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16. Abstract

A driver drowsiness detection/alarm/countermeasures system was specified, tested and evaluated, resulting in the development of revised algorithms for the detection of driver drowsiness. Previous algorithms were examined in a test and evaluation study, and were found to be ineffective in detecting drowsiness. These previous algorithms had been developed and validated under simulator conditions that did not emphasize the demand for maintaining the vehicle in the lane as would be expected in normal driving. Revised algorithms were them developed under conditions that encouraged more natural lane-keeping behavior by drivers in the simulator. In these revised algorithms, correlations between dependent drowsiness measures and independent performance-related measures were lower than expected. However, classification accuracy improved when a criterion of "drowsiness *or* performance" was used, with performance assessed directly from a lane-related measure.

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EXECUTIVE SUMMARY

This document specifies a complete Driver Drowsiness Detection/Alarm/ Countermeasures System (DDDACS) intended for implementation in an instrumented automobile. The system is based on numerous experiments performed in a moving-base, computer-controlled simulator using sleep-deprived driver subjects.

There are two main detection aspects to the system: 1) driver status (i.e. drowsiness)/ performance monitoring, which is used to detect gradual driver deterioration, and 2) lane-departure detection. The second aspect is necessary because the first aspect (gradual deterioration) has been shown to be unable to detect all instances of rapidly-occurring lane departures. The lane departure system uses seat vibration to quickly re-alert the driver, so that hopefully the driver can recover.

Detection of gradual driver deterioration is accomplished by "or"ing an algorithm that estimates slow eye closure (which is believed to be strongly related to drowsiness) with a measure of lane keeping performance. Values are initially computed over one-minute intervals that are then "pipelined" to produce moving three-minute averages. These are then applied to the detection algorithm to see if either the drowsiness "or" the performance deterioration thresholds have been exceeded. If gradual deterioration is detected, the system so advises the driver, and if the driver does not respond, it provides an alarm sound (that can be supplemented with either a brake pulse or seat vibration). Once the driver responds, the system offers drowsiness countermeasures to the driver including a charge of peppermint (menthol) scent, a draft of cool air, or a lane-minder which helps the driver keep the vehicle in lane. The purpose of these countermeasures is to help the driver over a period of perhaps 15 minutes, so that an appropriate place can be found to rest or refresh. Also, when a lane-departure occurs and the driver has brought the vehicle back into the lane, the system offers the same countermeasures to the driver (after a brief delay).

The proposed system is designed to allow for modifications or enhancements. For example, it includes provisions for a direct eye-closure monitoring system, should one be developed in the near future. The proposed system also specifies a video system which can be used to record drowsiness incidents for later examination and analysis.

ACKNOWLEDGMENTS

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INTRODUCTION

This document is intended to provide information on the preliminary design of a Drowsy Driver Detection/Alarm/Countermeasures System (DDDACS) for use in planning for field test experiments. The design information presented is believed to be the best available and is based primarily on the research performed at Virginia Tech in the Vehicle Analysis and Simulation Laboratory. This research has been sponsored by NHTSA under Cooperative Agreement DTNH 22-91-Y-07266. Dr. Ron Knipling served as the contract technical representative during the earlier phases of the project, and Jeff Woods served in that capacity during the last phase. The design information is also based, to a lesser extent, on earlier research conducted at Virginia Tech and on research conducted elsewhere.

A complete DDDACS includes not only capabilities for detection of drowsiness, but also capabilities of advising and re-awakening the driver if necessary. In addition, a complete system should include countermeasures intended to help the driver maintain a re-alerted state for a period of perhaps 15 minutes, so that a safe place to rest can be reached. Such a system is necessarily rather complex, particularly if various options are considered. The specifications described in his document would allow for flexibility because they include several options that might be implemented. In addition, hardware development could be "phased," so that different parts of the overall system are implemented in stages. For example, the implementation could begin with a single-channel video system, a status/performance monitoring system, and a roadway departure system. Thereafter, a more complex video system might be implemented along with the addition of an advisory/alarm system. Finally, countermeasures could be implemented. Such an approach would allow logical development and checkout as well as specification of milestones by which progress could be gauged.

It is important to understand that the specifications presented herein have been developed for an instrumented automobile application. It is recognized that drowsiness is also a major problem in heavy vehicles. The main reason for the automobile application is that the algorithms were developed using an automobile simulator. Because heavy vehicles differ greatly from automobiles in their handling characteristics, it should not be assumed that the same algorithms could be used. Nevertheless, it is expected that much of the philosophy of design would transfer to heavy vehicles, and it would probably only be necessary to obtain new algorithms. Other aspects could probably be transferred relatively easily, with possible changes in the threshold settings.

Before the proposed DDDACS can be fully understood, it is absolutely necessary to develop a logical understanding of how such a system would work. A preliminary version was presented in the Seventh Semi-Annual Research Report (Fairbanks, Fahey, and Wierwille, 1995). However, the test and evaluation experiment reported as Part II of this final report series showed that substantial modifications would have to be made to have a viable system. New data were then gathered (as reported in Part III of this final report series) and new algorithms were then developed. Subsequently, a new version of the system was devised, which makes use of the information reported in Part II and the algorithms derived in Part III. The modified system differs substantially from the preliminary version. The modified system, which is considered to be the *recommended* system, is presented in this document.

Logic flow diagrams of the system will be presented first, and then specifications will be provided for the various components and subsystems. Obviously, there is a good deal of interaction among the components and subsystems. Nevertheless, the headings are set up so that, to the maximum extent possible, the subsystems can be envisioned separately and then tied together by common computation and power systems. Be referring back to the envisioned system and its flow diagrams, it should be possible to understand where the various components are used. Further explanation of algorithm computation is provided in Part III of the final report series, and further explanation of the advising/alarm and countermeasures systems is provided in the Seventh Semiannual Research Report, (Fairbanks, Fahey, and Wierwille, 1995).

ENVISIONED DDDACS

The proposed system consists of three stages. Detailed diagrams of the system are shown in Figures 1, 2 and 3.

Stage One — Detection System

The flow diagram is shown in Figure 1 for this part of the system. The detection system is composed of two major subsystems: a driver status (i.e., drowsiness)/ performance monitoring system and a lane departure system.

The status/performance monitoring system is intended to detect gradual deterioration in alertness and gradual deterioration in driving performance. It does so by computing three-minute, moving averages of measures that are updated each minute. Both drowsiness and performance are monitored, and a detection flag is sent to Stage 2 if there is either a reduction in alertness or a reduction in performance.

In the monitoring process, the system uses an algorithm to estimate PERCLOS or SLEEPER 3. These are defined measures of drowsiness and are described in Part III of the final report. For convenience, they are also defined in Appendix A herein. The recommended algorithms and their estimated accuracies are also included herein as Appendix B.

Measures are computed using variables taken online from sensors on the vehicle. One minute values or averages are first computed, and then these are "pipelined" to produce three-minute moving averages.* The three-minute moving averages are then input to an algorithm to estimate the selected drowsiness measure (either PERCLOS or SLEEPER 3). If a specified threshold is exceeded, a drowsiness

*See page 41, part III, for an explanation.

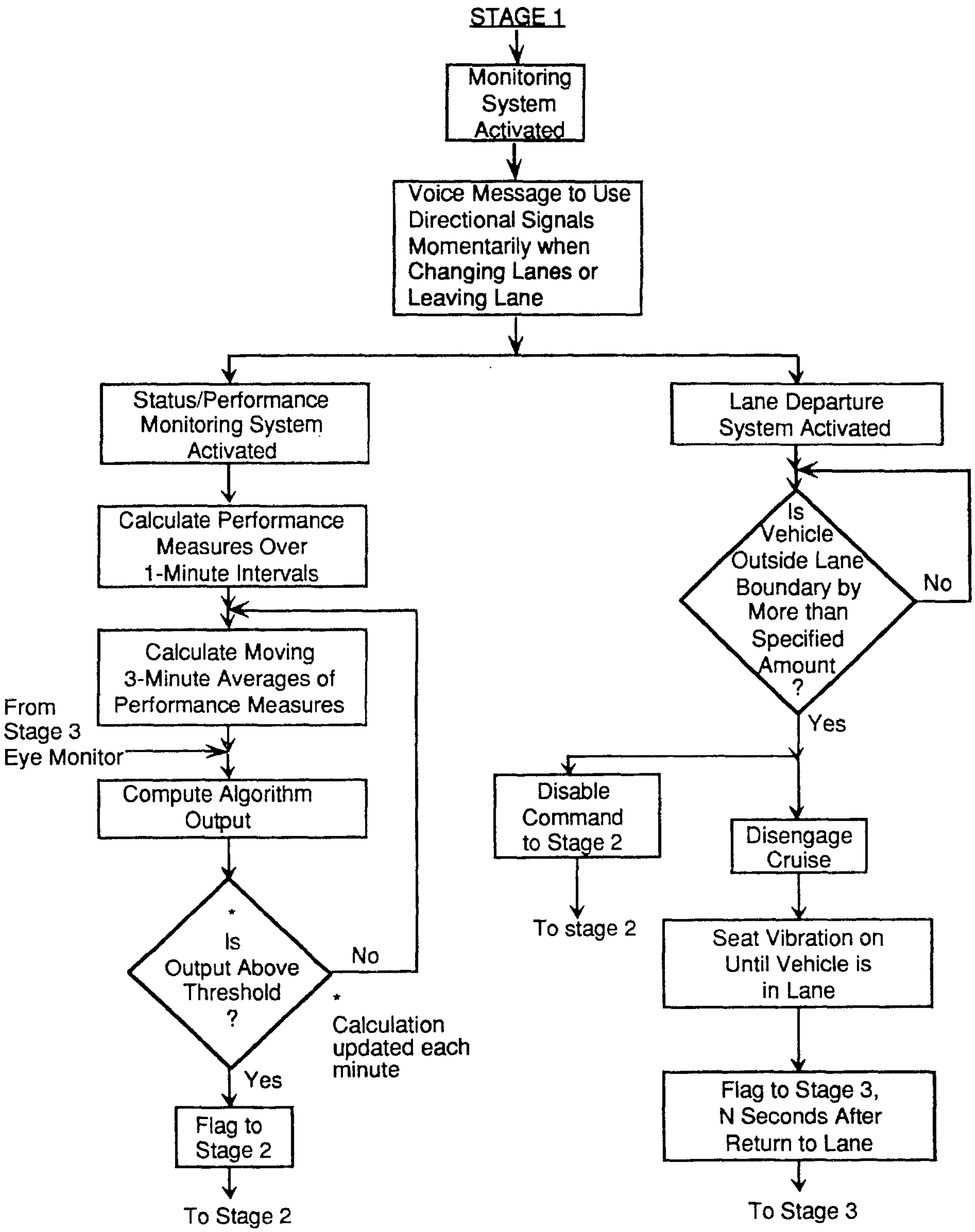

Figure 1. SYSTEM FLOW DIAGRAM FOR DETECTION PORTION OF SYSTEM (STAGE 1)

