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TERRAIN PREVIEWING FOR AN ACTIVE SUSPENSION SYSTEM (U)

by

A.W. McCormac and D.M. Hanna
R.J. Anderson and J.E. Tragenza*

*Queen's University Department of Mechanical Engineering

PCN No. 0318N-11

February 1994

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ABSTRACT

A terrain previewing system has been created for the experimental active suspension vehicle that exists at Defence Research Establishment Suffield. The system employs ultrasonic transducers to measure the terrain elevation just ahead of the vehicle's front wheels. The elevation information is processed and correlated to vehicle forward speed by an on-board microcomputer. The elevation profile is then passed to the active suspension control computer so that algorithms used to control the active suspension acutators can have advance warning of impending bumps and dips. Preliminary results on a fabricated steel calibration bump show that active control using preview information performs significantly better than passive suspension, and measurably better than active control without preview.

EXECUTIVE SUMMARY

In support of the Canadian Forces vehicle acquisition offices, testing establishments and operators, Defence Research Establishment Suffield (DRES) has had a long term program of applied R&D in the field of vehicle mobility. Mobility is one of the key criteria used to select vehicles (along with Firepower and Protection), as it is an important element in battlefield tactics. DRES was requested by PMO AALV 05, to evaluate the benefits and disadvantages of active suspension systems in military vehicles. Active suspensions typically use computer-controlled hydraulic wheel actuators to lift and drop the wheels in response to the terrain, hence improving the ride quality and handling characteristics of the vehicle. DRES refitted a SMP Iltis 1/4 ton Utility Truck with an active suspension system and then proceeded to evaluate the performance. One method of improving the system was through the use of an ultrasonic terrain previewing device, which is the subject of this report.

The addition of terrain preview information allows two distinct paradigms of control to be investigated. Previously, only leading factor control algorithms could be used on the Iltis, as only dynamic state variables were being measured. Leading factor control depends on measuring a disturbance in one or more state variables, and controlling the response to the disturbance. Force and motion sensors used to measure the vehicle dynamic state all require that physical disturbance to occur before it can be measured. That is the important distinction.

With terrain previewing, anticipatory control algorithms may also be investigated, which predict the change in state and attempt to prevent it from occuring. In other words, if the terrain profile is known in advance, the active suspension actuators can be modulated to follow that profile, such that the state disturbance is not necessary. Such ideal performance is unlikely however, due to physical constraints on the actuators and the limitations of the terrain previewing system itself.

Following an extensive review of sensor technology, ultrasonic sensors were selected to provide preview information. These sensors are rugged, sufficiently accurate and cost effective for this application. The system provides useful information up to vehicle speeds of about 70 km/h.

One preview control algorithm was implemented in software. Results from preliminary experiments are presented which show that the preview control algorithm performed significantly better than the passive suspension and marginally better than another active suspension algorithm for the discrete disturbance tested. Only temporal tests have been done to evaluate performance of the previewing algorithm. Statistical performance analysis must wait until test data are returned by the independent contractors currently performing a complete on- and off-road test battery of the active suspension test vehicle.

TABLE OF CONTENTS

	Page No.
Abstract	ii
Executive Summary	iii
Table of contents	v
Introduction	1
Active Suspension System	2
Terrain Preview System	5
Preview Control	6
Preliminary Results	9
Conclusions	10
References	11

INTRODUCTION

Recent research conducted by Queen's University and the Defence Research Establishment Suffield (DRES) has resulted in the development of a microcomputer controlled, hydraulically actuated active suspension system for the 1/4 ton four wheel drive utility truck called the Iltis, shown in Figure 1. The system has been designed to accommodate various control schemes through relatively straightforward changes to software and to transducers which collect the state variable data required for the specific algorithm. Some algorithms have been tested and the active suspension, both hardware and software, has been shown to be capable and reliable.

