Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER
UNCLASSIFIED	508617

TITLE

DEVELOPMENT OF A PREVIEW CONTROL SYSTEM FOR THE DRES ACTIVE SUSPENSION RESEARCH VEHICLE

System Number:

Patron Number:

Requester:

Notes:

DSIS Use only:

Deliver to:

DRES

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD

CR 98-16

UNCLASSIFIED

Development of a Preview Control System for the DRES Active Suspension Research Vehicle *(Final Report)*

BY:

R.J. Anderson
Dynamics Laboratory
Queen's University

SUBMITTED TO:
SCIENTIFIC AUTHORITY

D. Hanna
Defence Research Establishment Suffield
Box 4000, Medicine Hat, Alberta, T1A 8K6

February 1995

CRAD

National Defence Défense nationale

Canada

Queen's University at Kingston

DEVELOPMENT OF A PREVIEW CONTROL SYSTEM FOR THE DRES ACTIVE SUSPENSION RESEARCH VEHICLE

FINAL REPORT
February, 1995

R.J. Anderson
Department of Mechanical Engineering
Queen's University

Dynamics Laboratory

Department of Mechanical Engineering

DEVELOPMENT OF A PREVIEW CONTROL SYSTEM FOR THE DRES ACTIVE SUSPENSION RESEARCH VEHICLE

FINAL REPORT
February, 1995

prepared for

D.M. Hanna
Vehicle Mobility Section
Defence Research Establishment Suffield
Ralston, Alberta
T0J 2N0

submitted by

R.J. Anderson
Department of Mechanical Engineering
Queen's University
Kingston, Ontario
K7L 3N6

SUMMARY

This document is the final report for Contract Serial No. W7702-0-R186/01-XSG entitled "Development of a Preview Control System for the Defence Research Establishment Suffield Active Suspension Research Vehicle". The work was sponsored by the Defence Research Establishment Suffield (DRES) with D.M. Hanna as the Scientific Authority at DRES.

A previous contract between DRES and Queen's University had produced a working prototype of an active suspension mounted on a Canadian Forces Iltis 1/4 ton utility vehicle. The goal of this contract was to develop a"preview control" system capable of determining the profile of the ground ahead of the vehicle and feeding this information back to the active suspension system in order to improve its ability to enhance vehicle ride and handling performance.

The preview system has been designed, built, installed and delivered to DRES for further testing. The details of the system are described in companion reports which are referred to in the body of this report.

Contents

1 INTRODUCTION

A contract between DRES and Queen's University for development of a prototype active suspension system on an Iltis military jeep led to the design and installation of a fully active suspension system. This work is described in [1,2,3,4,5, and 6]. The contract did not call for the development or testing of a control algorithm. It required that relatively simple tests of the system be undertaken to establish an ability to control the motion of the vehicle without specifying the need for improving ride quality. The task was to provide a vehicle on which algorithms could be tested at a later date.

In subsequent consideration of a control strategy for the Iltis, the operational role of the vehicle had to be kept in mind. Unlike many civilian vehicles where the ride quality and handling on relatively smooth roads is of primary importance, the Iltis must also be able to operate in severe off-road conditions.

Control schemes for highway operation rely to a large extent on the stochastic nature of the disturbing input, namely road roughness. The roughness is characterized by short wave-length vertical disturbances which affect the vertical ride-quality of the vehicle. In addition, an active suspension designed for good handling performance will account for very low frequency motions which arise from curve negotiation. The active suspension will respond to these maneuvers by adjusting roll angle, vertical tire load, or any other handling parameter so that the desired handling characteristic is achieved.

The situation for off-road conditions is unlike either of the above cases. Off-road operation is likely to result in encounters with discrete obstacles at random times. It is impossible to predict the location, size, or shape of the obstacles by any statistical method so that the stochastic control scheme suggested above will not work. The handling control system relies on recognition of certain low frequency maneuvers before control is applied. The resulting slow response is adequate for handling but will not be sufficient to account for interaction with obstacles at off-road speeds.

A viable method for improving vehicle operation under off-road conditions is one where the control system is able to sense the impending arrival of an obstacle so that the actuators in the active suspension can respond in an

optimal fashion. The implementation of such a system requires provision for a forward looking vision system which records the profile of the ground ahead of the vehicle and feeds this information to the control system. The profile information can be used calculate the action which should be taken by the suspension in order to provide the best possible vehicle motion.