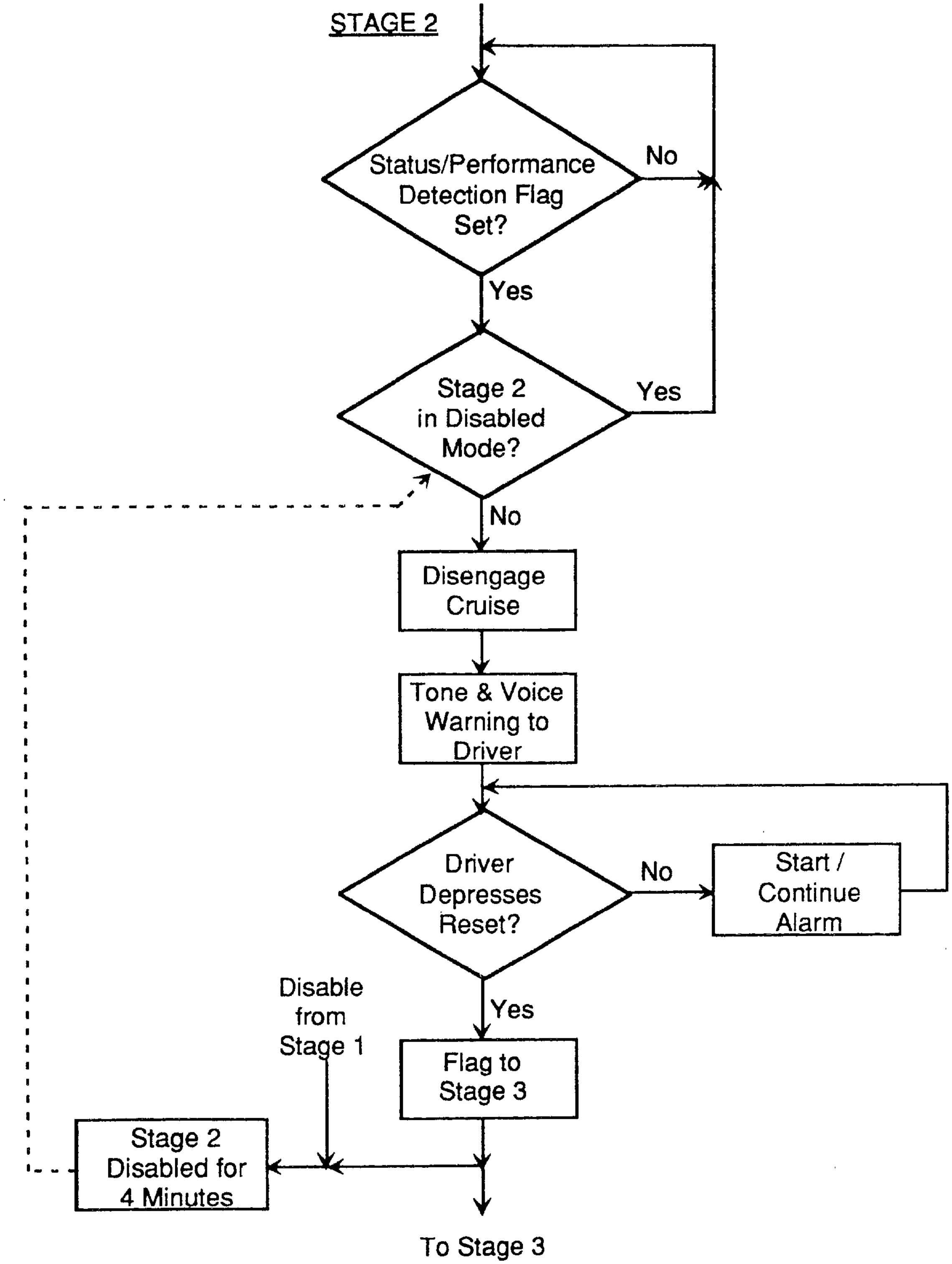

Figure 2. SYSTEM FLOW DIAGRAM FOR RE-ALERTING DRIVER AFTER STATUS / PERFORMANCE MONITORING DETECTION (STAGE 2)

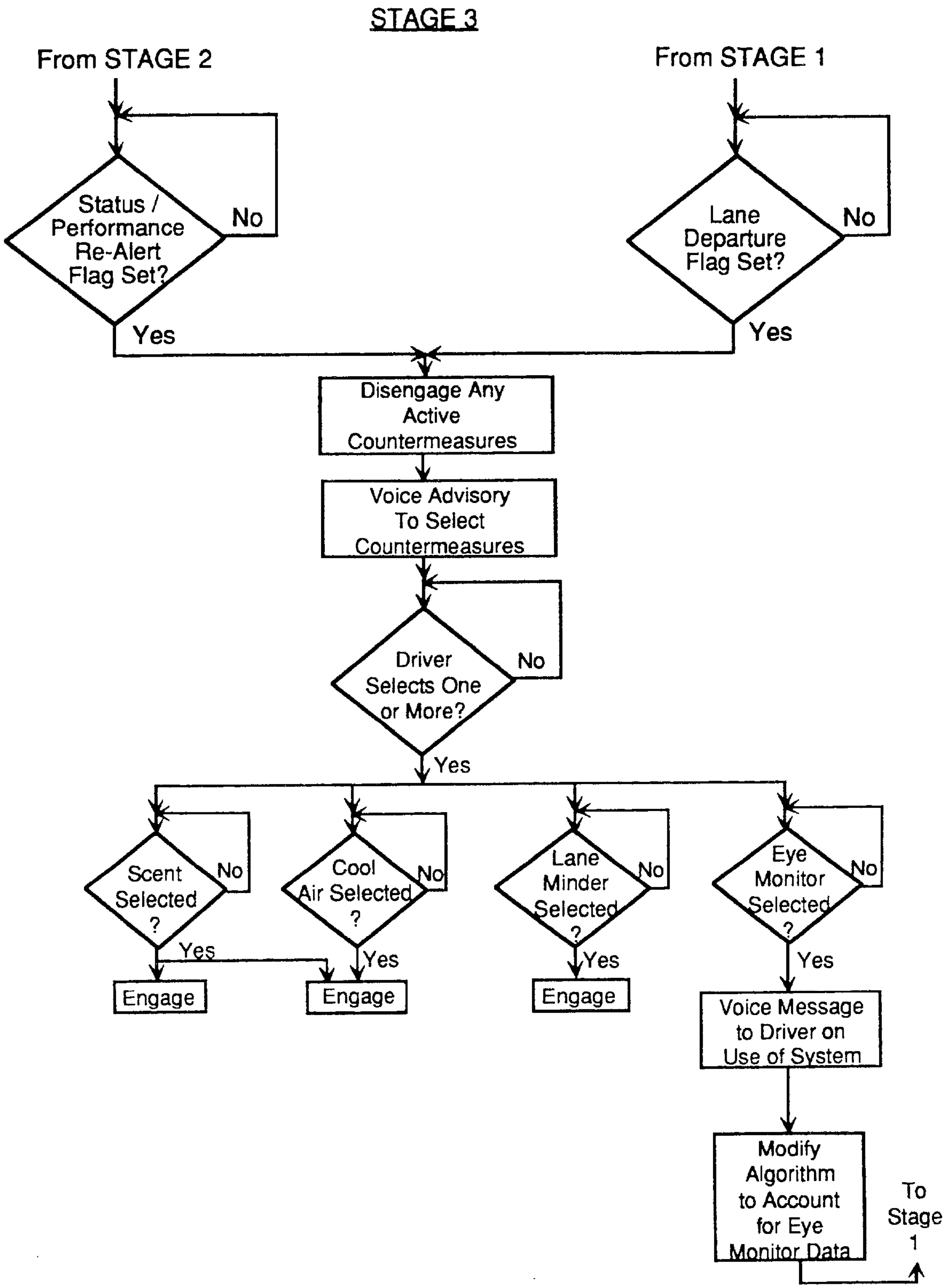

Figure 3. SYSTEM FLOW DIAGRAM FOR MAINTAINING ALERTNESS (STAGE 3)

condition is said to exist, and a detection flag is sent to Stage 2. (Recommended thresholds for the algorithms are specified in Appendix B, and other parameters are specified in Appendix C.)

The monitoring process also employs a direct measure of performance, LANEX or LNMNSQ. These are defined measures of performance deterioration and are described in Part III of the final report (as well as Appendix A herein). A lane sensing system is included in the sensor system array and is used directly to compute one-minute values of LANEX or LNMNSQ. These values are also pipelined to produce a three-minute moving average that is updated each minute. Whenever the three-minute moving average of LANEX (or LNMNSQ) exceeds a specified threshold, a performance deterioration condition is said to exist, and a detection flag is sent to Stage 2. Thus, both gradual drowsiness and gradual performance deterioration are monitored by the system. Drowsiness is detected by an estimation algorithm and degraded performance by lane keeping slow deteriorations.

Additional aspects of the status/performance monitoring system are that the driver is expected to use directional signals at least momentarily whenever changing or purposely deviating from the lane. The activation signal is then used by the algorithm computation process to delete those computations so that false alarms are minimized. Also, whenever lane position and boundaries cannot be determined, the computations are placed in a "hold" mode until valid lane computations can be resumed.

The detection system also contains a separate fast-acting system, because the system detecting gradual deterioration may not detect rapidly occurring losses of alertness or reductions in performance. The fast-acting system is a lane-departure detection and warning system. Its purpose is to reduce the probability that the driver will suffer a run-off-the-road crash or near miss, which might occur because of a rapidly occurring lapse of attention or alertness.

The lane-departure warning system detects when the vehicle is deviating from the driving lane by more than a specified distance. If the directional signals have not been activated momentarily before or when this happens, a lane departure is said to have occurred, and seat vibration is immediately initiated. This seat vibration is of such a magnitude that it should alert or re-awaken the driver. The vibration continues until the vehicle is returned to the lane.

