A Mobile Illumination Evaluation System

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State and local transportation agencies have responsibility for the design, construction, and inspection of high-mast roadway lighting projects, using prescribed guidelines. These guidelines require many measurements of the illuminance levels of highway lighting installations to determine whether the installations achieve the desired design goals, to determine whether manufacture specifications are met, and to document long-term aging effects. The state of the art in photometry, or the measurement of light visible to the human eye, has been developed to a very high degree of accuracy and reliability by commercial manufacturers of photometric instruments. One large drawback to these instruments in highway work is that the readings are normally taken by an operator carrying the instrument to the location to be measured and hand-recording the value. This approach is very time consuming and dangerous as well, if readings are required from a busy, in-service roadway. This study has resulted in the development of a simple, cost-effective, and easily assembled illuminance measurement system to evaluate high-mast (80–180-ft) roadway lighting systems from a passenger vehicle traveling at traffic speeds. The system provides readings, in footcandles, at fixed distance intervals as short as 15 ft. The measurements are then recorded on a computer disk for later analysis. The printed analysis provides a footcandle value for each traffic lane at each distance interval and a calculation of the maximum, minimum, average, and uniformity ratio. The system is assembled from commercially available units with a minimal amount of construction, resulting in easy implementation.

State transportation agencies have responsibility for the design, construction, and inspection of roadway lighting projects, using prescribed guidelines (*1*, *2*). In the course of carrying out this responsibility, it is periodically necessary to measure illuminance levels of highway lighting installations to determine whether they achieve the desired design goals, to determine whether manufacture specifications are met, and to document long-term aging effects. The development of equipment, techniques, and methods for these measurements is not a new requirement, to judge from publications such as *Measurements Carried Out on Road Lighting Systems Already Installed* written by P. J. Bouma in 1939 (*3*).

The state of the art in photometry, or the measurement of light visible to the human eye, has been developed to a very high degree of accuracy and reliability by commercial manufacturers of photometric instruments. One such instrument, used by the Texas State Department of Highways and Public Transportation (SDHPT), is the Tektronix J16 Digital Photometer. This highly accurate instrument (2 percent) has been used to obtain illuminance readings both at controlled research facilities such as Texas Transportation Institute (TTI) and on highways throughout the state of Texas. To obtain the data, the operator is required to carry the portable photometer to each location, place the sensor on the pavement and write down the digital footcandle meter reading. Such a method produces accurate results but is very time consuming and dangerous as well, if readings are required from a busy, in-service roadway. Vehicle-mounted measurement systems are not new either. One example is the measuring van used to measure illuminance and luminance on road surfaces, developed by Baba in 1969 (*3*). Even though this system was quite functional, it had a drawback in that a large van was needed for the large amount of electronic equipment and power supply, producing a high cost. As technology has progressed the microprocessor has made the mobile measurement system approach more manageable, as exemplified by the "Dynamic Roadway Lighting Measuring System with Split Type Photocells" developed by Y. Ohno (*4*). This system appears to be effective in measurement work, but it uses two CIE-corrected sensors (CIE = International Commission on Illumination) and two signal conditioners, a complex position correction algorithm, and noncommercial processor equipment. These characteristics limit availability and restrict service and calibration support, as well as increase the cost. Because the primary requirement given by SDHPT was to evaluate high mast-lighting systems, it was determined that a simpler system could be implemented. This is because of the small difference between the lamp height to the road and the lamp height to the sensor mounted on the roof of an automobile.

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SYSTEM REQUIREMENTS

So that a large number of illuminance readings could be obtained to provide a record of average, minimum, and maximum footcandle levels along heavily traveled highways, the measurement system would have to be automated and operated in a vehicle traveling at traffic speeds. Footcandle readings could then be taken at reasonable speeds (up to 50 mph) every 20–30 ft on roadway test sections and stored. The stored data could then be analyzed by computer later to determine photometric performance of the roadway lighting system.

Specific requirements of the system were as follows:

- Equipment (photometer, distance measurement device, data storage element, and necessary cabling) should be portable, that is, easily attached and removed from an automobile.
- The system should provide footcandle readings to be taken at 20-foot intervals at speeds up to 50 mph. The computer interface and software program should be compatible with IBM-PC™ computer. The system should be designed for entering identification data (ID) for each test run (i.e., highway and lane, start and stop points, etc.).
- The computer program should provide calculations for each test section, including average footcandles, minimum

footcandles, maximum footcandles, and average to minimum ratio.

