1. INTRODUCTION

The modeling and analysis of networked systems is complex due to unpredictable behavior of the communication network. Most of the time the analysis of networked systems is carried out with the assumption such as network transmission are error free, every frame or packet always has the same constant length, the network cannot be overloaded, and the difference between the sampling time of the controller and the sensor is constant. Liu and Layland published a paper on the scheduling of periodic tasks that is generally regarded as the foundational and most influential work in fixed-priority real-time scheduling theory [1]. The paper considers the assumptions such as all tasks are periodic, all tasks are released at the beginning of a period and have a deadline equal to their period, all tasks are independent, i.e. have no resource or precedence relationships, all tasks have a fixed computation time, or at least a fixed upper bound on their computation times, which is less than or equal to their period and so on.

However, in real time the above mentioned assumptions are not realistic and result in the analysis of networked industrial system more complex. This causes the occurrence of unpredictable events which result in the increase of network traffic and result in the loss of data packets [2], [3], [4]. This degrades the system performance and demands the development of scheduling algorithm with task dependencies. The scheduling algorithms are based on fixed parameters that are configured at the time of startup [5]. At run time, the communication medium is shared and accessed by all components having same pre-established rules regardless of application requirements. Therefore, if the application characteristics changes and some of the networked components do not need all the assigned bandwidth, the effective utilization of the network decreases [6], [7]. Further, the application of static and dynamic scheduling algorithm such as Rate Monotonic and Earliest Deadline First algorithm in networked system have been discussed [8], [9], [10], [11].

In this paper, the task can be periodic as well as a periodic, and adopts both time triggered and event triggered mechanisms. In this work, the criterion used to dynamically assign the priorities to the messages which also have dependencies within each subsystem. Also the lengths of the data packets are not same and hence developing a dynamic scheduling algorithm for such constraints will considered being unique. A threshold technique which helps to avoid transmission of repeated information, is used here to reduce the network traffic [12], [13].

2. PRESENT WORK

2.1 DC Motor System Model

The plant chosen is an armature voltage controlled DC Motor [14]. Figure 1 shows the equivalent diagram of DC motor, from which model can be developed to analyze its performance under varied conditions. From this the armature voltage equation can be expressed as

\[ u(t) = e_a = R i_a + L di_a/dt + K_b \omega \]  ... (1)

The mechanical torque balance based on Newton’s law is
where $u(t) = e_a$ is the armature input voltage, $L$ is the armature winding inductance, $i_a$ is the armature current, $R$ is the armature winding resistance, $J$ is the system moment of inertia, $B$ is the system damping coefficient, $K$ and $K_b$ are the torque constant and the back emf constant, respectively. Also, $T_l$ is the load torque in Nm and $\omega$ is the rotor angular speed. The PI controller can be designed using the state-space model derived from the above equations. The parameters of the PI controllers are computed as $K_p = 1.042$, $K_i = 0.0002$ and considers the following specifications:

DC supply voltage of 240 V. $R_a = 0.5$ ohms and $L_a = 0.01$ H. Torque constant, $K_t = 1.95$ Back emf constant, $K_b = 1.845$. $J = 0.05$ kg-m² and $B = 0.02$ N-s/m. Load torque $T_l = 25$ N-m.

The steady state speed of the DC motor for a simple closed loop system with the rated voltage and rated torque is obtained as 126 rad/sec and is shown in Fig. 2. The same model is considered for analysis of networked system with and without task dependencies. It is desired to achieve the same value of speed as the reference speed, irrespective of the algorithms as well as type of communication network used in the closed loop.

**2.2 Fixed Priority Scheduling with Single Message from Each System**

A simple two motor system networked through CAN bus modeled as shown in Fig. 3. The quantities (messages) torque and speed are transmitted to controller through CAN bus and the required control signal will be generated. In general, the Torque and Speed are related through the equation:

\[
\text{Output Power} = \text{Load Torque} \times \text{Speed} \quad \ldots (3)
\]
Based on real-time values of Torque (T) and Speed (ω) in both the motors the algorithm assigns priorities to the motors and sends the corresponding messages. The messages considered in a motor are dependent upon each other by a definite relationship as specified in Eq. (3).

In this case, only the speed information is considered and priority among the information from each motor is fixed. Based on that, the message from Motor 1 is fixed as higher priority with respect to the Motor 2. The speed information of Motor 1 (ω₁) and Motor 2 (ω₂) are connected directly to the respective input port, namely Ins1 and 2, of the CAN bus. The output ports of CAN bus namely Outs1 and 2 are directly feedback to Motors 1 and 2 respectively through their respective controller. With the fixed priority scheduling, when the system is being simulated with small disturbance applied in the load, the Motor 1 is running at steady state speed and is shown in Fig. 4.