Additional aspects of this system are that if the directional signals are activated after vibration begins, the vibration is then de-activated. Similarly, if the "reset" button on the drowsiness monitoring panel (to be described later) is depressed, the vibration is deactivated. Also, if the vehicle is in cruise at the time of the detection, cruise is disengaged. Finally, once the vehicle has returned to a lane and the vibration has stopped, and after a specified delay of a few seconds to allow the driver to recompose himself or herself, a flag is sent to Stage 3.

The lane-departure warning system is intended to take advantage of the "rumble strip" idea used for re-alerting drivers, but without the need for actual physical indentations in the pavement. The lane departure warning system has the advantage of being able to operate on both sides of the lane, rather than on just one side (as is the case with most rumble strips).

The lane departure warning system uses seat vibration alone to re-alert or re-awaken the driver. However, the warning system could also include sound which is similar to the rumble sound created by rumble strips. Full scale testing should probably be used to determine whether the addition of sound is desirable.

Because of the possibility that the status/performance monitoring system may indicate a detection at the same time that the lane-departure system has detected a departure, or shortly thereafter, the lane departure system also sends a disable flag to Stage 2. In so doing, simultaneous or near simultaneous activations of the two systems are avoided.

Stage 2 — Re-alerting the driver after a status/performance monitoring detection. The second stage (Figure 2) would begin with an auditory stimulus informing the driver that a drowsiness condition has been detected. A full alarm would then be activated unless the driver manually depresses the reset button. The advisory stimulus would consist of an audible tone followed by a voice message. If cruise control is engaged at this point it would be disengaged by the detection system. The option to reset the system would give the driver the opportunity to avoid unnecessary exposure to a full alarm. When the driver depresses the reset button, the initial alert would be disengaged for four minutes. (After the reset button is depressed the algorithm used would most likely still be detecting a noticeable reduction in alertness level. Therefore, the four-minute delay in the system is intended to avoid an immediate reactivation of the initial alerting tone and voice message after the driver has depressed the reset button.)

If a status/performance monitoring flag is set by the first stage and the driver does not reset the system after the initial advisory tone and voice message (at the beginning of Stage 2), a subsequent full alarm would be sounded. Peripheral cues of seat vibration or decelerating brake pulse might be used to enhance the effectiveness of the alarm. The alarm would continue until it is manually deactivated by the driver. Again, deactivation would be accomplished by depressing the reset button. When the reset button is depressed the system would again delay re-activating the initial advisory tone and message for four minutes. Whenever the driver depresses the reset button, stage two would end and stage three would begin. (As noted earlier, a disable flag from the Stage 1 lane-departure system also disables Stage 2 for four minutes, as shown in Figure 2.)

Stage Three — Maintaining Alertness. At the beginning of this stage (Figure 3)., a voice message would advise the driver to engage one or more countermeasures to help maintain the driver's alerted state. This stage would be initiated under either of two conditions: the driver depresses the reset button for Stage 2 or the driver returns the vehicle to a lane after the lane-departure warning system has been activated and a brief interval of time has past to allow the driver to recompose (Stage 1). The driver may feel that an alertness aid is needed to help remain alert while looking for a safe rest area, and there may be several countermeasures from which to choose. Possibilities would include inhaling a stimulating scent, directing cool air toward the driver's face, activating a lane-minder, and using eye monitoring equipment which measures slow eye closure. The driver would select countermeasures by means of a control panel as shown in Figure 4.

Scent. When the scent button is depressed the cool air blower would be activated and a single charge of scent would be discharged into the air in front of the driver. This button would be illuminated along with the cool air button. The blower would continue to operate for a predetermined length of time to disperse the scent and then would automatically deactivate.

Cool air. The cool air button would activate the cool air blower. The button would be illuminated when the blower is activated. The cool air would continue until the button was depressed a second time.

Lane-minder. When the lane-minder button is depressed it would be illuminated and the lane-minder would be activated. If the driver allows the vehicle to approach or exceed the lane boundaries, a tone would be activated. The lane-minder would be deactivated by depressing the lane-minder button a second time.

The lane-minder system differs from the lane-departure warning system in several ways. First, it uses sound (only) to advise the driver that some portion of the vehicle is approaching or exceeding a lane boundary, whereas the lane departure system uses seat vibration and is activated when the vehicle exceeds a lane boundary by more than a specified amount. The lane-minder warning sound onset is gradually increasing in amplitude and "urgency" with increasing excursion. And, finally, the lane-minder is considered a countermeasure and must be selected by the driver. In contrast, the lane-departure warning system is automatically activated whenever the DDDACS is activated.

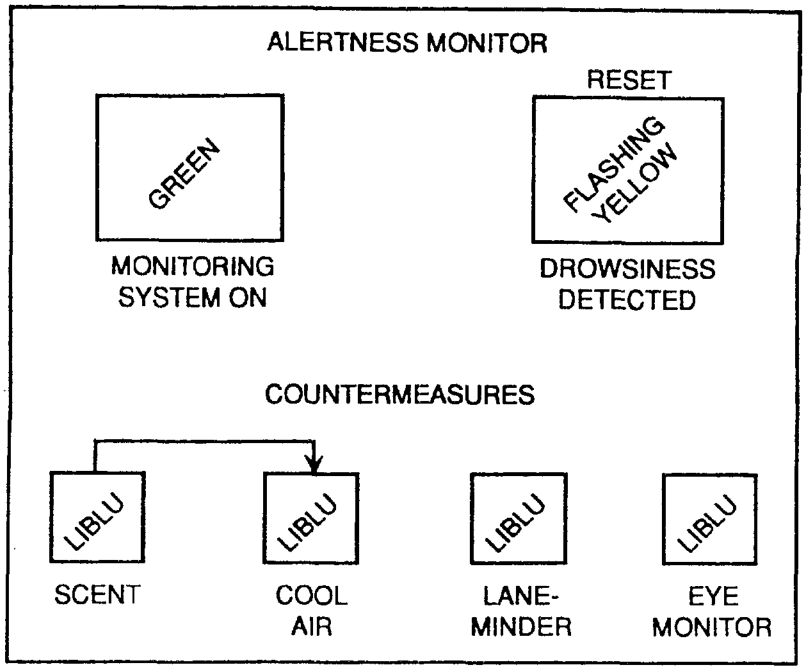

Figure 4. DRIVER'S CONTROL PANEL

Eye-monitoring system. As technology advances, it may become possible to measure slow eye closure directly. Possible approaches include the wearing of special eyeglass frames equipped with sensors to measure closure. Other approaches might require wearing some other type of sensor or simply activating a camera-like sensor. In general, these devices would probably be designed to measure PERCLOS. However, other measures such as those devised from eyeblinks or eye scan patterns might be used.

Strictly speaking, eye-monitoring is not a drowsiness countermeasure. Rather, it represents a means of direct monitoring of eye-related measures for purposes of drowsiness detection. Nevertheless, if the device does require the driver's attention to don or use, it may have a mild countermeasure effect. The primary reason for including it as a countermeasure is that it may require specific behavior on the part of the driver and probably should not be considered feasible for drowsiness detection under all circumstances. Algorithms which *estimate* PERCLOS, on the other hand, are always feasible (although some detection inaccuracies may result). If an instrument-panel eye-closure monitoring system is eventually developed (that is, one that does not require driver attention), it would become part of the detection process and would not be included in the countermeasures portion of the panel.

It should be understood that the general architecture of Stage 3 is such that countermeasures can be added or deleted. If a given countermeasure proves ineffective in field tests, it can be deleted. On the other hand, if a promising new technique is developed, it can be added without requiring a complete system redesign.

It should be mentioned that the purpose of the countermeasures (and the entire DDDACS for that matter) is to warn the driver of deterioration and prevent crashes over the short term. The idea is to help maintain alertness for a short period of time so that the driver can find a safe place to pull off the road and rest.

Finally, it is important to note that this system is intended for use at highway speeds. Whenever vehicle speed drops below 50 mph, the system goes into a "hold" state. Computations resume only when the vehicle speed is 50 mph or greater*. Also, the system is deactivated any time the ignition is turned off. To activate or reactivate the system, the driver must have the ignition on and must then depress the "monitoring system on" button (Figure 4).

* The use of a threshold of 50 mph should be considered an estimate; the system should be designed so that the speed at which computatons go into a hold mode may be set at any speed between 40 and 55 mph.

VIDEO SYSTEM

The purpose of the video system is to provide a visual (and auditory) record of the driving run so that the DDDACS can be qualitatively and quantitatively evaluated. Strictly speaking, the video system is not part of the DDDACS and would probably not be used in a production system, except as a means of checking system operation. Nevertheless, for purposes of test and evaluation, such a system is essential. The system is to be capable of operating up to 8 hours using a single videotape in the extended play (EP) or super-long-play (SLP) mode. A high-quality video recorder having stereo sound capability is to be used.

The system is to have four video channels as follows:

Channel 1 would view the driver's face with sufficient resolution to make possible the evaluation of facial expression and mannerisms as well as percent slow eye closure. The camera would be mounted at about top-of-IP level near the pillar between the windshield and the front left side window (A-pillar). This camera must be capable of operating from near complete darkness to bright daylight using an auto-iris system. If necessary, an infrared illumination source may be used to illuminate the driver's face in the darkness. A lens with a horizontal field of view of approximately 45° is to be used.

Channel 2 would view the forward roadway with sufficient resolution to make it possible to evaluate the traffic scene and position of the vehicle relative to the lane. The camera would be mounted at or near the interior rear-view mirror, with the lens axis pointed downward somewhat and forward. The field of view of the lens should be chosen so that lane lines relative to the hood of the vehicle are easily detected, and so that the forward roadway scene appears in the upper part of the video image. Probable field of view is about 50°; however, this field of view may need to be adjusted based on type of vehicle and hood shape. This camera must be capable of operating in a luminance range of headlight reflection on dark pavement to bright sunlight using an auto-iris system. It should minimize "blooming" effects caused by headlights of oncoming vehicles.

Channel 3 would view the instrument panel and the driver's activation of the controls. The camera should be mounted on the headliner at the center of the vehicle with the lens axis pointed down and to the left. The camera should be mounted so that the speedometer, part of the steering wheel, directional signal indicators, radio, and drowsiness detection system control panel are visible. This camera must be capable of operating from interior nighttime luminance levels to high-brightness daytime levels using an auto-iris. If necessary, an infrared illumination source may be used to illuminate the IP in darkness. Care must be taken to insure that Channel 1 and Channel 3 illumination sources do not interfere with the opposite channel's camera.

