TABLE 3

Amplitudes and time-locations of the developed input shapers

Command Shaping Techniques	Amplitudes (volts)			Time locations (sec)		
	a_1	a_2	a_3	t_1	t_2	ta_3
Standard 3-impulse IS	0.151	0.398	0.349	0	0.7	1.4
Adaptive 3-impulse IS (amplitudes)	0.250	0.50	0.249	0	0.7	1.4
Adaptive 3-impulse IS (time locations)	0.151	0.398	0.349	0	1.5	3.0
Adaptive 3-impulse IS (ampl. & time)	0.184	0.490	0.249	0	1.4	2.8

TABLE 4

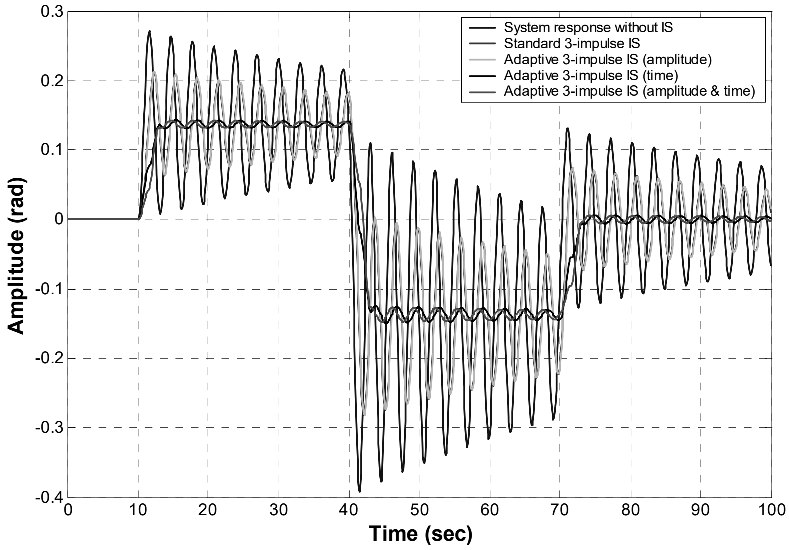
Rise time of the employed command shaping techniques

Employed Techniques	Rise time (sec)
System response without IS	0.775
Standard 3-impulse IS	1.355
Adaptive 3-impulse IS (amplitudes)	1.42
Adaptive 3-impulse IS (time)	2.46
Adaptive 3-impulse IS (amp & time)	2.53

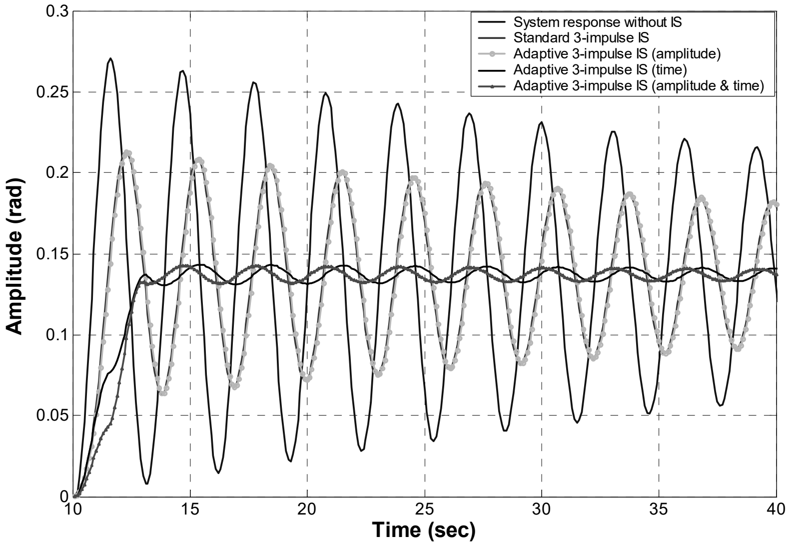
The magnitude and time location of the impulses of the 3-impulse input shaper were obtained by solving Eq. (12). Table 3 shows the amplitudes of the three impulses and their corresponding time locations. For discrete implementation of the input-shaper, locations of the impulses were selected at the nearest sample time-step.

The corresponding system responses to the applied shaped and unshaped input signals are shown in Figure 19. With the three-impulse sequence, the oscillations in the system response were found significantly reduced. These can be observed by comparing the system response to the unshaped input. Figure 19(a) shows the system response for the duration of experiment (100 sec), while Figure 19(b) represents the operation from 10 to 40 seconds. It can be seen from this figure that there is a significant amount of vibration reduction achieved with the employed controllers in comparison to the system without command shaping.