The subject of this report is the development of a "Preview Control System" for the Iltis vehicle equipped with the hydraulic active suspension hardware. The work was accomplished under Contract Serial No. W7702-0-R186/01-XSG entitled "Development of a Preview Control System for the Defence Research Establishment Suffield Active Suspension Research Vehicle". The work was sponsored by the Defence Research Establishment Suffield (DRES) with D.M. Hanna as the Scientific Authority at DRES.

This report and the three others which accompany it:

- Langlois, R.G., McGregor, G.F., and Anderson, R.J., *Feasibility of Preview Control for the Iltis*, Queen's University Dynamics Laboratory report No. DL/DRES/90/1, September, 1990.

- Tregenza, J.E., *Operator's Manual and Technical Reference Manual for the Active Iltis*, Queen's University Dynamics Laboratory Report No. DL/DRES/91/100, October, 1991.

- Langlois, R.G., *Preview Control Algorithms for the Active Suspension of an Off-Road Vehicle*, M.Sc. Thesis, Queen's University, Department of Mechanical Engineering, August, 1991.

constitute the full description of the work accomplished under the contract. Other reports are referred to in the text and have either been previously supplied to DRES or are available from the author on request.

2 BACKGROUND STUDY

There are many possible ways of sensing the ground profile ahead of a moving vehicle. Possible sensors include those using light, sound, microwaves or

radar. The use of vision systems like those currently being used in robotics applications is also a possibility. As an initial task, it was necessary to perform a comprehensive search of the literature to establish the current state-of-the-art in this area.

2.1 Literature Search

An initial survey of available sensors was made in order to ascertain which meet the performance and price specifications required for this project. The sensor had to be able to distinguish the profile of oncoming obstacles with reasonable accuracy and, ideally, should have been able to estimate the stiffness of the obstacles. For example, in winter operation, there is a significant difference between driving over a snow covered rock and driving over a pile of soft snow having the same profile.

Additionally, a literature search aimed at determining the current state of research into Preview Control Systems for vehicles was undertaken.

The results of the first phase of the program are summarized by Langlois, McGregor, and Anderson [8]. That report documents the results of the literature survey and hardware considerations.

The overwhelming conclusion of the literature survey was that very significant gains in performance were theoretically possible with preview control. Typical of these results were those of Sharp [9] who compared the performance of a half-car mathematical model with no preview ('uncorrelated'), with front wheel response acting as preview for the rear wheels ('wheelbase'), and with look-ahead capability ('overtaking'). The performance of the vehicle was enhanced with each step toward full preview capability. The vehicle with 'overtaking' preview clearly outperforms all of the others.

Consideration of sensor technology covered five types of noncontacting sensors. These were: ultrasonic, laser, photoelectric, microwave, and electro-optical. Each of these technologies is described in [8] and, finally, a case is made for using ultrasonic sensors. It was the only sensor that was able to meet the specifications as well as cost and availability requirements. Ulti-

mately, ultrasonic sensors were procured and installed on the active Iltis.

3 PREVIEW SYSTEM DEVELOPMENT

The initiation of this phase of the contract was dependent upon a favourable outcome of the background study. The Scientific Authority made the decision to proceed based upon three criteria:

1. The information gathered from the literature search had to show evidence of promising results stemming from a preview control scheme.

2. The sensors chosen had to be available within the budgetary and time constraints of the project and had to be based upon a proven and reliable technology.

3. The estimated performance of the vehicle using preview control under off-road conditions had to be sufficiently improved over other options to warrant further investigation.

After the Scientific Authority decided to proceed, the following tasks were undertaken.

4 DESIGN AND PROCUREMENT

During this phase of the project, detailed design of modifications necessary to install the system on the Iltis were be made. Equipment was ordered and received.

Full descriptions of the equipment and the design of the system are given by Tregenza in *Operator's Manual and Technical Reference Manual for the Active Iltis* [4]. That document also describes the operation of the vehicle when equipped with the preview control system and lists the source code of all software used by the on-board computer.