Channel 4 would be the computer screen video. It may be obtained by a direct video output from the display card of the computer display or by a custom scan-conversion interface. The purpose of this channel is to allow pertinent computer or computed information to be combined with the video camera outputs. Thus, flags, lane excursions, measure values, and "detections" could be displayed. Channel 4 would also be used to provide timing information, so that after completion of a run computer time and videotape time could be synchronized in playback. If the computer does not provide timing information, then a separate system must be included to provide a time stamp for the videorecorder and corresponding input for the computer to be included in data arrays.

Because of the need to operate over very-wide luminance ranges, the cameras would probably have to be monochrome. However, if color cameras capable of such operation become available, they may be used. In particular, the forward-view should be considered a candidate for a color camera.

Because (physically) large cameras can be distracting, and can block the driver's view, preference should be given to cameras that are as small as possible. Also, preference should be given to CCD (charge-coupled device) cameras because of their small size, lower power requirements, and ruggedness.

The four channels of video are to be combined using a quad splitter that is capable of taking unsynchronized video signals and combining them into a single (quad) video image, each using one-quarter of the output video image area. Thus, all four channels would be viewable simultaneously on a single video monitor. The quad output is to be recorded using the video recorder.

A small, high resolution monitor is also to be included in the video system. The monitor should be capable of switching from one video image to another so that focus and aiming can be adjusted and so that image quality can be checked at the beginning or possibly during a run. The monitor should also be capable of being switched to the quad-splitter output.

The first audio channel of the video recorder is to be used to record the sound in the vehicle. A microphone should be placed near the Channel 3 video camera and pointed in the same direction as the camera. The video recorder should have an automatic gain control for audio.

The second audio channel of the video recorder is to be available for special use as needed in specific experiments. If not used, then the output of the microphone recording the sound in the vehicle should be recorded on both audio channels.

SENSORS AND OTHER INPUT DEVICES

The DDDACS must have accurate information from the vehicle to detect driver drowsiness. Therefore, particular care should be taken in designing and implementing the various sensors and output devices described in this section.

Steering Sensors

The steering wheel should be equipped with an angular position sensor and an angular velocity sensor. The position sensor should be a precision potentiometer that is coupled to the steering shaft in such a way that it has high repeatability and high accuracy. A cog-belt arrangement is preferred because of its repeatability and resolution. The potentiometer should be a single turn device (without stops) with approximately one-to-one gearing to the steering shaft. Since the drowsiness detection system goes to standby whenever vehicle speed goes below threshold (to be initially set at 50 mph), there is no need to measure steering beyond $\pm$ 180°. (Steering inputs greater than 180° do not ordinarily occur at high speeds in normal driving.) It should be possible to rotate and lock the steering potentiometer on its mount so that it can be mechanically/electrically zeroed to the straight-ahead position.

Steering velocity is to be obtained by a tach generator coupled to the steering wheel shaft. A belt and pulley, or rubber edged wheel arrangement can be used. The sensor should be a servo tach-generator or similar device that provides a polarized voltage output proportional to steering rotational velocity. A high-output sensor should be used so that signal-to-noise ratio is maximized. To increase output and precision, a step up pulley ratio of approximately 6 to 1 should be considered. As an alternative, a high-resolution steering position sensor could be used, thereby making it possible to differentiate the signal over a limited bandwidth to obtain steering velocity.

Both the steering position and velocity sensors should be located in the vehicle interior, if possible, so that they sense steering near the steering wheel-end of the shaft and so that vibrational and environmental effects are minimized. Both signals should be passed to the computer interface for computation of STVELV, LGREV, MDREV, SMREV, and STEXED.

The velocity signal obtained from the tach-generator (or position sensor) should also be passed to a special analog/logic circuit. This circuit should provide a logic-high output whenever the steering wheel has been held still for 0.4 second or longer. It should provide a logic-low output if the steering wheel has been moved during the last 0.4 sec. The circuit should be designed using comparators on the steering velocity signal with the outputs coupled to a retriggerable one-shot set for 0.4 sec. The output logic signal should be passed to the computer interface for use in computation of NMRHOLD and THRSHLD.

Lateral Accelerometer Sensor

A lateral accelerometer sensor is to be mounted near the floor of the vehicle along the vehicle's centerline. It should be located at the approximate center of mass of the vehicle. If a front-wheel drive test car is used, the center of mass is usually located at console position between the front seats. If the test car is a rear-wheel drive vehicle, the center of mass is usually located slightly behind the front seats on the drive-shaft hump. The accelerometer's full range should be $\pm 1.0g$. The accelerometer should be mounted on a plate with an adjustment that allows it to be mechanically/ electrically zeroed for a level road.

Accelerometer output should be an analog voltage proportional to lateral acceleration of the vehicle. Roll stabilization need not be made, since vehicle roll angles are expected to be small during operation.

The output of the accelerometer is to be processed by an analog network designed to produce two modified signals. First, the output is to be passed through an active single pole low-pass filter with a corner frequency of 7.25 Hz. The purpose of this filter is to remove high-frequency vibration from the accelerometer output. The output of this filter is to be passed on to the computer interface for use in computing ACCDEV, ACCVAR, and ACEXEED. The output of the low-pass filter is also to be passed through a second active low-pass filter having a corner frequency of 0.004Hz. This second filter will serve as a "leaking integrator." The DC gain of this second filter should be selected so that one volt of output corresponds to a smoothed lateral velocity of 73.3 ft per second. The output of this second filter is to be passed on to the computer interface for computation of INTACDEV and INTACVAR.

Forward Velocity Sensor

Vehicle forward velocity is to be obtained either by using sensors already on the vehicle that are part of the engine management or braking system, or by using independent sensor equipment. Because high precision is not needed, and because a fifth (bicycle) wheel is cumbersome, a fifth wheel approach is not to be used.

If the vehicle's existing forward velocity sensing system is used, the added circuitry sampling this signal must not "load" the signal or interfere with the vehicle's proper operation. In addition, the vehicle's grounding system and that of the detection system must remain isolated. Therefore, double-ended pickup of the vehicle's velocity sensing system should be employed, with the lower end sensing local common or ground. The vehicle's velocity sensing should then be conditioned by necessary circuitry that provides an analog output proportional to vehicle forward velocity. Scaling should be in the range of 0.1 volt per mph.

If independent sensor equipment is used, it may sense forward velocity at a half-shaft, the drive shaft, the transmission, or the speedometer cable. A magnetic proximity sensor/magnet or hall-effect/magnet approach can be used in a location where direct contact with a moving shaft is unfeasible. Alternatively, a tach-generator can be used on the speedometer cable, provided a suitable mechanical linkage can be developed. In any case, circuitry should provide a smooth noise-free analog output proportional to forward velocity and should not interfere with the normal operation of the vehicle.

Lane Track Sensor(s)

This equipment is intended to provide signals to the computer interface that make it possible to compute lane position-related measures. These include LANDEV, LANVAR, LNMNSQ, LNRTDEV, LNRTVAR, LANEX, and LNERRSQ. The equipment must not only make it possible to determine lane-related measures when they are available, it must also provide a flag or logic signal indicating when a valid lane position signal is available.

There are two possible approaches to establishing lane position:

1. A video camera/machine vision approach can be used, with the camera looking forward and down at the roadway in front of the vehicle. Computer processing would be used to establish the positions of the lane boundaries and determine the vehicle's position relative to them. (It is possible that the video from Camera 2 described in the Video System section could serve as the sensor source if this approach is used.)
2. Video or optical sensors can be mounted on each side of the vehicle, with processing used to detect lane edge lines. In either case, since lane width varies from approximately 9 to 12 feet depending on the road, the system should supply information that allows determination of both lane width and vehicle position relative to the lane. All lane-related measures can be computed once these two variables are known.

The lane track subsystem probably represents the most complex part of the instrumentation and may require a substantial amount of experimental testing and development to achieve reliability.

Directional Signal Activation Signal

This activation signal is intended to inform the computation system that the driver is changing lanes, purposely deviating from a lane, or turning onto a new road. It is used by the algorithm computation system to indicate that computations should be temporarily halted or that a short segment of data is to be deleted. It is also used to deactivate seat vibration in the lane-departure portion of the system.

The activation signal is to be a logic signal that is nominally 100 milliseconds long and is to occur each time the directional signal lever is activated. The logic signal duration should be independent of the length of time that directional signal lever is activated. A non-retriggerable one-shot should be used to achieve the (nominal) 100 millisecond pulse. (The one shot pulse duration should be screwdriver adjustable over a range from 10 milliseconds to 500 milliseconds.)

Driver's Control Panel

The purpose of the driver's control panel is to allow the driver to activate the DDDACS and its various countermeasures. It includes a "Drowsiness Detected/Reset" button which terminates the alarm or seat vibration when it is depressed. This control panel is interfaced with special purpose hardware and the computational system. The control panel, as envisioned, is shown in Figure 4. All legends on the panel are backlit, so that they can be seen during night driving. The diagonal lettering shown in the figure designates the hue of each button and would not be included as a label.

The panel includes provisions for four possible countermeasures, which the driver can actuate after drowsiness has been detected, or possibly, when the driver "feels" drowsy and would like to use a countermeasure. It is possible that countermeasure options may change as a result of new research information. If so, the control panel would have to be modified. However, the *concept* of the interface panel and the system would remain the same. This flexibility is important in view of new research results that may be forthcoming.

The panel should be located to the right of the driver at IP level. The system should be "integrated" into the IP if possible so that it appears to the driver to be original equipment and not an add-on. Of course the ability to integrate will depend on the vehicle used and its IP configuration. If the vehicle can be freely selected, consideration should be given to these integration aspects. Preference should be given to a mounting that is higher on the IP rather than lower, so that "eyes-off-road-time" when using the system is minimized.

The controls on the panel are all to be lighted pushbuttons. The lighting and functions for each button are as follows:

1. "Monitoring System On" (Push-on, Push off)

   Activates the entire system, beginning at the top of the logic flow diagram shown in Figure 1.

   Provides a voice caution to the driver to use directional signals when changing lanes.

   Lights when the system is activated.

2. "Drowsiness Detected/Reset" (Momentary)

   Flashes with high intensity (1 Hz) when the DDDACS has detected drowsiness via the status/performance monitoring system. Also flashes when the lane-departure warning system initiates seat vibration. However, in the latter case, the flashing stops when the seat vibration goes off or when the reset button is depressed.

   When the pushbutton is depressed (after drowsiness has been detected by the status/performance monitoring system),

   Advisory/alarm sound sequence and peripheral cues (if any) cease immediately.