From Fig. 4, it is observed that there will be momentary disturbance at the time of starting, however it is controlled and the speed is quickly reaching its steady speed. This is because the Motor 1 is given higher priority. On the other hand from Fig. 5, it is observed that, because of lower priority in scheduling, the speed of the Motor 2 is subjected to oscillation and requires larger settling time. In this case, fixed priority scheduling algorithm offers much reduced overall performance, if the number of motors connected on the network increases.

2.3 Dynamic Assignment of Priority with Single Message from Each System

In the previous section, the performance of the networked system under fixed priority scheduling is dealt with assumption that the messages are independent with respect to each other. Also, the disturbance is given only in the load side. Similarly, in this section a multi-motor is modeled using MATLAB/SIMULINK and are networked through a CAN bus is considered. The dynamic priority assignment of messages are based on the error in the signal and computed during the run time. Thus, if the error in motor1 speed is greater than that of Motor 2 speed, then motor1 is assigned first priority and its speed is transmitted first and vice-versa. In this case load disturbance as well network disturbance are applied and the relative performance of both the motor is studied.

3. RESULT AND DISCUSSION

For the sake of simplicity, it is considered two motors of the same rating described earlier. The motors are subject to a step disturbance of 10 Nm and not simultaneously. The Motor 1 is first subject to a step disturbance torque of 10 Nm for a period of 5 s after which it becomes 0. At this instant, this disturbance gets applied to Motor 2. Thus, the motor 1 gets higher priority for the first 5 s and its speed gets transmitted through the port In1 of CAN bus as observed from the plot In1. After 5 s the Motor 2 gets higher priority and its speed ω₂ is transmitted through In2 as observed from the plot In2.

The speed of Motor 1 (ω₁) is measured and compared with the reference speed of 126 rad/sec to compute the error in speed (ωe₁). Similarly, the error in speed of Motor 2 can be calculated. The errors ωe₁ and ωe₂ are compared twice in relational operator blocks ωe₁ > ωe₂ and ωe₁ < ωe₂. At any instant of time, if the output of the first block is true (1), the output of the second block is false (0). The outputs of the relational operator blocks are Boolean and hence to be converted to double through data-type conversion blocks. These signals are the control signals for the two switches Switchs 1 and 2. The threshold value for both the switches are set at 0.5 to reduce the number of data transmitted over the network. Thus if control signal for Switch1 exceeds the threshold, the control signal for the other switch falls below the threshold and vice-versa. The speeds of both the motors are connected to the input lines of both the switches. Thus if ω₁ > ω₂, the control signal for Switch1 is 1 if it is > 0.5, otherwise it will be 0. Thus the Switch1 transmits the first signal ω₁ (higher priority) and the Switch2 transmits the second signal ω₂ (lower priority). Similarly if ω₁ < ω₂, then ω₂ gets higher priority and is transmitted through Switch1 and ω₁ through Switch2. The switches are
connected to the input pins In1 and 3 of the CAN bus through which the signals are transmitted. The step disturbance is applied to both the motors and the Motor 1 is initially disturbed by a torque of 10 Nm for a period of 5 seconds after which it is removed from Motor 1 and transferred to Motor 2. Thus the speed and torque of Motor 1 deviate from the reference values as shown in Figs 7 and 6 respectively till a time of 5 seconds. After which they move towards their reference values.

![Fig. 6: Speed of Motor 1](image)

![Fig. 7: Torque of Motor 1](image)

The torque of both the motors is shown in Figs 7 and 9 respectively. It is observed that the value of torque is inversed with respect to each other during the time interval 0 to 5 seconds and after 5 seconds. This is normally happens in constant speed applications, wherein the loads are shared by different motors.

The speed of the Motors 1 and 2 are shown in Figs 6 and 8 respectively. Similar to torque characteristic, the speed of both the motors also are inverse with respect to each other. At the same time the value of the speed settles to a desired value depending upon torque disturbance.

![Fig. 8: Speed of Motor 2](image)

![Fig. 9: Torque for Motor 2](image)

The integral time error of Motor 1 is shown in Fig. 10 and the error rises up to 5 seconds because of the disturbance and after which it starts declining towards 0. However the Motor 2 is initially undisturbed and runs at its rated values but after 5 seconds, because of the disturbance, there is a sudden change in both its speed and torque as seen from Figs 8 and 9 respectively. The integral time error of Motor 2 is shown in Fig. 11 remains negative up to 5 seconds after which it starts increasing in the presence of a disturbance.

