Control Authority Transition System, Half-Car Platform, Vehicular Simulator and Dynamic Switching Analysis between The Human Being and Driver Assistance System [1]

Tankut Acarman
School of Engineering
Ondokuz Mayıs University
Samsun, TR-55139, Turkey
acarman@omu.edu.tr

Coşku Kasnakoğlu
Department of Electrical Engineering
The Ohio State University
Columbus, OH 43210, USA
kasnakoglu.1@osu.edu

Yaodong Pan
Department of Electrical Engineering
The Ohio State University
Columbus, OH 43210, USA
pan.68@osu.edu

Ümit Özgüner
Department of Electrical Engineering
The Ohio State University
Columbus, OH 43210, USA
ozguner.1@osu.edu

Abstract

The Control Authority Transition (CAT) system project (supported by The OSU Center for Automotive Research and Intelligent Transportation Consortium) has led to emulation of the control authority transition algorithms in the physical half-car environment through The Ohio State Virtual Environment System (OSU-VES). By creation of the artificial traffic environment and possible accident hazards scenarios, the CAT system's interventions to the "inattentive" or "inadequate" drivers are under consideration. The development and improvement of the CAT, OSU-VES and half-car platform is a test-bed for the study of driver's perception-reaction time, behavior, driver-vehicle interactions, crash avoidance maneuvers, advanced safety systems, and Intelligent Transportation System technologies.

1 Introduction

One of the objectives of Intelligent Vehicle (IV) technologies is to improve safe operation of the vehicle on a real-time basis by monitoring driver behavior. Most recent IV literature is focused on collision and accident avoidance systems supporting the driver and compensating his/her responses in case of an emergency maneuvering actions. An active safety system supporting average drivers in controlling laterally critical and emergency situations has been proposed in [3]. Safe lane keeping or lane following for the attentive or temporarily inattentive driver has been proposed, [4]. An automated Control Authority Transition (CAT) system has been proposed in [1, 2]: The CAT system will help the driver's short-term maneuvering decisions by adding or compensating his/her steering and breaking/throttle inputs in case of his/her anomalies especially when he/she is impaired by drugs, fatigue or physical handicaps. The main goal of this paper is to present the CAT system, Half-Car Platform and Virtual Environment Simulator proposed to be a test-bed for Intelligent Vehicle Technologies and to show the effectiveness of the CAT system using physical half-car platform and Vehicular Simulator capable of creating different traffic, environment and accident scenarios. Also this test-bed is used to study different intervention mechanisms to the driver in order to observe time-responses of the vehicle states (yaw rate, longitudinal velocity, etc.,) and accident scenarios.

The paper is divided in five sections. In Section II, we present the Control Authority Transition (CAT) system and its main tasks. In Section III, we present The Virtual Environment System (OSU-VES), its architecture and modules as a highly capable test-bed for IV technology research. In Section IV, we emulate some accident scenarios created by OSU-VES related to some modes of operation of the CAT system in the half-car platform and implement different authority transition mechanisms to prevent accidents. Finally, we present some conclusions from this work.

[1] This work is supported through a project ("Control Authority Transition System, Half-Car Platform and The Virtual Environment System as a test-bed for ITS Technologies", 2002-2003) by the OSU CAR-IT Consortium, ITS Thrust Area.

0-7803-7848-2/03/$17.00 ©2003 IEEE

2 Control Authority Transition (CAT) system

Impaired drivers may show substantially reduced capabilities in reaction while driving. Intelligent Vehicle technology may help in providing an intervention setup that would shift the control authority to an automatic control system. Such a system would compensate for the driver's performance reduction. A system, called Control Authority Transition (CAT) system, developed at OSU, aimed to accomplish the above goal. Initial work of the authors to improve safe operation of the vehicle on a real-time basis by modifying the control and by compensating the driver's anomalies or short-term maneuvering decision errors was reported in [1, 2]. A new driver assistance system was introduced for safety enhancement, and the concept of transferring some of the driver's control authority to an automated system was investigated. The research was concentrated on assessing a driver's operating characteristics and modifying the control to improve safe operation of the vehicle on a real-time basis. An automated Control Authority Transition (CAT) system and its modules for planning, decision making, execution, reference or expert driver and sensor modules were described. The CAT system helps the driver's short-term maneuvering actions by adding or intervening to his/her steering and braking/throttle inputs in case of his/her anomalies. This technology should be acceptable from the user point of view - being user friendly, not threatening personal integrity and driver personnel control over the vehicle. Furthermore, the technology does not introduce any new safety problems such as distraction and information overload. Possibilities to improve safety are almost innumerable provided we can, in a reliable way solve problems, e.g. advance warning, speed reduction, electronic vision, collision avoidance. But the most challenging possibility is perhaps to use this technology in order to improve driver behavior and his decisions to avoid accidents.