   Illumination goes to a low intensity level for four minutes, then extinguishes.

Any countermeasures currently in use are discontinued.

A voice message is given to select countermeasures.

When the pushbutton is depressed and drowsiness had *not* been detected),

Illumination is low intensity while depressed.

Any countermeasures currently in use are discontinued.

A voice message is given to select countermeasures.

3. "Scent" (Push-on, Timed out after scent is dispersed)

Causes scent to be injected into the cool air in front of the driver.

Illuminates the "scent" pushbutton while the scent is being dispensed.

Extinguishes after timing out.

Activates the cool air blower and illuminates the cool air pushbutton.

These remain energized for a fixed period of time.

4. "Cool Air" (Push-on, Push-off)

Activates the cool air pushbutton illumination and cool air blower.

If scent light is lit, "Cool Air" button has no effect when depressed.

5. "Lane-Minder" (Push-on, Push-off)

Initiates lane-minder system and pushbutton light, which remains lit as long as the system is engaged.

Mutes the radio if it is in use.*

Provides a voice message to the driver to use directional signals when changing lanes, which in turn mutes the lane-minder sound cues while out of lane.

*Radio muting when using the lane-minder is one option. Another is to increase the sound level of the lane-minder to a level that can be heard with the radio on. These options should be explored experimentally.

6. "Eye Monitor" (Push-on, Push-off)

Instructs driver to don or use the measuring equipment. If no special instructions are needed, the system informs the driver that the eye monitor is engaged.

Commands DDDACS to measure closure (and other possible measures) and use them for detection of drowsiness, after sixty seconds.

Initiates the pushbutton light, which remains lit as long as the system is engaged.

OUTPUT SYSTEMS

The DDDACS produces many outputs that are intended to affect the driver directly through sound and somesthetic cues. In addition there are outputs that affect the vehicle and therefore indirectly affect the driver. These outputs, taken together are the means by which the DDDACS provides necessary cues to the driver.

Radio Interface

The radio interface has two purposes. First, it is intended to mute the vehicle's standard radio whenever any type of auditory message is to be presented by the DDDACS. Second, it is intended to allow use of the existing front speakers of the radio to provide all the auditory messages from the DDDACS. The fundamental idea is to mute the radio when necessary and apply external audio signals from the DDDACS to the speakers.

There are two possible options for this system. One is to use the power amplifiers of the radio with line-level signals from the DDDACS. The other is to use power signals from the DDDACS and switch the speakers. Here, it will be assumed that the latter approach is used, because line level input jacks are not available on most original equipment radios. The specifications are as follows:

> Using a logic signal from the computation system, the radio interface should energize relays that switch the radio's audio power outputs to dummy loads, thereby protecting the radio's power output transistors. The relays should switch all four speaker power signals to dummy loads, thereby muting the radio. The relays should also *connect* the two power outputs of the DDDACS system to the two front speakers of the radio system, so that DDDACS auditory messages may be presented to the driver. During periods when the relays are not energized, the DDDACS power signals should be connected to dummy loads by the same relays.

The switching should be designed so that audio transients associated with switching are minimized. Inputs to the radio interface would consist of the logic signal that switches the speakers and the two floating audio power output signals from the DDDACS.

Audio Output and Sound Playback System

This system will software select sounds from computer memory, play them on command through a "sound card" installed in the computer system, and amplify them to appropriate levels for presentation to the driver through the radio interface (using the vehicle's front speakers). This system will be the primary means of communicating with the driver. It will supply audio tones and alarm sounds as well as prerecorded voice advisories. The levels of the outputs should be set so that they are correct in the vicinity of the driver's head position.

The sound playback system will have the following repertoire:

Voice advisories as follows:

"Please activate directional signals momentarily when changing lanes or turning on to new roads or exits."

"The system has detected possible drowsiness. Press reset now."

"Please select drowsiness countermeasures now."

"The lane-minder can be silenced when changing lanes by momentarily activating the directional signals."

Additional voice advisories may become necessary as a result of testing and also for use with the eye-monitor system. Therefore, provision should be made for additional messages.

Voice advisories should be presented at a level that has *peak* amplitudes 10 dBA above ambient average noise level in the vehicle at 60 mph. (This level should correspond to approximately 5 dBA *average* below the average ambient noise level in the vehicle at 60 mph.) Since sound levels in vehicles vary only slightly over the range from 50 to 65 mph, the sound levels of the advisory messages need not be varied with speed.

Advisory Tone:

An advisory tone would be used to alert the driver to forthcoming messages. It is intended to minimize the need to repeat voice advisories. The tone should have the following characteristics:

Duration:	0.8 sec
Frequency:	1000 Hz
Waveshape:	rectangular, 50% duty cycle
Level:	8.1 dBA average below average ambient noise level of the vehicle at 60 mph

Alarm Sound:

The alarm sound is intended to reawaken a dozing or sleeping driver. It is activated only after the driver fails to respond to an advisory to "press reset now." It is therefore set at a substantially higher sound level than advisory messages and tones.

The alarm sound should have the following characteristics:

Description: on-off tone

Characteristics of the tone itself: 1000 Hz rectangular wave, 50% duty cycle

On-off repetition frequency: 3 Hz

Duty cycle of the on times: 50%

Level: 3.5 dBA (average) above average ambient noise level of the vehicle at 60 mph

Onset rate: The alarm sound should increase linearly from 0 to 100% of final amplitude in 2 seconds.

Note that the alarm waveform "ramps up" to full amplitude, rather than simply starting at full amplitude. Figure 5 depicts the waveform, once it has reached full amplitude.

Lane-Minder Tones:

The lane-minder is a countermeasure that provides an audible warning that the vehicle is near a lane edge or partly out of lane. The alarm begins with a continuous tone as soon as the vehicle approaches the lane edge. As the deviation continues, the sound level increases and then begins "beeping." Maximum sound level and beeping occur when the vehicle is three feet or more out of lane.

If the vehicle goes out of lane on the left, the sound emanates from the speaker to the left of the driver. If the vehicle goes out of lane on the right, the sound emanates from the speaker to the right of the driver.

The frequency of each output is 2800 Hz and the beep frequency is 3 Hz. Sound level at maximum excursion is 0 dBA above average ambient noise level at 60 mph. (The output has the same average sound level as the vehicle noise level.)

The lane-minder tones may be generated by the sound card or by a separate special purpose generator that is energized when the lane-minder is activated. Similarly, the vehicle's speakers may be used, or independent sound transducers may be added to the vehicle. If so, they should be placed so that they have left/right directional qualities distinguishable by the driver.

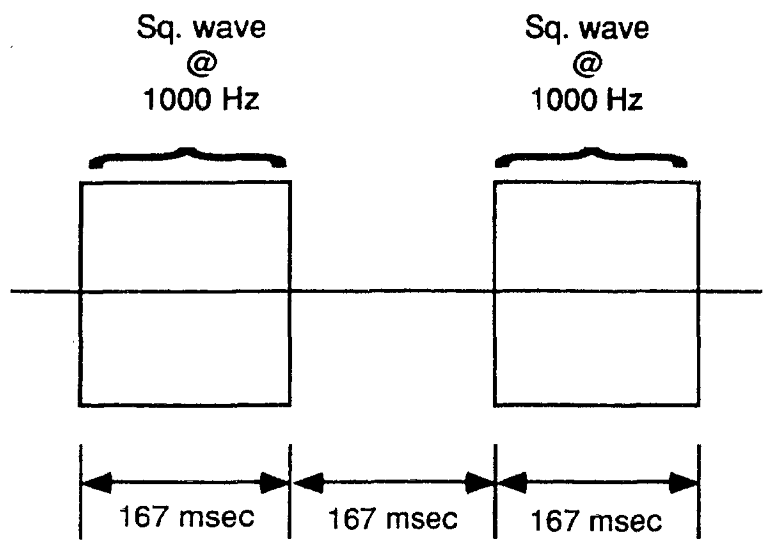

Figure 5. Characteristics of the Alarm Waveform, Once it has Reached Full Amplitude

Power amplifiers

All sounds emanating from the sound card or cards will pass through separate amplifiers for the left and right front speakers of the vehicle. The power amplifiers should have flat response across the audio band, should have good stereo separation, and should be capable of generating 20 Watts RMS of audio power for each channel. Gain should be screwdriver or knob adjustable, and must be such that the sound levels specified earlier in this section are attainable when taking signals from a sound card.

Seat Vibration System

The seat vibration system provides the main stimulus to the driver when lane departure exceeds a specified amount. (Seat vibration could possibly also be used as a supplementary cue for the audio alarm in the status/performance monitoring system. This latter application would need to be tested experimentally.) The vibration is implemented by means of rotational eccentrics that are energized when the auditory alarm begins to sound. Specifications on these two vibration devices are as follows:

Vibrators should be installed in the seat pan (bottom) and in the seat back (opposite the L-1 point of the spine for an average height male).* The vibrators are to be composed of eccentric masses driven by small servomotors that are run open loop (Figure 6). The motors are mounted on brackets that are attached to flexible lucite sheets. The sheets are 7" by 7" by 3/16" thick and are lashed to the seat springs. For the seat pan installation, the lucite is placed between the springs and the foam padding of the seat (which is approximately 1 1/2" thick). For the seat back installation, the lucite is against the back side of the foam pad,

*Because the seat back vibrator may protrude somewhat from the seat back, there should be no rear-seat passenger on the driver's side until safety concerns have been evaluated and the system redesigned as necessary for rear passenger protection.