- The system should exhibit a high degree of accuracy; it should at least be comparable with current practice.
- The system should be cost effective (approximately $5,000 hardware cost) and should not use higher orders of sophistication than those necessary to accomplish the required tasks.

SYSTEM DESIGN APPROACH

In an effort to provide a working system that met the system requirements, four tasks were undertaken:

1. Determine system hardware and software requirements;
2. Identify, acquire, and assemble required hardware subsystems;
3. Develop and test the required software; and
4. Test and finalize the system design.

SYSTEM HARDWARE

Photometer

Because highly accurate electronic digital photometers are commercially available, it was decided that improvement of the current technology should not be pursued. Instead, a unit that met the system requirements was purchased. Because SDHPT has successfully used the Tektronix J16 in the past (Figure 1), it was considered highly suitable for the task. The requirement for interfacing the unit with a digital data acquisition system without degrading its accuracy was obtainable by requesting option 07. This option is a BCD (binary coded decimal) output that is simply an electrical representation of the digital display. This BCD output, which is available at a connector on top of the unit, is updated at a rate of six readings per second. This rate exceeds the system requirement of a reading every 20 ft at 50 mph, or 3.66 readings per second. The J16 uses a separate probe at the end of a 25-ft cable that is magnetically mounted on the roof of the vehicle. The probe is very accurately cosine-corrected; thus oncoming traffic headlights have no effect because the cosine of 90 degrees is zero. In addition to the 13 data lines from the J16, there are two control lines. One indicates when the data are valid, and the other is an input to hold the current reading.

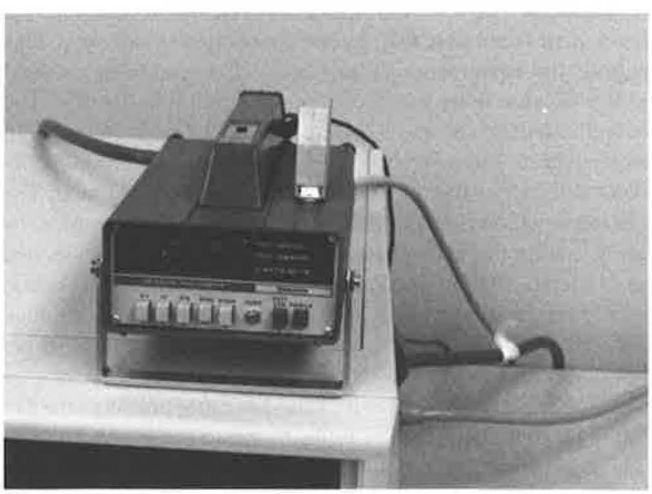

FIGURE 1 Digital photometer.

Computer

The requirements for the computer were that it must be portable; must possess parallel input capability as well as a counter, or have card slots available; be IBM-PC™ compatible; and have adequate storage capability. After a survey of current laptop and portable computers was made, a Compaq portable with dual floppy disk drives was selected for use. This unit provided the required expansion slots needed for the parallel I/O card and counter/timer card. Because technology is rapidly changing, a smaller unit may be found in the near future. The current Compaq, however, already fits nicely in a passenger vehicle (Figure 2).

Distance Sensor

Originally, a "fifth wheel" was considered for obtaining distance information for the computer. The device would be attached to the bumper of the test vehicle. This highly accurate unit is very expensive and easily damaged if the vehicle is backed up over it, so alternate sensors were considered. A low-cost sensor that attached in line with the vehicle speedometer cable was located (Figure 3). The attachment point is quite simple if the vehicle has a "cruise control" under the hood with removable speedometer cables. Because typical speedometer cables turn 1,000 revolutions per mile, a sensor that produces 20 pulses per revolution will provide 20,000 pulses in a mile. This equals a pulse every 3.169 in. of forward travel, which provides adequate resolution for the system. The sensor used in the

FIGURE 2 System computer located in rear seat of an automobile.