The system achieves two main tasks: Validation and interpretation of data coming from sensors to detect dangers in accordance with the driving task and driver state, and, assessing driver's operating characteristics and modifying vehicle control to improve safe operation of vehicle on a real-time basis by emulating reference driver. Such a system can support or intervene the driver in many collision avoidance situations. According to the US Department of Transportation's definitions of Intelligent Vehicle-Highway Systems services to support the driver in order to avoid collision,

- The longitudinal collision avoidance system provides for maintaining safe vehicle headways and avoiding rear end and backing collisions
- The lateral collision avoidance system provides for avoidance of lane change, merge and roadway departure collisions
- Intersection collision avoidance concerns hazardous situations occurring in the vicinity of intersections
- Vision enhancement to improve the driver's ability to detect hazardous situations under low visibility conditions (fog, night, rain, snow etc.)
- Safety readiness system for monitoring driver (e.g. fatigue, intoxication) and vehicle condition, continuous and individual driver education.

In fact, these are typical modes of operation of the CAT system.

The validity of CAT System to prevent accidents was shown based on computer simulations of accident scenarios involving operation in the modes described above (see [1, 2]). Real-time experimental results to show the effectiveness of CAT system and its intervention/assistance's effects to the driver may not be feasible in real traffic environment with a computer and sensors installed vehicle at the beginning of the research. CAT system, Half-Car Platform and Virtual Environment Simulator are proposed to be a test-bed for Intelligent Vehicle Technologies and one of the goals of the proposed test-bed is to study the effects of the driver assistance systems and the effects of the switching dynamics between the driver assistance systems and the human being when the human being needs to be compensated or intervened in order to prevent an accident or collision.

3 The OSU Virtual Environment System

The OSU Virtual Environment System developed by C. Kasnakoğlu, J. Martin, Dr. Redmill and Dr. Özgüner and at OSU is a software system introduced in 1996 and it has come a long way since then to become a highly capable test-bed for automotive research. This system consists of two parts: The first part is The Virtual Environment Builder (RoadEZ), used for road/terrain generation/editing, 3D object placement/editing and vehicle path definition/editing. The second part is The Virtual Environment Simulator, (VeSim), which performs simulations of virtual environments, using modules that communicate over the simulation network, each implementing a dedicated task such as vehicle dynamics, scene generation with 3D motion, sensor modelling and state monitoring. Interested readers are encouraged to refer to [5] for a more thorough description.

One of the key elements of this virtual environment system is The Half-Car Platform, which provides the driver the possibility to sit inside an actual car cut into half, and use its steering wheel and pedals to control the simulation. In addition to its major role of controlling the simulation vehicle, The Half-Car Platform also provides additional details of a real driving experience such as the instrument panel, radio, adjustable car seat, mirrors and so on, which greatly increase the realism provided to the driver. The Virtual Environment System, powered by the Half-Car Platform, is therefore an invaluable tool that provides the opportunity to conduct experimental testing, verification and analysis for the CAT system with a high degree of realism, but without the risks that would have been present in a real world driving situation, which would have put the driver into very dangerous situations, with the potential of causing him/her severe injury or worse.

OSU-VES program and vehicle dynamics' submodules, steering feeling, traction and braking capabilities and their controllers for different pavement types, yaw rate controller can be programmed and adjusted through vehicle simulation model developed in Matlab/Simulink. Virtual traffic environment with surrounding vehicles, stationary and non-stationary obstacles coming onto the path of the driven vehicle or lane changing, merging scenarios such as emerging pedestrian or the vehicle in the blind-spot of the driver can be emulated by OSU-VES.