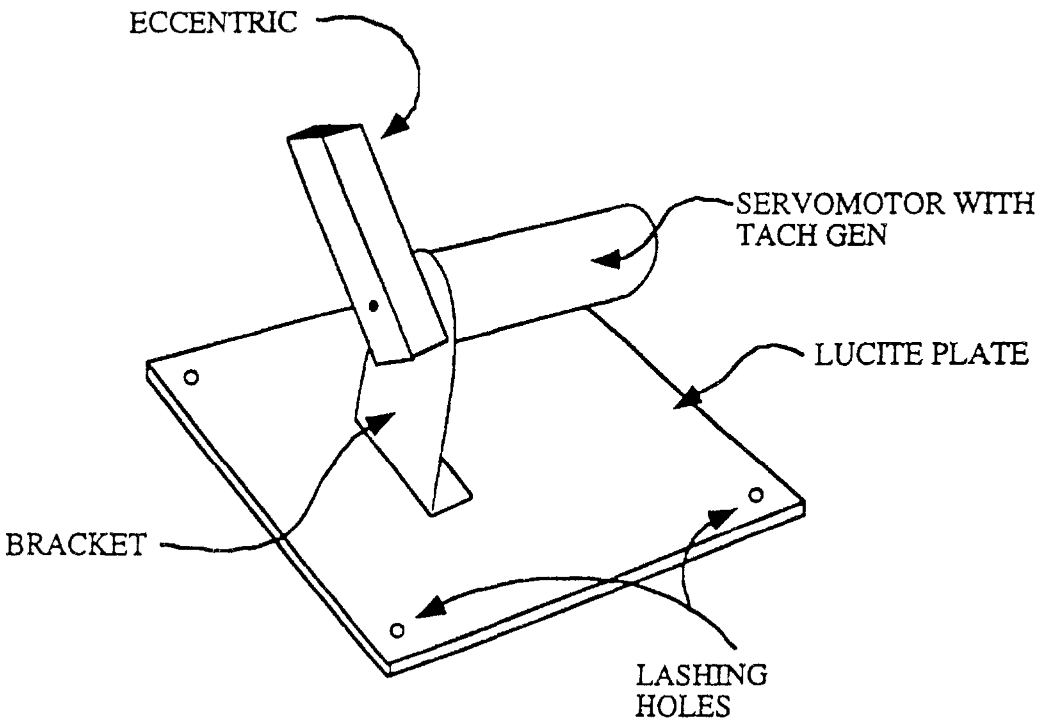

Figure 6. Sketch of Vibrator Assembly

because the springs are usually embedded *in* the foam pad. The upper eccentric should spin at 1380 RPM and the lower should spin at 1440 RPM. This combination of angular velocities produces a "walk-through" effect.

The eccentric for the upper vibrator is to be a rectangular solid made of mild steel. It should be 1/2" by 1/2" by 2" long. The shaft hole for the drive motor and the set screw to hold the eccentric are 1 3/8" from one end of the eccentric.

The eccentric for the lower vibrator is to also be a rectangular solid made of mild steel. It should be 1/2" by 1/2" by 2 3/16" long. The shaft hole for the drive motor and the set screw to hold the eccentric are 1 9/16" from one end of the eccentric.

Both motors are to be mounted on brackets with their shafts parallel to the lucite sheets. The shafts are to be 1 13/16" from the lucite sheets.

The upper vibrator is to be mounted in the seat back with the motor shaft vertical (actually, tilted rearward slightly) and the eccentric at the top. The lower vibrator is to be mounted with the shaft horizontal and aligned with the longitudinal axis of the vehicle. The eccentric is to be mounted at the front end.

A logic relay interface and power supply system are to be provided so that a logic signal available from the computation system is capable of turning the vibrators on and off. The power supplies should be adjustable so that the rotational velocity of the eccentrics can be set to the specifications given above.

Brake Pulse System

The brake pulse system is an optional system that could provide a supplementary cue for the alarm associated with the status/performance monitoring system. It is intended to help reawaken a sleeping driver. (If the seat vibration system is used, the brake pulse system is not used, and vice versa.) The brake pulse system provides a short burst of deceleration to the vehicle and the driver, thereby helping to reawaken the driver. The brake pulse is implemented by applying an appropriate signal to the ABS of the vehicle when the auditory alarm begins to sound. Specifications are as follows:

When a logic signal is provided from the computational system, the brake pulse will be actuated. Actuation time should be approximately 0.5 second and the speed of the vehicle should decrease by approximately 6 mph for an initial speed of 60 mph. Brake pulse length and brake pulse pressure may need to be adjusted based on field tests. Therefore, the interface system should be designed to make this possible.

Brake Light Actuation Interface

The purpose of this system is to energize the brake lights of the vehicle when drowsiness detection occurs. Brake light actuation may serve to advise a following driver to proceed with caution and to use the brakes as required.

Two modes of brake light actuation are envisioned. One of these is associated with the status/performance monitoring system and the other with the lane departure system. They are described separately:

Status/performance monitoring system: Whenever the status performance monitoring system sends a flag to Stage 2 (indicating detection of gradual drowsiness or general performance deterioration), the brake lights are activated. The lights remain activated until the driver depresses the reset button. If the brake pulse system is used, the brake lights remain activated until 3 seconds after the brake pulse ends.

Lane departure system: Whenever the seat vibration system is activated, the brake lights are also activated. Thus, brake lights will stay on until the driver returns to a lane (because vibration remains on until then) or until the driver activates a turn signal (which causes the vibration to deactivate).

The brake light actuation is to be accomplished by paralleling relay contacts with the brake pedal switch. The coil of the relay is to be driven by a circuit that accepts a logic signal from the computer or other system hardware, indicating that the brake lights should be activated. Thus, either the DDDACS system hardware or brake pedal actuation would turn on the brake lights.* This approach allows the directional signals to interact in the normal manner with the brake lights.

<u>Cruise Control Interface</u>

The purpose of the cruise control interface is to allow the DDDACS to appropriately disengage the cruise control (if it is engaged). Cruise should disengage using a logic signal from the computation system that will be timed to occur at the beginning of the initial advisory tone (in the case of a status/performance degradation detection) and to occur when the seat-vibration system is activated (in the case of a lane departure detection).

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*An alternative design would activate the hazard flashers whenever a Step 2 flag is set or the seat vibration system is activated. This alternative should be considered prior to final implementation.

Scent/Cool Air System

This system is intended to blow cool air in the direction of the driver's face and also, on command, to dispense a small amount of peppermint scent into the airstream. The system should be designed to operate directly from commands provided by the driver's control panel. The "scent" and "cool-air" pushbuttons, specified in the section on the control panel, describe the operation of this system.

The cool air to be blown at the driver should be produced by a small squirrel-cage or tube axial fan and duct. The design of the system producing the cool air is potentially complex. Preliminary suggestions can be provided here as follows:

> Modern HVAC systems with automatic temperature controls generally have the air conditioning compressor cycling on and off. Thus, cool air exists on the exit-air side of the evaporator. This air is then re-heated to some extent by the heater core. By tapping air from between the evaporator and heater core, it should be possible to obtain a source of cool air. This air could be used as the source for the cool air blower.
>
> A second approach would be to add a second small evaporator core to fit directly into the ducting of the tubing supplying air to the driver's face.
>
> Again, these are only suggestions. The services of engineers familiar with automotive HVAC systems should be retained in the design of this system.

The scent should be dispensed from a pressurized container by means of an electrically controlled valve. To prevent overdose, the valve control system should shut off after a predetermined time of perhaps 1 second and should not be re-energizable for a period of 3 minutes. The scent contained in the pressurized container is to be composed of equal parts of peppermint oil and water. Only the vapors are to be dispensed — not the liquid mixture. Initial results indicate that an initial pressure of 90 psi is appropriate. The container should be capable of providing a minimum of six one-second bursts without needing repressurization. The nozzle through which the scent is dispensed into the duct between the fan and exit vent should be similar in orifice to that of a spray-paint can.

Ducting for the "cool air" should be made as unobtrusive as possible, yet should direct air to the driver's face. The pattern should be such that drivers of various physical sizes will receive the air flow.

Driver's Control Panel

The drivers control panel is both an input and output device, in that it allows the driver to input information and to receive feedback indicating system status. The panel has been described previously, but is listed again here because *outputs* must be supplied to the panel from the computation system and other special purpose hardware. The reader is referred to the earlier description, which includes the outputs required.

Video Output for Channel 4

Another output previously described is the computer video for Channel 4 of the video system. This output is intended to provide information to the video analyst on the conditions associated with the occurrence of events in the recorded video. The reader is referred to the Video System section, and also to CPU-2 specifications in the next section.

COMPUTATION SYSTEM

The computation system is to be composed of one or more PC type CPUs (central processing units) and all peripherals. The system would include input interface cards, output interface cards, a display and display driver, keyboard, and both hard and floppy disk memory devices. Special purpose hardware may also be needed to accomplish the full range of tasks required of the computation system. For example, the lane-minder system might be realized as a stand-alone system controlled directly from the driver's control panel with a relatively simple interface to the remainder of the computation system.

Functions of the Computation System

The computation system is intended to serve as the "heart" of the DDDACS. It would take inputs from many sources on the vehicle, perform all necessary computations, and provide necessary outputs. This is a relatively complex set of tasks when taken together. As a result, precise specifications cannot be given. Instead, general statements are made on how the computation system is expected to operate along with suggested approaches. The various subsystems are described separately.

Input Interface

The input interface is envisioned as an analog and logic level interface. The sensors on the vehicle are specified as analog or logic level devices. As examples, the steering sensor is to be an analog potentiometer and the directional signal activation signal is to be a logic level signal. The advantages of analog/logic devices are their simplicity *and* their ability to be queried at any time without two-way communication between the computation system and the device. This means that the computation system can obtain a sample from any sensor or logic level device whenever it needs one. Thus, the computer need not wait for a handshake from a sensor when it wishes to sample the sensor.

The primary input interface device should be a multichannel A/D conversion card. It should have at least 16 single-ended channels. It should also have a minimum of 12-bit resolution and it should be able to obtain a single sample from all sixteen channels and place them in memory in less than 5 milliseconds. Between commands to obtain samples from all 16 channels, the CPU to which the card is connected should be available for other processing. It is anticipated that a sampling frequency of 40 samples per second (25 milliseconds between samples) will be used, thereby leaving 20 milliseconds of CPU time between samples for other computations.

A logic I/O card may also be needed. This card would allow logic level devices to be queried to determine status. Many A/D converter boards also contain a limited amount of logic I/O. If there is a sufficient amount, then a separate card may not be necessary. On the other hand, if there is an insufficient amount, an additional card will be needed.

CPUs

As is well known, CPUs of today are fast, reliable, and inexpensive. Portable (laptop) computers are now available that approach the power of desk models. Portable units offer the advantages of smaller package size, less weight, less power consumption, and voltage levels more compatible with automotive electrical power. Thus, preference should be given to the use of one or more portable CPUs.

The number of CPUs to be included cannot be determined with certainty at this time. However, an estimate can be provided. To begin, the Soundblaster 16 sound card, which is typical of today's sound cards, must be supported by a CPU when it is in use. The reason for this is that the CPU controls the flow of data from memory to the sound card during playback of any message. (The manufacturer provides a high-level language to accomplish this.) Unless one wishes to take on the task of developing special software to time-share the CPU while retrieving sound data stored in memory, one must dedicate a CPU whenever the card is playing a message. Since other computations must be ongoing, a CPU must be dedicated to sound generation.