5 COMPUTER SIMULATION AND CONTROL SCHEME DEVELOPMENT

The development of the control scheme for the Active Iltis equipped with preview sensors required initial effort in the area of laboratory testing of sensors. The ultrasonic sensors and their related electronics were assembled in a laboratory and the sensors were fixed in place over a platform mounted to a controllable hydraulic cylinder.

The sensors and software developed for their control were operated over simulated road profiles in an effort to gauge the performance of the preview system before it was mounted on the vehicle. The road profiles were simulated by using the hydraulic cylinder to move the platform. This gave two measures of the vertical position of the platform; one form the ultrasonic sensors and another from the LVDT mounted within the hydraulic cylinder.

These initial tests were successful and the sensors were mounted on the Iltis with confidence.

The existing A'GEM computer simulation of the dynamics of the Iltis was modified to include the preview control scheme and become a design tool for optimizing the system.

Langlois [7] conducted a major study into the dynamics of vehicles with preview control. He developed simulations of the Iltis and predicted the response of the vehicle, over a standard off-road profile supplied by DRES, with suspensions ranging from passive to fully active with preview.

He developed a preview control algorithm based upon isolating the vehicle body from dynamic loads transmitted through the suspension, the so-called "Zero-Force Controller" which promised far superior performance to that achievable with a passive suspension alone.

6 INSTALLATION AND TESTING

During this portion of the contract, the hardware which has been subjected to laboratory testing was installed on the Iltis which was fitted with velocity, steering angle, and preview sensors. The development of software continued and the on-board computer was installed and tested in the stationary Iltis. Final pretests of the system were made by driving over predetermined profiles in the Kingston area.

The final component of this project involved the analysis of experimental results from off-road tests. Comparisons were made with the measured performance for the Iltis equipped with suspension systems varying from passive to active with preview. These data are summarized by Langlois, Hanna, and Anderson in [9].

Further tests have been conducted by DRES staff in Suffield. Data from these tests are not available for this report.

7 CONCLUSION

The goals of the original project have, to a large extent, been met by the work carried out under this contract. An Iltis vehicle with an active suspension system incorporating preview sensors has been delivered to DRES and tested. A simulation capability for active suspensions has been developed and continues to be modified for more complex non-linear suspensions and incorporation of four-wheel steering. CAD pre- and post- processors are the latest development in this area and they are nearly ready for delivery to DRES.

8 REFERENCES

[1] Tregenza, J.E., *State of the Art Review - Active Suspension Evaluation Program*, Queen's University Dynamics Laboratory report No. DL/DRES/89/1, January 1989.

[2] Tregenza, J.E., *Active Suspension Conceptual Design Report*, Queen's University Dynamics Laboratory Report No. DL/DRES/88/2, November, 1988.

[3] Tregenza, J.E., *Operator's Manual Version 3.3 - Active Suspension Iltis*, Queen's University Dynamics Laboratory Report No. DL/DRES/90/2, August, 1990.

[4] Tregenza, J.E., *Operator's Manual and Technical Reference Manual for the Active Iltis*, Queen's University Dynamics Laboratory Report No. DL/DRES/91/100, October, 1991.

[5] Tregenza, J.E. and Anderson, R.J., *Iltis Data Package*, Queen's University Dynamics Laboratory Report No. DL/SPEC/90/1, September, 1990.

[6] Langlois, R.G., *Terrain Profile Processing*, Queen's University Dynamics Laboratory Report No. DL/91/RGL/1, January, 1991.

[7] Langlois, R.G., *Preview Control Algorithms for the Active Suspension of an Off-Road Vehicle*, M.Sc. Thesis, Queen's University, Department of Mechanical Engineering, August, 1991.

[8] Langlois, R.G., McGregor, G.F., and Anderson, R.J., *Feasibility of Preview Control for the Iltis*, Queen's University Dynamics Laboratory report No. DL/DRES/90/1, September, 1990.

[9] Sharp, R., *Preview Control of Vehicle Ride - Optimal Control Theory Background*, CCG Course Notes, July, 1990.

[9] Langlois, R.G., Hanna, D.M. and Anderson, R.J., *Implementing Preview Control on an Off-Road Vehicle with Active Suspension*, Proceedings of the 12th IAVSD Symposium on the Dynamics of Vehicles on Roads and Tracks, pp. 340-353, 1991.

#508617