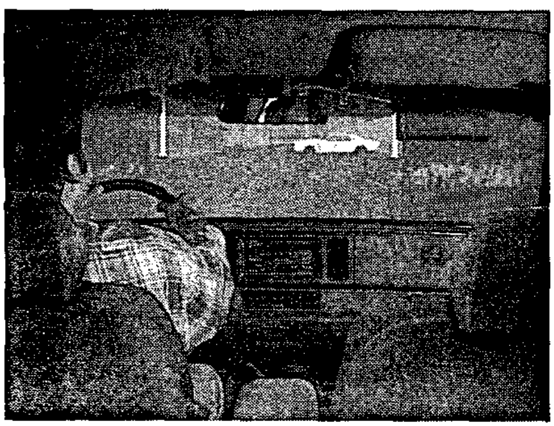

Figure 1: Present view of the simulator with possible test scenario

4 Switching Analysis between The Driver and The Control Authority Transition System

This chapter mainly deals with the issue described above, i.e., achieving experimental testing and verification of the CAT system. Specifically, the switching effects between the human driver and CAT system will be analyzed to understand the nature of transitions and to be able to suggest intervention methodologies, in an attempt to provide natural compensation and/or interference to the driver without causing abrupt changes in vehicle dynamic responses so as not to cause total loose of the human being's authority, while at the same time, ensuring safe and reliable operation under dangerous situations.

The interest in the present chapter is to make operational of the CAT system, OSU-VES and physical half-car platform and to introduce our capability of testing different approaches such as dwell-time, hysteresis, saturation etc., in order to prevent improper timing and infinite time intervention of the CAT system to the driver during short-time emergency situations.

Through all the scenarios, we emulate that the actual driver does not drive safe, speeds up and attempts to depart from the road. All the lane borders are considered as obstacles and the CAT system intervenes to the driver if the vehicle is about to exceed safe operation distance (in lateral and longitudinal distances) and to modify control to improve safe operation of the vehicle on a real-time basis by emulating the reference driver. The inputs to the brake and steering actuators are given as steering wheel angle, throttle and brake pedal positions, the CAT system flag("1" when there is intervention, and "0" when there is no intervention and the vehicle is operated safely by the actual driver) are plotted. The vehicle variables are chosen as yaw rate and longitudinal velocity. And the lateral and longitudinal distance of the center of gravity of the vehicle to the obstacles placed on the lane departure borders are plotted in order to visualize emergency and emulated accident scenarios.

We first consider the scenario that the CAT system is capable of infinite time intervening if the vehicle is not operated by the driver safely and accident is unavoidable without emergency braking or steering compensation. From the possible accident scenario results, infinite time intervening is allowed (Fig.2) to the actual driver who is attempting to depart from the road (Fig.4). In this scenario, possible accident is avoided by CAT system's intervention to the brake actuator and reducing the longitudinal velocity of the vehicle to zero. In the next scenario, the driver attempts to depart from the road more often by steering to the borders even though the CAT system intervenes to the driver in infinite time and transfers the authority to the driver after reaching to the safe operation region. CAT control flag is plotted in Fig.5 with infinite intervention frequency. Due to more often attempts of the actual driver to make accident, collision can not be avoided by the infinite time intervention's of the CAT system. An infinite time control authority transition occurs between the CAT system and the driver and some chattering occur around the $10m/sec$ longitudinal velocity, Fig.6.

Considering the infinite time transition in the accident scenario given by Fig.5 thru Fig.7, we constrain control flag switching to "dwell" at each authority transition for a constant amount of time, usually called dwell-time, [7]. Dwell-time is chosen as $5msec$ and it is seen that from plots in Fig.8, the CAT flag switching frequency is lowered and the chattering effects due to constrained authority transitions are reduced. But accident is forced to be occurred with excessive driver's attempts to depart from the road as plotted in Fig.10 due to constrained authority transition frequency. But the longitudinal velocity of the vehicle is reduced to $10m/sec$ by the CAT system's interventions.