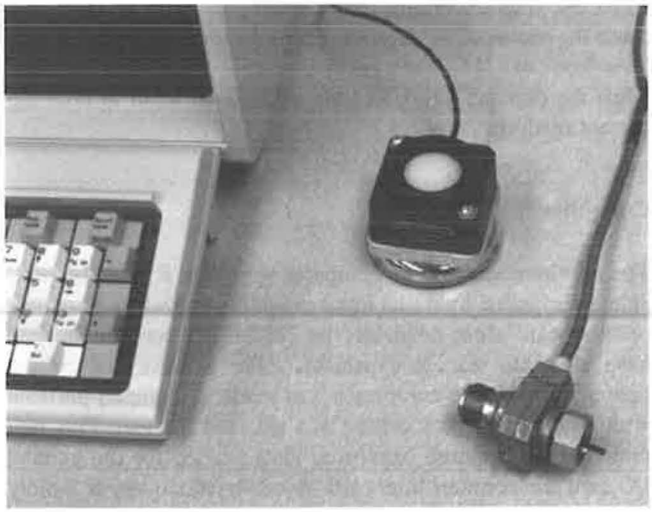

FIGURE 3 Illuminance probe and magnet (center) and distance sensor (bottom).

FIGURE 4 System power inverter.

prototype is a Hall Effect unit (Model AA-1422-20, Arthur Allen Manufacturing Corporation), which requires 5 volts power and produces a 5-volt (TTL) clean square wave output.

Counter Interface Board

So that illumination readings could be taken at regular intervals along the roadway it was necessary to have the computer system be capable of counting distance pulses from the sensor. This was done by using a CTM-5 plug-in circuit board manufactured by Metrabyte Corporation. This board provided five counter/timers that were readable from the main program by means of a binary subroutine. The distance sensor obtains its operating power through a 37-pin connector on the card and connects to two concatenated counters to provide a maximum count of 4×10^9.

Parallel Interface Board

A MetraByte PIO 24 parallel I/O board was used to interface the J16 photometer with the computer. A 37-pin connector located on the end of the board and accessible at the side of the computer provides for the 13 data lines and 2 control lines. The card is initialized and configured for input or output from software.

Power Supply

Because the system was to operate in a mobile environment in a standard passenger vehicle, the only source of power to be considered was the vehicle electrical system or auxiliary batteries. It was decided to use the 12-volt automotive system. Because the photometer and computer operate on 120 V ac, a power inverter was required. A frequency-stabilized 250-watt Tripp Lite unit was obtained and was found to supply an adequate amount of power (Figure 4).

THEORY OF OPERATION (HARDWARE)

Many of the critical design aspects in a well-established photometer such as the Tektronix J16 are taken care of by the manufacturer. The J6511 probe is used with the J16 to provide illuminance readings in footcandles (Figure 3). The J6511 is a multielement glass filter and silicone photodiode that ensures a close match to the CIE photopic curve (color corrected). The silicon sensor recovery time is virtually instantaneous, so low light levels can be measured immediately after exposure to bright light. The angular response is accurately cosine corrected, simulating an ideal 180-degree field-of-view detector. Because the unit is cosine corrected and located on the roof of the vehicle, oncoming traffic headlights have no effect on the readings. The sensor is attached to the roof of the vehicle by a doughnut ceramic magnet, similar to those found on mobile antennas. A 25-ft cable connects the sensor to the J16, which operates inside the vehicle near the computer. The J16 was ordered with options 03 and 07. Option 03 provides for 115 V ac operation, and option 07 provides the BCD output, as noted previously. Because The BCD output to the computer is a direct representation of the LED digital display, the accuracy of the instrument is not degraded by the connection in any way. This permits the equipment warranty and calibration to be retained in full because there has been no modification to the unit. The overall accuracy of the J16 and J6511 probe is very good: linear within 2 percent over the entire range, enabling single-point calibration and a stability within 2 percent per year. The electrical calibration of the J16 mainframe is performed by using a calibrated voltage source or digital volt meter calibrated to National Bureau of Standards specifications. Calibrated probes can be used with any J16 without additional calibration. BCD data are transferred from the $3^1/_2$ digit display (4 bits per full digit and 1 bit for the $^1/_2$ digit) from a 25-pin connector on top of the unit. A 4-ft, 25-wire shielded cable connects the J16 to the parallel interface card in the Compaq computer. Thirteen TTL compatible lines are used to provide BCD data to the card, one line is common, and one line is used to hold the J16 reading.

The other source of information to the computer is the forward travel distance of the vehicle, originating with the speedometer line pulser. The Hall Effect unit used in this study produces 20 pulses per revolution and attaches easily at a General Motors cruise control unit. Arthur Allen Corporation provides other fittings, extensions, and adapters to fit many types of vehicles. The sensor requires 5 volts at about 10 milliamps and produces a TTL-compatible output if it is ordered with a pullup resistor. The pulse or square wave output is connected to the CTM-5 card by means of a three-wire shielded cable. The pulser output is connected directly to counter 2, and counter 2 output is connected to counter 3 input. This way, if counter 2 should reach an overflow condition of 65,537, counter 3 will be incremented by 1, and counter 2 will be reset to zero and continue counting. Thus a total count of $65{,}536^2$ is permissible for distance calibration or data collection.