![Fig. 10: Integral Time Error of Motor 1](image)

![Fig. 11: Integral Time Error of Motor 2](image)

The results obtained in both the methods dynamic and fixed are shown in Table 1. From the table, the deviation in speeds from their reference values is far lesser for the dynamic scheduling (greatest error first) compared to fixed priority.
2.4 Dynamic Scheduling with Multiple Signals from Each System

In this section, the dynamic scheduling algorithm for messages with dependencies is considered.

For a control of DC motor the calculation of torque and speed is essential. In a networked system, it is known that all the information will be transmitted through CAN bus having its own priorities. Hence, it is essential to construct logic in the dynamic scheduling algorithm, to decide on which data is to be transmitted.

In dynamic scheduling algorithm, the torque $T_1$ and speed $\omega_1$ of Motor 1 are measured continuously and their instantaneous values are shown in Figs 12 and 13 respectively. Their errors with respect to the reference values are calculated. $\omega_1$ and $T_1$ are connected to Pins 1 and 2 of Switch 1 respectively, the threshold of switch1 is set to 0.5 as seen in the previous stage and the control pulse is the output of the relational operator $\omega_1 > T_1$ that compares the errors in speed and torque. The output of Switch 1 is connected to the pin1 of Switch 3 as well as Switch 4.

A very similar procedure is adopted for Motor 2 as well, whose torque $T_2$ and speed $\omega_2$ are shown in Figs 14 and 15 respectively. The data transmitted over the CAN bus will either corresponds to the instantaneous torque or the instantaneous speed of the motors depending on whichever quantity in each motor has the greatest error.

### Table 1: Results Comparison

<table>
<thead>
<tr>
<th>Motor</th>
<th>Priority</th>
<th>Loss probability</th>
<th>Data Transfer (kbps)</th>
<th>Measured speed (rad/s)</th>
<th>Deviation from Reference (rad/s)</th>
<th>Kp</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/C1</td>
<td>Greatest</td>
<td>0.6</td>
<td>256</td>
<td>124.7</td>
<td>1.3</td>
<td>1.03</td>
</tr>
<tr>
<td>M/C2</td>
<td>Error first</td>
<td>0.6</td>
<td>256</td>
<td>123.6</td>
<td>2.4</td>
<td>1.03</td>
</tr>
<tr>
<td>M/C1</td>
<td>Error first</td>
<td>0.01</td>
<td>256</td>
<td>124.7</td>
<td>1.3</td>
<td>1.03</td>
</tr>
<tr>
<td>M/C2</td>
<td>Error first</td>
<td>0.01</td>
<td>256</td>
<td>123.6</td>
<td>2.4</td>
<td>1.03</td>
</tr>
<tr>
<td>M/C1</td>
<td>Fixed</td>
<td>0.6</td>
<td>256</td>
<td>83</td>
<td>43</td>
<td>1.03</td>
</tr>
<tr>
<td>M/C2</td>
<td>Priority</td>
<td>0.6</td>
<td>256</td>
<td>82</td>
<td>44</td>
<td>1.03</td>
</tr>
<tr>
<td>M/C1</td>
<td>Priority</td>
<td>0.01</td>
<td>256</td>
<td>83</td>
<td>43</td>
<td>1.03</td>
</tr>
<tr>
<td>M/C2</td>
<td>Priority</td>
<td>0.01</td>
<td>256</td>
<td>82</td>
<td>44</td>
<td>1.03</td>
</tr>
</tbody>
</table>

Motor 1 is initially undisturbed whereas Motor 2 has a disturbance torque of 10 Nm for the first 5 seconds. After this, the disturbance in Motor 2 is removed and applied to Motor 1. Thus for the first 5 second Motor 2 gets higher priority and its signal is transmitted through In 1 of CAN bus.

During this time, the signal of Motor 1 gets transmitted through CAN input port. From the above observation, either $T_1$ or $\omega_1$ gets transmitted based on their instantaneous error. After 5 s, Motor 1 is disturbed and hence its signal gets
transmitted followed by the signal from Motor 2. From this observation, it can be seen that most of the time only torque gets transmitted. This is because the error in torque \( T_e \) of the motor that is disturbed is greater than the error in speed \( w_e \).

4. CONCLUSION
This paper presents the need for developing a scheduling algorithm which must consider dependencies among the tasks. This is very essential for real time industrial system, in which each data from sensors and controller are important. This solution will be more applicable wherever there is a communication constraint as well as the controller design were not possible to change.

REFERENCES