To investigate time domain response of the system with the employed techniques, rise time was recorded, see Table 4. The system response without



(a) Time domain response over the complete cycle



(b) Time domain response from 10 to 40 secs

Fig. 19: Performance of the employed 3-impulse input shapers

command shaping has recorded the shortest rise time of 0.7775 sec, followed by that with the standard input shaper with a rise time of 1.355 sec. However, the adaptive input shapers have recorded slow system response with rise times of 1.42 sec, 2.46 sec and 2.53 sec for adaptive amplitude, adaptive time-location and adaptive amplitude and time-location, respectively.

Generally, the obtained results show that the introduction of command shaping resulted in a delay in the system response. This delay is equivalent to the convoluted impulses during the shaping process. This can be attributed as a main drawback of the command shaping algorithms in general. To obtain a faster system response, a feedback control method would be augmented with the command shaping algorithm.

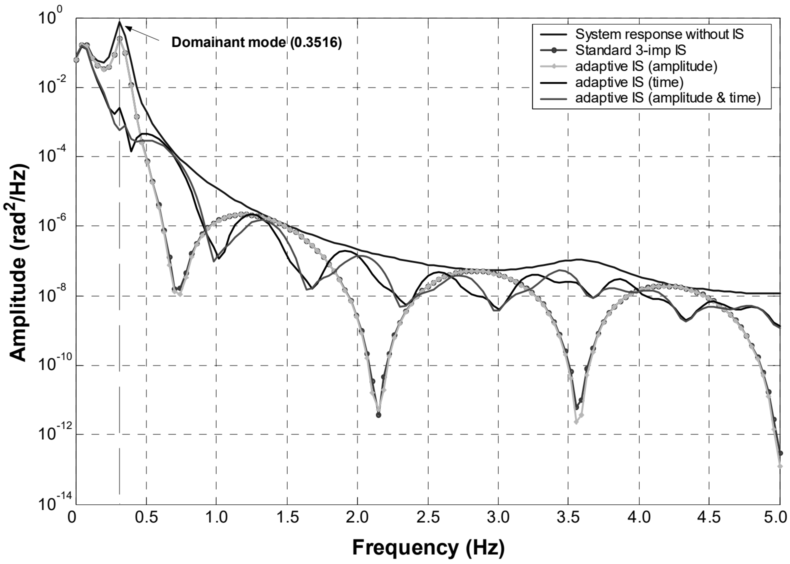
It can also be noticed from the power spectral density (PSD) plot shown in Figure 20 and vibration reduction in Table 5 that vibration of the system was dramatically reduced. As shown in Figure 20(a), the system has a single dominant mode at 0.3516Hz. Since, this work focuses on the vibration control of the system, the spectral attenuation at the dominant mode region is recorded in Table 5 and plotted in Figure 20(b).

A comparative performance of the system with the standard 3-impulse input shaper, adaptive amplitude 3-impulse input shaper, adaptive time-location 3-impulse input shaper and adaptive amplitude-time 3-impulse input shaper is presented in Table 5. It is evident from the results that the standard and the three adaptive input shapers have performed well in reducing the system vibrations. Among the employed controllers, the best result in terms of vibration reduction was achieved with the adaptive amplitude-time input shaper (65.41dB), followed by the adaptive time input

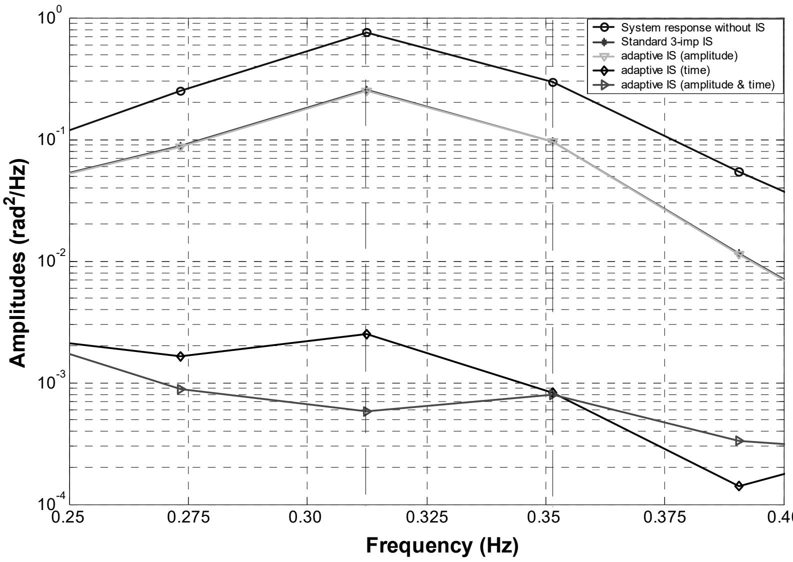
TABLE 5

Amount of vibration reduction with the employed 3-impulse input shapers

Employed Command Shaping Techniques	Vibration amount (dB)
Standard 3-impulse IS	11.11
Adaptive 3-impulse IS (amplitudes)	11.20
Adaptive 3-impulse IS (time)	57.95
Adaptive 3-impulse IS (amp & time)	65.41