Before the interface cards are installed in the Compaq computer, they must be properly configured for the hardware used in the system. This is simply done by setting their "base address" switches to the correct I/O address location. In this system the CTM-5 card is set to 300 hex, and the PIO 24 card is set to 200 hex. These locations will be referenced by the software to perform specific initialization or I/O functions. The interrupt control on the CTM-5 card is not used and should be left in the off or (x) position. Installation of the cards in the Compaq computer should be left to a qualified technician because opening first the plastic and then the metal case requires special tools, as outlined in the Compaq user's guide.

Power for the system is provided by the square wave, frequency stabilized power inverter (12 V dc-115 V ac) by Tripp Lite, mentioned earlier. The unit chosen for the system was model PV-250FC, which is frequency controlled to 60 Hz and has a maximum load rating of 250 watts. The computer and photometer draw 140 watts maximum, which results in a dc input to the inverter of about 10 amps. For best results the inverter should be connected directly to the vehicle battery through a 20 amp fuse and 10- or 12-gauge wire.

THEORY OF OPERATION (SOFTWARE)

The heart of the measurement system is the software programs that control the data gathering process. The main program is written in interpretive BASIC. Even though this language does not have the speed of compiled BASIC or other compiled languages, it is easily modified by the user to suit current or future requirements. The CTM-5 counter/timer card uses a special binary program, CTM5.BIN, to set the many mode registers and counter control registers and to handle initialization. The CTM5.BIN program must be on the same disk as the BASIC program but is user transparent because the BASIC program handles the loading and calling routines. The disk operating system (MS DOS™, Version 2), BASICA (Version 2), and AUTOEXEC.BAT must also be on the working disk. The AUTOEXEC program is set up to automatically start the main program running when the computer powers up if the working disk is in drive A.

The program (MILES1.BAS) consists of two sections. The first contains the measurement routines and the second is the analysis portion.

Measurement

When the program is started, an identification page appears on the screen with a two-choice menu. The first choice is to take measurements, an operation that will be discussed now, and the other to analyze the results of any recorded test. As the measurement program is started, the CTM-5 card is initialized by loading the binary driver by contracting BASIC's workspace to 48 kilobytes. The master mode registers are set, and the counter mode registers are initialized by call routines. Because the distance pulser may be changed from vehicle to vehicle, it is always necessary to calibrate this unit in a new installation by selecting "calibrate" from the menu, setting up the CTM-5 card as a simple counter. The space bar is used to start the counter totaling over a measured distance. The F10 key terminates the count at the end of the measurement run. While the counter is totaling, the program is looping and taking a "snapshot" of the count, which it displays on the screen for operator verification of proper operation several times per second. Once the count is terminated by the operator, the program requests the distance traveled. The total count is then divided by the distance in feet to provide a constant of pulses per foot to be used in later calculations. If the same vehicle has been used before, the program allows the operator to input the constant directly.

The next step is to ask whether the data are to be saved to disk. If permanent storage of data is not needed, the program will show photometer readings on the screen but will not save them to disk. If disk storage is chosen, the program will request that a formatted disk be placed in drive B and the space bar pressed. Once this is done, a certain amount of error checking is performed to see that the disk is formatted, that the "write protect" tab is off, and that the disk is in the drive correctly. If all is correct, a request for a file name will be made. This file name will be the name of the data disk file, with no extensions. Again, the error checking function will check whether the file name already exists and if so, request that it should be replaced.

Once the data disk is in place and initialized, the program will ask for the header information (ID). This information, which is pertinent to the test time and location, is entered on the keyboard by the operator and saved to disk in the same order in string variable form. Next, the operator is requested to input the J16 range setting used for the test. This is necessary because there is no way for the computer to know the distance of the meter from the BCD output connector. The program then requests information on how far apart the readings are to be taken. This number, in feet, is subsequently multiplied by the pulses per foot constant to arrive at a pulses per reading value. A limit of 15 ft has been placed in the selection to provide enough time for the J16 to integrate between readings at 50 mph (approximately six readings per second maximum). A request is then made for the distance from the luminaire to the center of the first measurement lane. This value is used in the analysis phase to determine lateral displacement. The lane width, which is used to provide for additional lateral displacement, is also requested. Once the constants have been determined, the program is ready to measure light values.