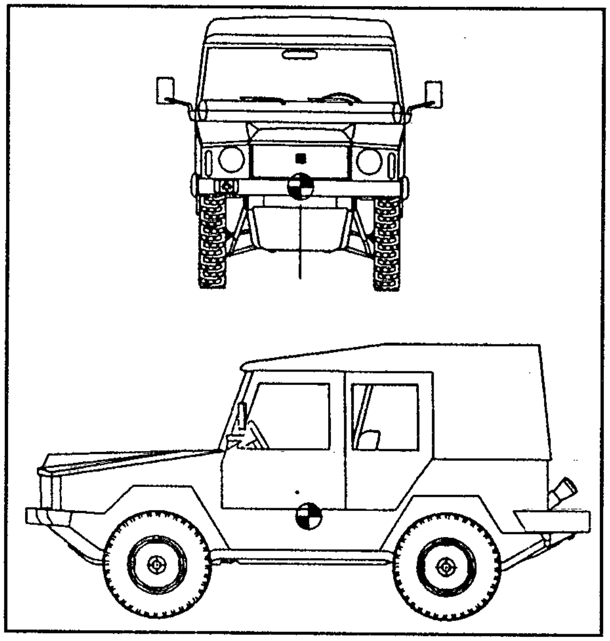

Figure 1: Bombardier Iltis 1/4 ton Utility Truck

A review of active suspension literature shows that for a number of years, there have been theoretical studies of the potential benefits of having a feed-forward path in the system, whereby information relating to roadway disturbances about to be encountered by the vehicle could be sensed and used in the control scheme. There is general agreement for example, in works by Sharp [1] and Foag and Grubel [2], as well as many older papers, that the benefits of this 'preview control' are substantial if such a controller can be realized in hardware.

Effort at Queen's and DRES has been aimed at implementing a terrain preview system on the Iltis. Following an extensive review of sensor technology, ultrasonic sensors were selected for use in a preview mode. These sensors are sufficiently rugged and accurate, and cost effective for this application.

The paper describes the vehicle, the active suspension hardware, the terrain preview system, a simple control algorithm, and the results of tests of the actively suspended Iltis with preview control. Since the Iltis is primarily intended for off-road operation, the main design goal is to improve performance when the vehicle encounters discrete obstacles or traverses very rough terrain. The behaviour of the system under these conditions is the primary focus of the paper.

ACTIVE SUSPENSION SYSTEM

The conventional Iltis is a 1/4 ton four wheel drive military vehicle used by the Canadian Forces. Figure 2 shows the suspension of the unmodified vehicle. The suspension stiffness is generated by two transverse leaf springs, one at the front and one at the rear. Added stiffness comes from rubber sleeves bonded to the shock absorbers which connect a lower control arm to the vehicle body at each wheel station.

Modifications have been made to a single Iltis vehicle in order to equip it with an active suspension. The vehicle was first fitted with an hydraulic system, various transducers and an on-board computer. The software was designed to read transducers and send control signals, but was purposefully flexible in that it did not contain a fixed control algorithm. Rather, any control scheme could be easily implemented by installing the required transducers and coding the algorithm into the supervisory program.

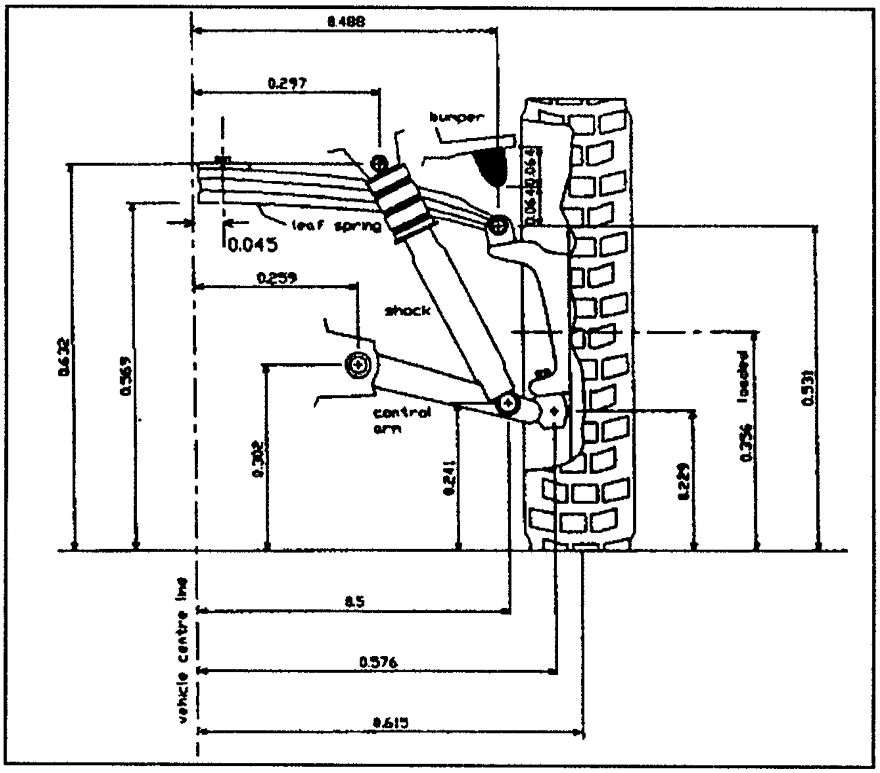

Figure 2: Stock Iltis Suspension Assembly

The hydraulic suspension supplements the existing Iltis suspension by adding four rapid response servo-actuators in the place of the shock absorbers. The leaf springs remain. A belt-driven hydraulic pump supplies 0.63 litres per second at 21 MPa (10 USGPM at 3000 psi). Peak flow demands are handled by accumulators located near each wheel station.