(a) PDS for the whole duration



(b) PSD for the dominant region

Fig. 20: Power spectral density

shaper with 57.95dB, and then the adaptive amplitude input shaper with 11.20dB, and finally the standard 3-impulse input shaper with 11.11dB reduction.

Figure 21 shows the GA objective function profile, sum of squared error (SSE), of the three adaptive input shapers. The change in the objective function for the adaptive amplitude input shaper is not significant in comparison to the other two adaptive input shapers. Table 6 shows the final values of the SSE at the end of 50 generations.

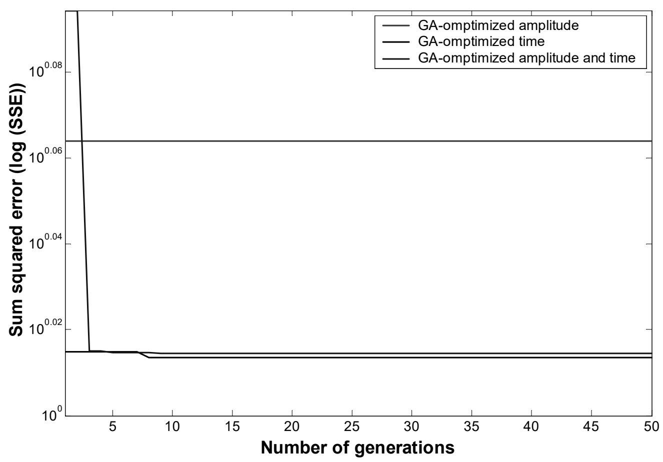


Fig. 21: GA objective function (SSE).

Legend: – – – GA optimized amplitude; - - - GA optimized time; —– GA optimized amplitude and time;

TABLE 6

GA objective function

Adaptive Input Shapers	Values of SSE after 50 generations
Adaptive 3-impulse IS (amplitudes)	14.4116
Adaptive 3-impulse IS (time)	10.7588
Adaptive 3-impulse IS (amp & time)	10.8138

5. CONCLUSION

Genetic algorithm (GA) is inspired by the mechanism of natural selection that emulates the laws of evolution and genetics to yield optimal solution to complex problems. This paper has presented an investigation into utilization of GA in the field of control engineering, specifically in tracking control and vibration suppression. The potential of GA has been assessed in three case studies.

Case 1 presented the development of hybrid learning control schemes with GA for input tracking and vibration suppression of a flexible manipulator. The control scheme has been implemented and tested within simulation and experimental environments and its performance has been evaluated in terms of input tracking capability and vibration suppression at the resonance modes of the manipulator. An acceptable input tracking control and vibration suppression have been achieved with the proposed control strategy.

In Case 2, the design and implementation of an adaptive active control mechanism using GA have been presented and verified through simulated exercises in a flexible fixed-free beam system. The performance of the control system in vibration reduction with different types of excitation has been assessed. It has been demonstrated that on average, a significant amount of vibration reduction over the full range of frequencies of the input signal has been achieved.

In Case 3, two types of command shaping methods, namely, standard input shaper and GA-based adaptive command shaper have been developed and investigated for vibration control in the vertical movement of a TRMS. Significant improvement in the reduction of system vibration has been achieved with the employed techniques as compared to the system with unshaped bang-bang input. Among the four employed command shapers, the best performance has been achieved with the adaptive amplitude and time 3-impulse input shaper.

We have shown that when locations of the impulses are fixed at the theoretical value there is no significant reduction in vibration compared to theoretical command shaping even though the amplitudes are varied. Speed of response depends on the locations of impulses, not on the amplitudes of the impulses. When the amplitudes of impulses are fixed at theoretical values but the locations are varied, a significant amount of reduction in vibration can be achieved at the cost of long delay. It is noted from the obtained results that there is a delay in the system response as compared with that using unshaped input. This is equivalent to the length of the impulse. This can be tackled by augmenting command shaping with a feedback control method.

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