A second CPU would be needed to support the A/D card, the separate I/O logic card if used, computation of measures, computation of algorithm outputs algorithm selection, thresholding, message strobing for the first CPU/sound card, and display of important information on line. This second CPU would carry the main computational burden of the DDDACS and in effect will be the master CPU.

It should be remembered that today's microcomputers are fundamentally serial devices. In addition, higher level languages usually tie up the CPU when in use. A designer is thus often faced with a dilemma:

> Add microprocessors (CPUs) or develop extremely expensive and time-consuming software.

Since this specification is directed toward development of an early prototype, it seems that using two CPUs is the appropriate way to achieve implementation. Doing so greatly simplifies programming and checkout. The cost of the additional CPU is small compared with the financial burdens of highly customized multi-purpose software.

If more than one CPU is used, each should have its own *removable* hard drive capable of storing 800 megabytes. Removable hard drives have the advantage that they can be removed after data collection and saved or studied at a later time. In addition, if a failure occurs, replacement is a simple matter.

The second CPU should also have a floppy drive for software loading and for transferring summary data easily to any PC-compatible.

The CPUs should be able to communicate using RS232 serial ports (null modems). The CPUs themselves should as a minimum, be comparable to Pentium 100 megahertz operation. Since computers are constantly being improved, greater capabilities may be achievable in reliable laptop computers. Care must be taken to insure package software compatibility with new CPU's and their operating systems.

Random access memory capacity for each of the CPUs should be specified based on what is necessary to run the software used. Since upgrades are anticipated, it is probably desirable to overestimate RAM rather than underestimate it. Probably a minimum of 16 megabytes of RAM should be specified. The displays of the computers should be legible with illumination levels from bright daylight to complete darkness. In addition, a video output should be provided for the second CPU, so that computer video can be recorded by the VCR as described in the Video System section.

Finally, it should be remembered that the great majority of programming would be developed using laboratory based PC compatibles. Therefore, provisions should be made for checking out software on the laptop CPUs by some convenient method.

Output Interface

The output interface is composed of line level audio signals from the sound card and logic output levels. The audio signals have already been described in the Audio Output and Sound Playback System section. Logic level output signals would be necessary for the following devices and systems:

- driver's control panel:
  - monitoring system on
  - drowsiness detected
  - scent activated
  - cool air activated
  - eye monitoring system activated
- radio interface switching command
- cruise control disengage command
- seat vibration command
- brake pulse activated
- brake lights on command

It is anticipated that all of these logic level output signals can be obtained using a logic level I/O card. Since the card described in the Input Interface section would most likely contain both input and output logic connections, the card can be used for both purposes. Care must be taken to insure that it has an adequate number of logic lines to service all logic I/O functions.

Finally, video output from the computer screen has already been described, and is of course, one of the outputs of the computation system.

Software

As indicated previously, the computation system is the heart of the DDDACS in that it carries out all functions tying the system together. An enormous amount of detail would be required to fully specify the software. For brevity, an overview will be provided here.

Fundamentally, the software follows from the system flow diagrams shown in Figures 1, 2, and 3. Software for the second CPU would perform the majority of tasks associated with status/performance monitoring as depicted in Figure 1. In particular, the second CPU would gather information through the A/D interface and logic I/O board(s), calculate performance measures for each minute, and subsequently compute moving three-minute averages. Thereafter, it would use these averages to compute algorithm output. One of two algorithms would be used for the detection of *drowsiness*:

Algorithm F4e-3, which estimates PERCLOS, or

Algorithm SLEEPER3-F-3, which estimates SLEEPER 3.

One of two actual measures would be used to assess *performance*:

LANEX, or

LNMNSQ

The lane sensing system would most likely be a self-contained system separate from the second CPU. This separate system would compute lane position relative to lane center, lane width, and a lane valid/invalid signal. Outputs from the lane sensing system would be transferred to the second CPU either through the A/D interface and logic card or through a serial interface (RS-232). Thereafter, LANEX (or LNMNSQ) and other lane-related measures needed for the *drowsiness* algorithm would be computed.

The total status/performance monitoring algorithm would threshold estimated PERCLOS (or estimated SLEEPER 3) and "OR" the result with thresholded LANEX (or thresholded LNMNSQ). Thus, four status/performance algorithms are possible, and one would have to be selected for implementation. As an example, assume the algorithm for estimating PERCLOS is combined with LANEX. Then if either estimated PERCLOS or LANEX or both are above their individual specified thresholds for any given three-minute average, a detection would be said to have occurred and a flag sent to Stage 2. (The definitions of the measures, the algorithms, and the thresholds are specified in the Appendices of this report.)

The second CPU would also play a role in the lane departure system shown in Figure 1. Inputs from the lane sensing system, which are used in computing the status/performance monitoring algorithms, would also be used to determine if a lane boundary had been exceeded by more than a specified amount. If so, it would perform the remaining functions shown on the right-hand side of Figure 1.

As already described there are several voice messages, tones, and an alarm in the system. These auditory outputs would be generated on command by the first CPU. Thus, the first CPU would carry out most of the functions of Figure 2, but would also need to interact with the other CPU via the serial port.

It is anticipated that the majority of the functions shown in Figure 3 would be handled by the second CPU. This CPU would take commands from and provide responses to the driver's control panel. It would also initiate and score the eye monitoring system when the system is activated.

POWER SYSTEM DESIGN AND GROUNDING

The power system to be developed for the DDDACS should be designed to take maximum advantage of the nominal 12-volt battery power already available in the vehicle. In addition, it may be necessary to have a limited amount of 115 volt A.C. power for specific devices that cannot be easily converted to operation from battery power. The vehicle itself should have a heavy duty electrical system so that it is capable of providing power for the DDDACS.

Power System Detail

Nominal 12-volt power should be supplied to the trunk of the vehicle by heavy cables, with the positive lead fused at the hood end of the run. The cables should be number 4 AWG stranded copper. They should be connected to an auxiliary battery in the trunk.). The trunk battery will minimize fluctuations in voltage by acting as a large capacitor. A 100 amp silicon diode should be used on the positive terminal to isolate the rear battery from the front battery during vehicle cranking and startup. The reason for using this arrangement is to prevent large voltage drops in the power supplied for the DDDACS during cranking. (Voltages as low as 9 volts are sometimes experienced during cranking.)

An alternative to the large silicon diode is to use a commercial "battery isolator." These devices are available for RV's (recreational vehicles) and boats. They allow two batteries to be isolated from one another while at the same time making it possible to charge each battery. The isolator selected should be of sufficient size to handle the full output of the vehicle's alternator.

The return (common) for the rear battery should be connected to a point near the front battery in the engine compartment, so that current loops in the chassis are minimized.

Battery power from the rear battery can then be supplied directly to all DDDACS 12-volt equipment having its own internal regulation or not requiring regulation. All commons should be returned to a point near the negative terminal of the rear battery, and all DDDACS equipment should be electrically isolated from the vehicle chassis to minimize loop currents in the vehicle's metal body components. If there are any 12-volt devices requiring regulated 12 volt power, a solid-state DC to DC converter of adequate current capacity, capable of adequate regulation should be used. (The seat vibrators will probably require regulated 12-volt power.)

A second DC to DC solid-state converter should also be included. It will supply +5, +12 (or +15) and −12 (or −15) volt regulated power for logic circuitry, for potentiometer reference voltages, and for circuitry requiring operational amplifiers and comparators. Power capabilities should be such as to handle maximum anticipated loads.

Finally, a DC to AC converter should be included for any devices requiring AC line voltage. Every effort in design should be made to minimize or eliminate the use of AC line devices because there is a loss of efficiency in power use. Quite often, devices operating from power line voltages simply convert the AC voltage back to one or more low-voltage DC sources within the device. In some cases it may be possible to convert the device for use with battery power by using a DC to DC converter having voltage outputs matching those required by the circuitry itself.

Once again, it should be mentioned that all commons should be returned to the power conversion equipment. The entire power distribution system should remain isolated from the vehicle, except for the tie point near the front battery that is part of the standard vehicle grounding system.

Signal Wiring

In connecting the various transducers and components, extreme care must be used to maintain isolation and proper shielding. All transducers should have their own common that is carried back to the input or output point. Shielding should be separately grounded, and should be grounded at only one end to prevent loop currents. These practices can add greatly to the precision of the information provided to or by the various transducers. In all cases, signal quality should be checked and carefully calibrated under typical running conditions to ensure that devices are in fact operating as expected with noise-free, precision. (Signals should be checked using a floating oscilloscope.)

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APPENDIX A

Definitions of Drowsiness Measures and Measures Needed

for Algorithm Computation.

This section lists and defines measures that were used in the revised-algorithm development experiment described in Part III of this final report series. This long list is provided because it may be desirable to compute the measures for diagnostic purposes or for field-development of new algorithms. Actually, only the independent measures designated with a single asterisk need be computed.

Six dependent (definitional) measures of drowsiness are also included. However, similarly, only PERCLOS or SLEEPER 3 would be estimated. They are designated with dual asterisks.

It should be noted once again that all measures are initially computed over one-minute intervals. Thereafter the one-minute values are "pipelined" to produce three-minute moving averages that are updated each minute.

Independent Measures

Steering-Related Measures:

- STVELV*: The variance of steering wheel velocity, where velocity is measures in degrees per second.
- LGREV*: The number of times that steering wheel movement exceeds 15° after steering velocity passes through zero.
- MDREV*: The number of times that steering wheel movement exceeds 5°, but does not exceed 15°, after steering velocity passes through zero.

- SMREV: The number of times that steering wheel movement exceeds 1°, but does not exceed 5°, after steering velocity passes through zero.
- STEXED: The proportion of time that steering wheel velocity exceeds 125° per second.
- NMRHOLD*: The number of times the hold circuit output on the steering wheel exceeds a threshold value (corresponding to holding the steering wheel still for 0.4 second or longer.)
- THRSHLD: The proportion of total time the hold circuit output on the steering wheel exceeds a threshold value.

Lane-Related Measures:

- LNMNSQ*: The mean square of lane position; "zero" position is defined as that position occurring when the vehicle is centered in the lane. (Lane position is measured in feet.)
- LANVAR*: The variance of lateral position relative to the lane. (Lane position is measured in feet.)
- LANDEV: The standard deviation of lateral position relative to the lane; the square root of LANVAR.
- LANEX: The proportion of time that any part of the vehicle exceeds the lane boundary.
- LNERRSQ: The mean square of the difference (in feet) between the outside edge of the vehicle and the lane edge when the vehicle exceeds the lane. When the vehicle does not exceed the lane, the contribution to the measure is zero.