Overall control of the suspension is handled by an IBM-compatible 80386 microcomputer. This computer samples transducer values, calculates the control force required in each actuator, and sends force set points to each of four analog servo-amplifiers, as shown in Figure 3. These analog devices, one per actuator, have circuitry on them to implement Proportional, Integral, and Derivative (PID) modes of control, employing either force or displacement feedback. However, integral control is only useful for steady state systems and is not used. The active Iltis is typically run with only proportional control and with force feedback. The two-level control scheme frees the computer to the extent that control signals can easily be updated and sent to all wheel stations in less than 5 milliseconds.

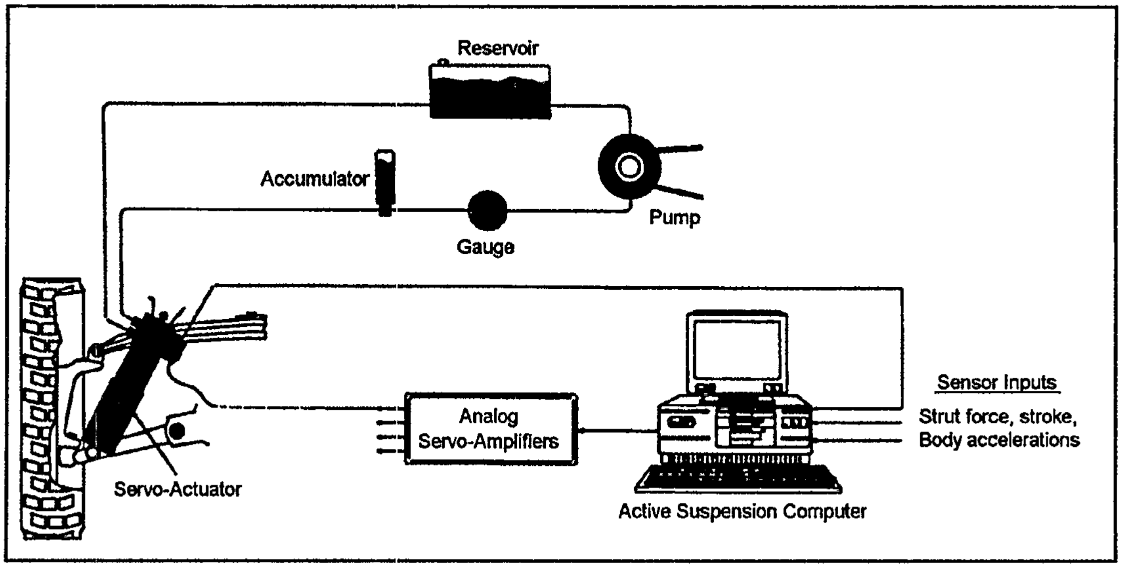

Figure 3: Iltis Active Suspension System Hardware

Transducers on the vehicle sample displacement and force in each actuator, velocity across each actuator, and tri-axial body acceleration. In this configuration, 15 of the available 32 channels of data acquisition are used. The remainder are free to be used for other transducers required by candidate control schemes.

The latest change made to the active Iltis has been the installation of 'preview' capability. It is now able to sense the vertical road profile ahead of the front wheels and use this information in the control algorithm. The sensors are ultrasonic and are controlled by a second 80386 on-board computer. Experiments are now being conducted with the Iltis and some early results are presented later in this paper.

TERRAIN PREVIEW SYSTEM

The preview system was designed in much the same way as the active system. It was intended to be a developmental system, and as such it has no specific algorithm for control. Rather, its flexible nature permits implementation of various preview information schemes. The primary limitations are dictated by system hardware, which consists of the following: ultrasonic transducers, sonar control modules, a control computer, and an ambient temperature sensor.