To prevent improper intervention frequency leading to an accident, and oscillations in the time responses of the vehicle states, hysteresis approach is implemented at the authority transition instances. The following Matlab command is applied to enhance safe operation of the vehicle;

If the CAT flag==0 at t=0,
flagNext=if(A*stopdist(speed)+B) $\leq$ C then 1 else 0

If the CAT flag==1 at t=0,
flagNext=if(A*stopdist(speed)+B) $\leq$ α*C then 1 else 0

the CAT flag can be active (intervention) if stopping distance of the vehicle using an emergency braking is less than a predetermined value C and it remains active until stopping distance of the vehicle using an emergency braking becomes bigger than a predetermined value that is greater than C where $\alpha \geq 1$ and A,B,C are positive constants. Fig.11 shows CAT's flag intervention frequency using hysteresis approach. The time-responses of yaw rate and longitudinal velocity of the vehicle is plotted in Fig.13, compared to previous constrained and non-constrained intervention frequency cases, oscillations occurring in the time-responses of the yaw rate and velocity are reduced. Under persistent attempts of the driver to cause an accident are prevented by the CAT system using hysteresis implementation into CAT software, Fig.13.

5 Conclusions

In this paper, we presented Control Authority Transition (CAT) system, Half-Car platform, Vehicular Simulator as a test-bed for Intelligent Transportation System technologies. By creation of the artificial traffic environment and possible accident hazards scenarios, we implemented different intervention mechanisms in order to investigate the control authority transition behavior, the time responses of the vehicle states and prevention of possible accident scenarios caused by the

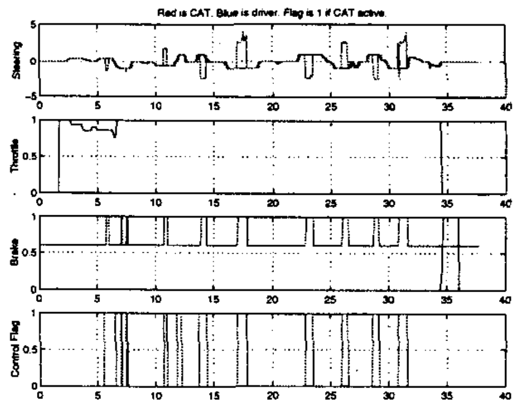

Figure 2: Steering wheel angle, throttle, brake commands to the actuators and CAT flag

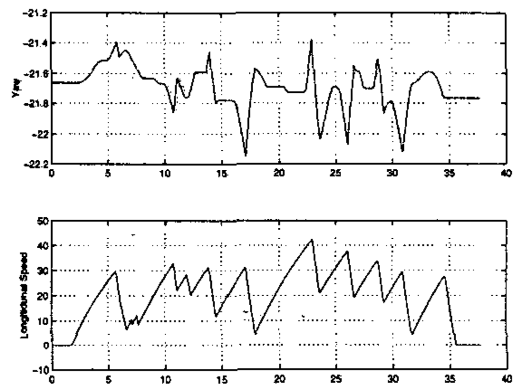

Figure 3: The time responses of yaw rate and longitudinal velocity of the vehicle

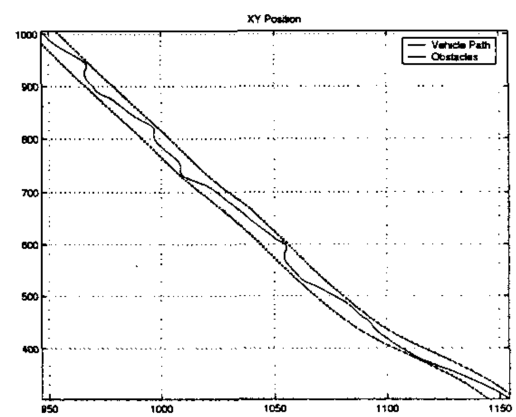

Figure 4: The longitudinal and lateral displacements of the vehicle and the obstacles placed on the lane borders

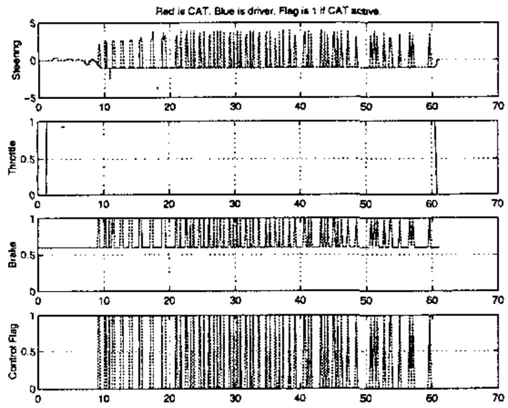

Figure 5: Steering wheel angle, throttle, brake commands to the actuators and CAT flag