- LNRTVAR: The variance of the time derivative of lane position. (Lane position is measured in feet.)
- LNRTDEV: The standard deviation of the time derivative of lane position (square root of LNRTVAR).

Accelerometer-related measures:

- ACCVAR: The variance of the smoothed output of the accelerometer where the output is first converted to feet per second-squared. (Smoothing is accomplished with a low-pass filter having a corner frequency at 7.25Hz.)
- ACCDEV: The standard deviation of the smoothed output of the accelerometer. (Square root of ACCVAR.)
- INTACVAR: The variance of the lateral velocity of the vehicle. (This signal is obtained by passing the smoothed accelerometer signal through an additional low pass filter with a corner frequency of 0.004 Hz. The unit of output is volts in which one unit (volt) corresponds to a smoothed lateral velocity of 73.34 feet per second.)
- INTACDEV*: The standard deviation of the lateral velocity of the vehicle. (Square root of INTACVAR).
- ACEXEED: The proportion of time that the magnitude of lateral acceleration exceeds 0.3 g (9.66 ft/second^2).

Heading-Related Measures:†

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† These measures may be computable by the lane track sensing system. They are not needed for the algorithms specified in Appendix B.

• HPHDGVAR: The variance of the high-pass heading signal in degrees. (The heading signal was passed through a single-pole high-pass filter with a corner frequency of 0.016 Hz.)

• HPHDGDEV: The standard deviation of the high-pass heading signal (square root of HPHDGVAR).

Lane-Departure Measures:

• VIBPROP: The proportion of time that the seat vibration system was activated.

• NUMVIB: The number of times that the seat vibration system was activated.

Dependent Measures*

• EYEMEAS: The mean square of the percentage of the subject's eye closure.

• PERCLOS**: The proportion of time that a subject's eyes were 80% to 100% closed.

• DRVDROW: The subject's online self-rating of drowsiness, which he or she inputs using the drowsiness control. Values range from zero (not drowsy) to 100 (extremely drowsy).

• SLEEPER1: The sum of weighted values of EYEMEAS and DRVDROW. Weighting is accomplished using values for each measure considered to signify a "very drowsy" level of drowsiness:

$$\text{SLEEPER1} = (1/2500)(\text{EYEMEAS}) + (1/75)(\text{DRVDROW})$$

• SLEEPER2: The sum of weighted values of EYEMEAS and DRVDROW. Weighting is accomplished using the mean values of three-minute averages for each measure:

$$\text{SLEEPER2} = (1/1179.8)(\text{EYEMEAS}) + (1/55.6)(\text{DRVDROW})$$

*These measures are listed here for research purposes. They could be computed off line to check the accuracy of algorithms. As indicated, PERCLOS or SLEEPER 3 would be estimated on line and used as part of the detection system.

- SLEEPER3**: The sum of weighted values of PERCLOS and DRVDROW. Weighting is accomplished using value for each measure considered to signify a "very drowsy" level of drowsiness:

$$SLEEPER3 = (1/0.014)(PERCLOS) + (1/75)(DRVDROW)$$

APPENDIX B

Recommended Algorithms and Estimated Accuracies

This appendix contains summary information on regressions for estimating PERCLOS and SLEEPER 3. It also contains classification matrices for PERCLOS by itself, PERCLOS "or"ed with LANEX, PERCLOS "or"ed with LNMNSQ, SLEEPER 3 by itself, SLEEPER 3 "or"ed with LANEX, and SLEEPER 3 "or"ed with LNMNSQ. Thresholds for all measures are also specified. Note that in the regression summaries, the "B" values are the coefficients that should be used in implementation. For example, to estimate PERCLOS, the following equation should be used:

$$\begin{aligned} \text{ePERCLOS} = {} & -0.00304 + 0.000055\ (\text{STVELV}) \\ & -0.00153\ (\text{LGREV}) -0.00038\ (\text{MDREV}) \\ & +0.003326\ (\text{LNMNSQ}) + 0.00524\ (\text{LANVAR}) \\ & -0.00796\ (\text{INTACDEV}) \end{aligned}$$

These algorithms are for use with three-minute averages.

Regression Summary for Dependent Variable: PERCLOS

R = 0.48232223 R^2 = 0.23263473 Adjusted R^2 = 0.22277565

F(6,467) = 23.596 p < 0.00000 Std. Error of estimate: 0.01074

	BETA	St. Err. of BETA	B	St. Err. of B	t(467)	p-level
Intercept			-0.00304	0.001063	-2.85703	0.004467
STVELV	0.387123	0.118343	0.000055	0.000017	3.27121	0.00115
LGREV	-0.20208	0.077889	-0.00153	0.00059	-2.5945	0.009771
MDREV	-0.33165	0.0933	-0.00038	0.000107	-3.55464	0.000417
LNMNSQ	0.333604	0.064803	0.003326	0.000646	5.14795	0
LANVAR	0.253799	0.06782	0.00524	0.0014	3.74227	0.000205
INTACDEV	-0.15691	0.047731	-0.00796	0.002423	-3.28727	0.001088

Observed

Predicted Algorithm Output		Low	High	Total
	High	17	16	33
	Low	424	17	441
	Total	441	33	**474**
	% Correct	96.15	48.48	92.83

PERCLOS R Value = 0.48232

Apparent Accuracy Rate: 0.928

Threshold: 0.012

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm F4e-3. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX, & LNERRSQ.)

Observed

Predicted Algorithm Output		Low	High	Total
	High	1	56	57
	Low	402	15	417
	Total	403	71	**474**
	% Correct	99.75	78.87	96.62

Algorithm F4e (Threshold = 0.012) - OR - LANEX (Threshold = 0.06667)

Apparent Accuracy Rate: 0.966

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm F4e-3 -OR- Measured LANEX Data.

Observed

Predicted Algorithm Output		Low	High	Total
	High	2	57	59
	Low	401	14	415
	Total	403	71	**474**
	% Correct	99.50	80.28	96.62

Algorithm F4e (Threshold = 0.012) - OR - LNMNSQ (Threshold = 3.00000)

Apparent Accuracy Rate: 0.966

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced PERCLOS Data Resulting in Algorithm F4e-3 -OR- Measured LNMNSQ Data.

Figure A1: Regression Summary and Classification Matrices for Algorithm F4e-3.

Regression Summary for Dependent Variable: SLEEPER3
$R = 0.53394126$ $R^2 = 0.28509327$ Adjusted $R^2 = 0.27435433$
$F(7,466) = 26.548$ $p < 0.00000$ Std. Error of estimate: 0.89238

	BETA	St. Err. of BETA	B	St. Err. of B	t(466)	p-level
Intercept			0.868176	0.232043	3.74145	0.000206
STVELV	0.393598	0.114568	0.004798	0.001397	3.43549	0.000644
LGREV	-0.20171	0.0763	-0.13147	0.049729	-2.64363	0.008479
MDREV	-0.2913	0.105169	-0.02869	0.010359	-2.7698	0.005833
NMRHOLD	-0.1756	0.065891	-0.02252	0.008448	-2.66502	0.007965
LNMNSQ	0.357999	0.062946	0.306987	0.053977	5.68737	0
LANVAR	0.265219	0.067738	0.470883	0.120265	3.91538	0.000104
INTACDEV	-0.24404	0.04804	-1.06524	0.209694	-5.07998	0.000001

		Observed		
		Low	High	Total
Predicted	High	51	28	79
Algorithm	Low	375	20	395
Output	Total	426	48	**474**
	% Correct	88.03	58.33	85.02

SLEEPER3 R Value = 0.53394
Apparent Accuracy Rate: 0.850
Threshold: 1.4

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-F-3. (Independent variables employed included Steering, Accelerometer, LANDEV/VAR, LNMNSQ, LANEX & LNERRSQ.)

		Observed		
		Low	High	Total
Predicted	High	31	66	97
Algorithm	Low	360	17	377
Output	Total	391	83	**474**
	% Correct	92.07	79.52	89.87

Algorithm SLEEPER3-F (Threshold = 1.4) - OR - LANEX (Threshold = 0.06667)
Apparent Accuracy Rate: 0.899

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-F-3 -OR- Measured LANEX Data.

		Observed		
		Low	High	Total
Predicted	High	31	66	97
Algorithm	Low	360	17	377
Output	Total	391	83	**474**
	% Correct	92.07	79.52	89.87

Algorithm SLEEPER3-F (Threshold = 1.4) - OR - LNMNSQ (Threshold = 3.00000)
Apparent Accuracy Rate: 0.899

Classification Matrix Generated from Multiple Regression Analysis of Lane-Enforced SLEEPER3 Data Resulting in Algorithm SLEEPER3-F-3 -OR- Measured LNMNSQ Data.

Figure A2: Regression Summary and Classification Matrices for Algorithm SLEEPER3-F-3.

APPENDIX C

Initial Specification of Miscellaneous System Parameters

In several instances, system parameters must be specified with limited available research information. Best estimates are provided here. They may need to be modified based on initial field test experience.

1. The threshold on speed below which computations are placed in a hold mode and the lane departure system becomes inactive: 50 mph
2. The time below 50 mph (or the threshold speed) after which the "pipeline" is cleared (detection system is re-activated as if it had just been turned on): 6 minutes
3. When the driver activates the directional signals, the computation program must delete data for a prior interval as well as for a future interval to prevent false alarms.

   The initial deletion durations are specified as 15 seconds into the past and 15 seconds into the future (referenced to initial actuation). However, if the vehicle is out of lane at a point 15 seconds into the past, then the interval of deletion should be extended into the past to a point where the vehicle is in lane. Similarly, if the vehicle is out of lane at a point 15 seconds into the future, the interval of deletion should be extended to a point where the vehicle is back in the lane.

   If for reasons of feasibility the above computations cannot be accomplished, then the deletions should be 20 seconds into the past and 50 seconds into the future.

4. The distance out of lane (for any portion of the vehicle) at which seat vibration is initiated: 2 feet. 6 inches (0.76 meter)
5. The amount of time between the driver's returning the vehicle to the lane (after a lane departure) and the message to "select countermeasures now": 10 seconds
6. The "cool air" blower activation time after the "scent" pushbutton has been activated: 1 minute, 30 seconds
7. The approach distance between the edge of the vehicle and the lane edge (on each side) at which the lane minder begins to sound: 6 inches (15.2 cm)