Ultrasonic transducers are located near the front bumper of the Iltis as indicated in Figure 4. They are triggered by sonar control modules located under the hood above the left front wheel. A signal from the control module causes the ultrasonic sensor to emit 16 cycles of a square wave at a frequency of 50 kHz. This is followed by a blanking signal of 2.5 milliseconds duration. The blanking signal is used to eliminate stray reflections from other than the ground surface of interest. The transducer then switches to receive mode for 2.5 milliseconds. This cycle is then repeated. The control module counts the time between the transmit and receive signals utilizing a precision counter timer. The count that is read is scaled to a voltage between -5.0 volts and +5.0 volts. In the most simple mode of operation, the voltage signal is sent directly to the active suspension system computer, with updates every 5 milliseconds.

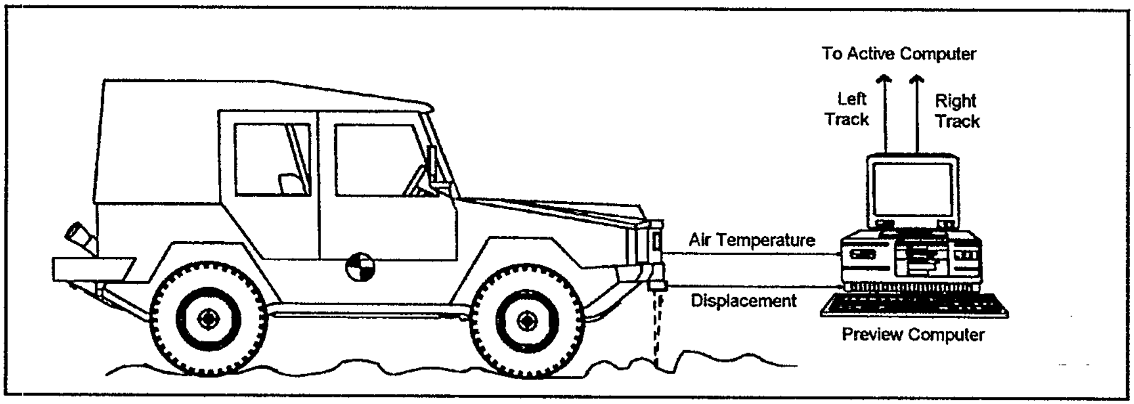

Figure 4: Terrain Preview System Hardware

Additional capability is built into the system in the form of a terrain preview computer. Although it performs a complete setup of the ultrasonic transducers upon system initiation, its main function is to make the system act as a 'smart' sensor. The preview computer may pass the voltage directly to the active control computer as described above, or it may manipulate this value. Once the preview computer reads the displacement (voltage) from the counter timer hold register, it may obtain other information to use to manipulate the basic displacement signal. For example, with a knowledge of instantaneous steer angle, it can change from one ultrasonic sensor to the other, or some combination of the two, to account for altered front wheel path. It can also sample the ambient air temperature transducer and adjust the speed of sound to further manipulate the displacement presented to the active suspension computer.

The specular reflectivity of the ultrasonic sensors makes them, as expected, sensitive to the surface being traversed. Reflectivities of approximately 0.90 from a plywood surface were observed in lab studies. While similar reflectivities have also been noticed on paved surfaces, as well as on a fabricated steel bump described later in this report, behaviour of the transducers in the off-road environment (i.e., dirt, grass, brush) has yet to be determined.

Based on a 5 millisecond update rate (which is achievable with control algorithms such as that described later in this paper), and based on a distance of 0.9 meters between the sensor and the front wheel, the maximum speed at which preview information can be obtained and processed is 70 km/h. This speed is sufficiently high for most off-road performance studies.

PREVIEW CONTROL

Langlois [4] surveyed the available active suspension preview literature and found that, although the theoretical development has advanced significantly, some difficulties remain with respect to implementation on a real vehicle. For example, most of the control schemes studied were based on quarter vehicle models due to the mathematical complexity of full vehicle models. In addition all of the controllers investigated used stochastic road profiles as input to the models. This creates difficulties when trying to respond to discrete bump inputs.

It was also necessary to find control algorithms which are realizable given the constraints of the Iltis as currently configured. In other words, given the vehicle measurements available from Iltis transducers and the limitations on physical location and response time of the ultrasonic sensors, Langlois needed a control scheme described in sufficient detail to allow implementation on the active Iltis.

Two controllers initially fit the above constraints. These were proposed by Tomizuka [5,6] and Thompson [7,8]. Both were initially subjected to an array of tests under computer simulation using the A'GEM multibody dynamics package [3]. Unfortunately, it was found that Tomizuka's control model required considerably more suspension travel than was available with the Iltis. Also, this controller was not speed adaptive, and thus would require recalculation of gains at each time step, making it unacceptable in terms of the required computation time.