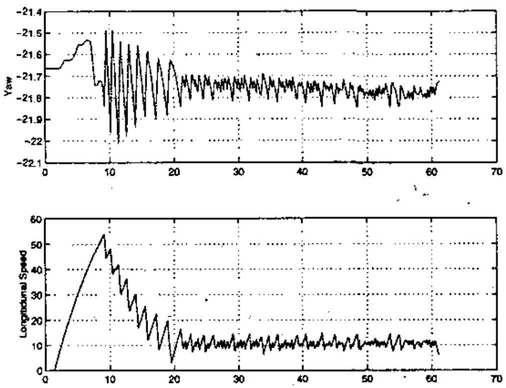

Figure 6: The time responses of yaw rate and longitudinal velocity of the vehicle

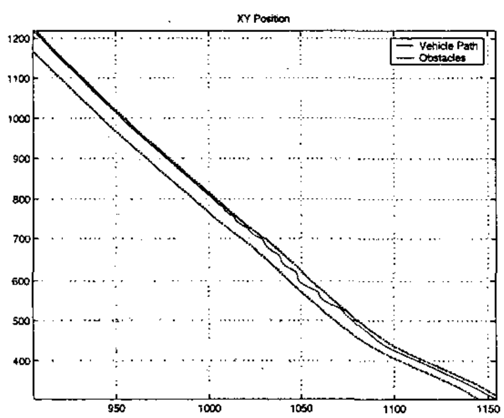

Figure 7: The longitudinal and lateral displacements of the vehicle and the obstacles placed on the lane borders

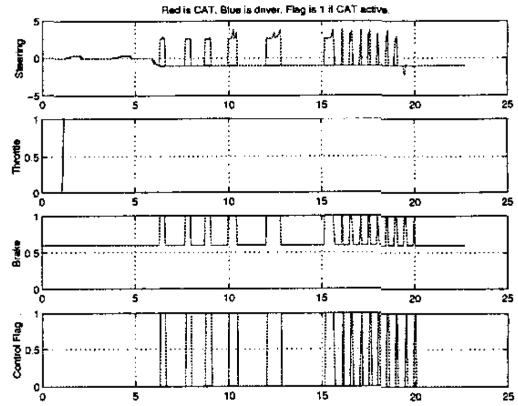

Figure 8: Steering wheel angle, throttle, brake commands to the actuators and CAT flag using dwell-time

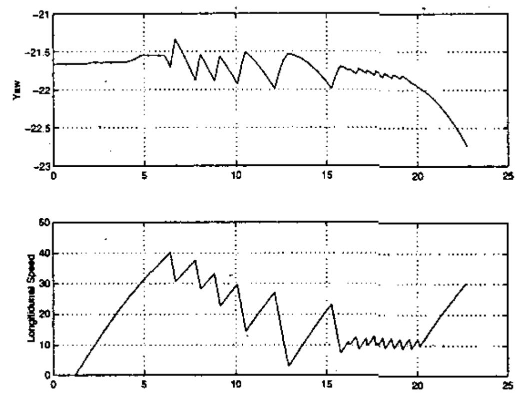

Figure 9: The time responses of yaw rate and longitudinal velocity of the vehicle using dwell-time

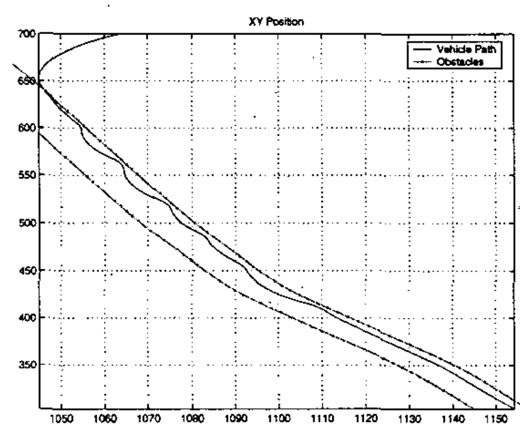

Figure 10: The longitudinal and lateral displacements of the vehicle and the obstacles placed on the lane borders using dwell-time