The light data taking routine is one of the most complex and demanding parts of the program. The CTM-5 card is reconfigured to count down repetitively from a value placed into the "load register." This value is the pulses per foot times the feet between readings. As the terminal count is reached (0), the output of the counter is set to toggle or flipflop, and a reading is processed. When initialization is complete, the screen will switch to a large print mode and request that the space bar be pressed to start the measurements. Once the operator presses the space bar at the appropriate roadway location, the screen will display photometer readings in the center and the measurement lane at the upper left corner. To do this, the program pauses until the terminal distance count is reached and the "status bit" of counter 2 changes (high to low or low to high). At that time, a "hold" level is sent to J16 via the PIO 24 card to freeze the display reading. The BCD data are read at that time by the PIO 24 card in 2 bytes, or 16 bits, and then the hold line is released. The two data bytes are mathematically operated on to rebuild the decimal representation of the J16 readout, between 0 and 1999. Each reading is tested for an over-range condition before it is stored. If a over-range condition from the J16 is detected (>2,000), an alarm beep will be sounded, and a value of 9999 will be substituted for the erroneous reading.

The photometer values are displayed on the screen and recorded in an array that was previously dimensioned to 1,000. A short beep is sounded each reading to confirm that measurements are being taken. Once a reading is saved in memory, the program stops and waits for another status change from the distance counter to take another reading. If the F10 key is pressed by the operator, indicating the end of the test section, the program stops taking data and proceeds to restore the counter to a reset and resting state. All data in the array are then written to the data disk in floating point form, using 4 bytes per data point with the number 999 at the end of the record. Storage efficiency could be increased by a factor of two by storing the data points as integers with one scale factor, but the method used allows the ASCII disk files to be examined directly in footcandles.

After the data from a test run are saved to disk, the program displays a menu with choices to Measure another lane, Measure another site, or Quit the program. If another lane is selected, the program will increment the lane number and loop back to start measurements again. Each additional lane will be saved sequentially under the same file name with a 999 at the end of each lane record. If a new site is selected, the program will close the disk file and loop back requesting a new disk file name and new header information. If Quit is selected, the disk file is closed, and the program returns to the initial menu page.

Analysis

The data analysis portion of the program is entered by selecting the second option on the main menu screen. After initialization, the program requests whether the output is to be directed to the screen or the printer. The file name to be analyzed is then requested, and the current data files on drive B are displayed. Once a name is entered, a test for errors is made. If none are found, the header information is printed on the selected device. If the screen has been selected, the output will stop at the end of the header information for viewing. Then the footcandle information will be displayed, with each lane as a separate column at the various lateral distances from the luminaire. Each row represents the forward distance from the starting point, and the cumulative measurement in feet is indicated. At the end of the

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            MOBILE ILLUMINATION EVALUATION SYSTEM
  Texas State Department of Highways and Public Transportation

FILE NAME                 test137
HWY. NO.                  IH35
CONTROL-SECTION-JOB       1807-6-9
COUNTY                    TRAVIS
DIRECTION                 NORTH
START STATIONING          234+50
STOP STATIONING           678+50
TESTING DATE              07/20/87

                 ILLUMINATION SUMMARY
                     (Footcandles)
```

Travel Dist. (ft.)	Lane Distance From Luminaire (ft.) 0	12	24
0	0.40	0.45	0.43
30	0.40	0.53	0.56
60	0.68	0.68	0.63
90	0.88	0.81	0.71
120	1.15	0.97	0.83
150	1.73	1.24	0.87
180	1.48	0.89	0.67
210	0.94	0.66	0.59
240	0.82	0.59	0.42
270	0.64	0.42	0.29
300			

```
Average=   .7453334
Maximum=   1.73
Minimum=   .29
Average/Min Ratio=   2.570115
```

FIGURE 5 Typical data printout.

footcandle readings are calculations of average, maximum, minimum, and the average to minimum ratio. A typical data printout is shown in Figure 5.

AVAILABILITY OF PROTOTYPE SYSTEM SOFTWARE

A copy of the BASIC program MILES1 and specific wiring information may be obtained by contacting the Texas State Department of Highways and Public Transportation D-8 or the Texas Transportation Institute.

The CTM5.BIN program is available under license from MetraByte Corporation and is supplied with a CTM-5 board.

MS DOS™ and MS BASIC™ are available under license from Microsoft Corporation.

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