Thompson's method showed promise in that it was speed adaptive even though it required state space information which is not available from the Iltis. An array of computer simulations with this controller provided a basis for development of a full vehicle controller.

Langlois [9] proposed a controller which would be better at negotiating discrete bumps with less attention given to off-road profiles. It is based on a full vehicle model but requires only limited state information. The primary goal of this controller was to minimize changes in force transmission into the vehicle body, resulting in small body accelerations and thus very good ride performance. In order to account for grades and corners, the controller must temporarily stiffen to create changes in body attitude. This adaptive stiffening is accomplished by measuring the average excursion of the preview signal from a nominal value over a specified length of terrain. If the excursion becomes large, the suspension stiffens allowing the body to follow grades. When the excursions are small, the suspension resumes zero force control for negotiation of small discrete bumps. The equation for the force disturbance rejection control algorithm is:

$$u_i = -S_{\lim} k_{eff} A_{scl} \Delta_i + c_1 \frac{\Delta_i}{\delta_w} + (c_2 + c_{eff}(1 - S_{\lim}))\dot{\Delta}_i \qquad (1)$$

where

k_{eff} = effective spring stiffness,
A_{scl} = actuator inclination scaling factor,
Δ_i = suspension travel (compression positive),
δ_w = maximum allowable wheel excursion, and
c_1, c_2 = undetermined parameters.

S_{lim} is a control limiting factor which adjusts the control to the wavelength of the disturbance. The control reduction is proportional to the ratio of average measured terrain height, h_{mavg} to the equilibrium sensor measurement distance h_{equiv}. The equation for S_{lim} is:

$$S_{\lim} = 1 - \frac{|h_{mavg} - h_{equiv}|}{h_{equiv}}; \quad for\,|h_{mavg} - h_{equiv}| < h_{equiv} \qquad (2)$$

$$S_{\lim} = 0; \qquad for\,|h_{mavg} - h_{equiv}| \geq h_{equiv}$$

and the value of S_{lim} varies between 0 and 1. A value of 0 prevents any transmitted force reduction. The same value of S_{lim} is used for the front and rear quarters on both sides.

PRELIMINARY RESULTS

The full vehicle preview controller proposed by Langlois was implemented on the Iltis in order to perform preliminary tests of the Terrain Preview System. Figure 5 compares vertical accelerations measured at the centre of mass of the Iltis as it is operated in three different control modes over a rounded bump 50 mm high and 176 mm long. The three curves are time delayed from each other for clarity. The first response curve indicates the body vertical acceleration time history for the anticipatory disturbance rejection algorithm based on preview information. The second is an active control algorithm which attempts, by leading factor control, to maintain constant load at the actuators at all times. The third response curve shows the response of a viscous shock absorber, simulated by using the actuators to produce velocity-dependent resistance only.