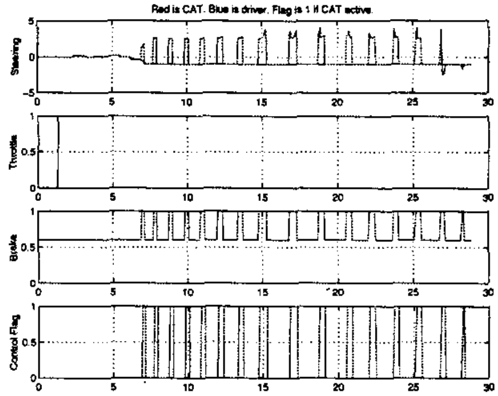

Figure 11: Steering wheel angle, throttle, brake commands to the actuators and CAT flag using hysteresis

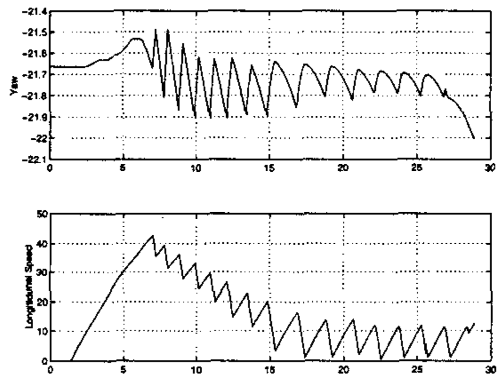

Figure 12: The time responses of yaw rate and longitudinal velocity of the vehicle using hysteresis

"inattentive" or "inadequate" drivers in the real half-car body platform.

Future directions include performing a thorough mathematical analysis of the system including analyzing stability properties and improving our switching controller design, using detailed nonlinear mathematical models including various parametric uncertainties and unmodeled dynamics, utilizing recent framework and tools in the field such as that laid down by [6]. We will add rear projector to the half-car to emulate also rear traffic, a more realistic vehicle mathematical model capable of generating roll, pitch and vertical motions of the emulation program outputs through hydraulic actuators. OSU-VES half-car emulator will be able to emulate the dynamics, responses of the wide range (from economy to luxury class) production vehicles.

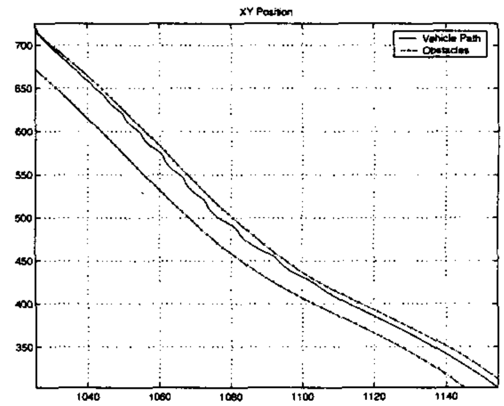

Figure 13: The longitudinal and lateral displacements of the vehicle and the obstacles placed on the lane borders using hysteresis

References

[1] T. Acarman, Y. Pan and Ü. Özgüner. A Control authority transition system for collision and accident avoidance. *Journal of Vehicle System Dynamics, The Special Issue on Intelligent Transportation Systems*, 39(2):149-187, 2003.

[2] T. Acarman, Y. Pan and Ü. Özgüner. A Control authority transition system for collision avoidance. *The 4th International IEEE Conference on Intelligent Transportation Systems*, pp.468-473, 2001.

[3] A.T. Zanten, R. Erhardt and G. Pfaff. VDC, The vehicle dynamics control system of bosch. *SAE paper*, paper :950759, 1995.

[4] M.A. Goodrich and E.R. Roer. Designing human-centered automation: tradeoffs in collision avoidance system design. *IEEE Transactions on Intelligent Transportation Systems*, 1(1), pp.40-54.

[5] C. Kasnakoğlu and Ü. Özgüner. Recent Advances on the OSU Virtual Environment System Test-Bed and Its Applications *IEEE Intelligent Vehicles Symposium*, Columbus, Ohio, 2003, To appear.

[6] J. Hespanha, D. Liberzon and A. S. Morse. Overcoming the limitations of adaptive control by means of logic-based switching. *Syst. & Contr. Lett.*, 49(1):49-65, 2004, To appear.

[7] C.P. Persis, R. Santis and A.S. Morse. Nonlinear switched systems with state dependent dwell-time *Proceedings of the 41st IEEE Conf. on Decision and Control*,Las Vegas, NV, pp. 4419-4424, 2002.

[8] E. Skafida, R.J. Evans, A.V. Savkin and I.R. Petersen. Stability results for switched controller systems *Automatica*, 35:553-564, 1999. 2003, To appear.