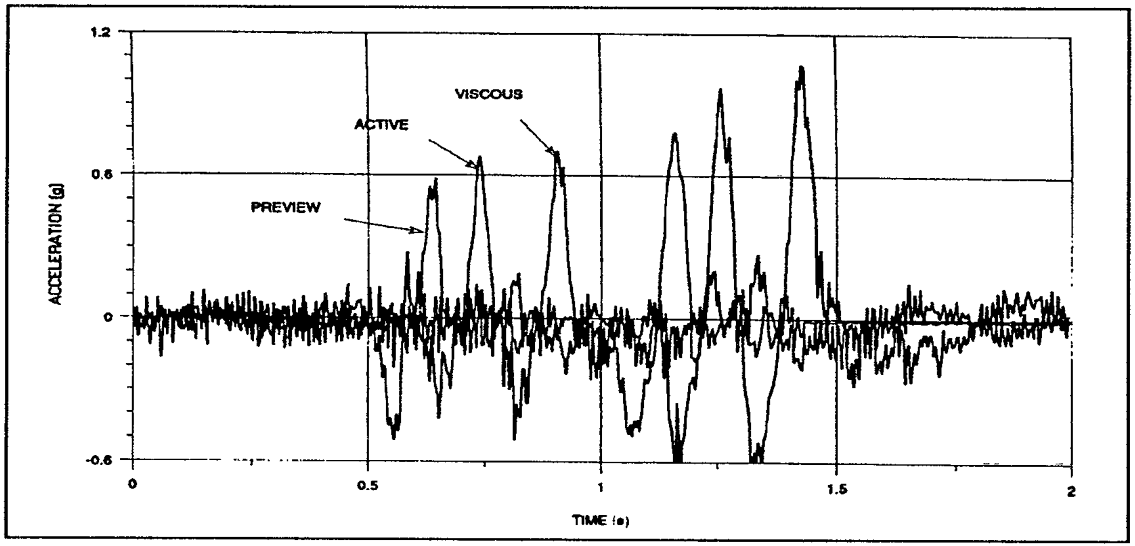

Figure 5: Vertical Acceleration of Experimental Iltis Centre of Mass, over 50 mm Bump

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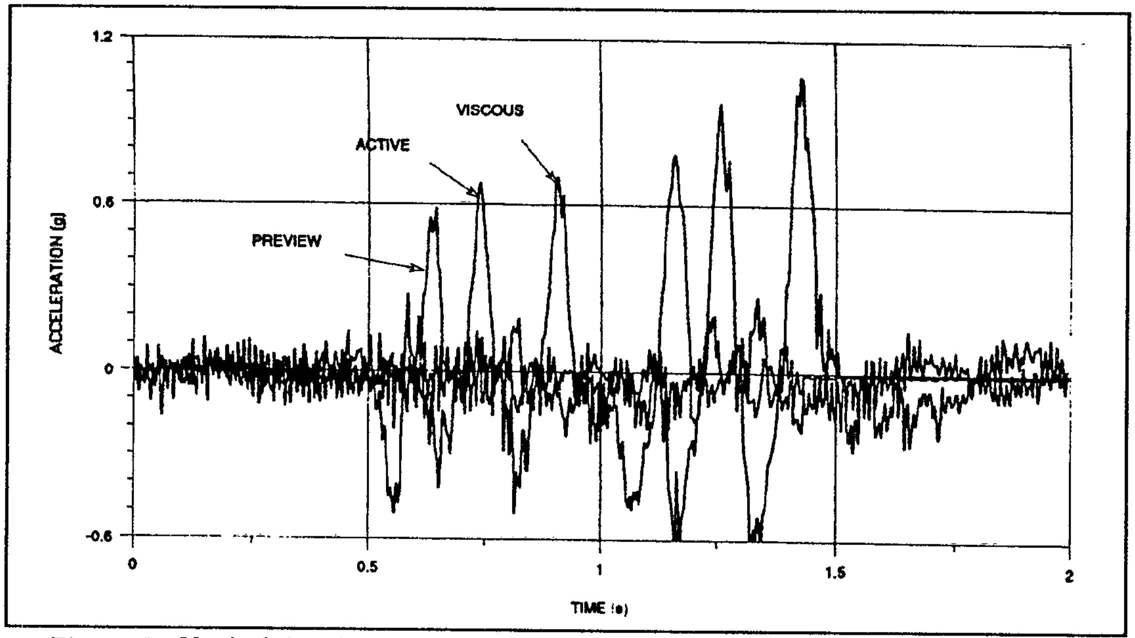

Figure 5: Vertical Acceleration of Experimental Iltis Centre of Mass, over 50 mm Bump

The leading factor active control algorithm reduces the body peak accelerations below those of the viscous shock absorber response. A further improvement in vehicle ride is evident with the preview controller. Root-Mean-Square acceleration values for the viscous, active, and preview curves are 0.205 g, 0.182 g, and 0.175 g respectively. Ignoring any frequency weighting normally associated with human ride comfort, in this case preview control provided approximately a 15% improvement in ride over the conventional shock absorber and a 4% improvement over the active suspension configuration without preview.

CONCLUSIONS

A terrain preview system has been realized on the Iltis active suspension research vehicle which utilizes ultrasonic sensors as the look-ahead device. The system provides new displacement information every 5 milliseconds which corresponds well with the active control computer, which also has a 5 millisecond update rate. In addition, this gives the system the capability to provide useful information up to approximately 70 km/h, which is in the range of interest for off-road travel. Sensitivity of the ultrasonic sensors to various surfaces has yet to be determined.

A simple disturbance rejection controller was implemented and preliminary test results are presented in this paper. The results are promising and show that the preview control algorithm performed significantly better than the passive suspension and measurably better than the active suspension force control algorithm without preview, for the discrete disturbance tested.

It appears that terrain previewing with an active suspension system promises improvements in performance. Effort must now be directed at developing and testing control algorithms for the preview system.

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