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The Feasibility of Applying the Active TvTime System to Automatic Vehicle Location

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Abstract

The National Bureau of Standards Boulder Laboratory has studied the use of television as a carrier for accurate time and frequency signals. The usefulness of the TvTime System applied to locating cars and other vehicles automatically is examined. Such a need exists in transit, police, taxi, utility and many commercial fleets. Past approaches to the problem are outlined. The NBS TvTime System and experimental results will be discussed. Two models of a car locating system are outlined, each having three parts: (1) a TV decoder in the car, (2) a radio link such as a mobile channel between car and central dispatch, and (3) a computer which determines the car's position. Results show that this system is capable of achieving a location accuracy of better than 60 m with 95 percent confidence. Some advantages and limitations of the system will be discussed and cost estimates for the equipment given.

Introduction

Automatic vehicle monitoring (AVM) is defined as a system which will allow the position of a properly equipped vehicle to be known with accuracy, in real time, and without any direct action on the part of the vehicle operator. For several years, a need has existed for an effective, low cost system of car location for fleet vehicle command and control. Transit, police, taxi, utility, and commercial fleets are aware of this great need and many varied techniques have been proposed. It is possible to incorporate time and frequency dissemination techniques in conjunction with various navigation plans to achieve AVM.

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In the past there have been three basic approaches to the problem of automatically locating vehicles.

1. *Dead Reckoning.* Dead reckoning (DR) devices essentially measure the distance and direction traveled from a known starting point by the use of mechanical devices such as wheel revolution counters and gyrocompasses.
2. *Signpost or Proximity.* This system makes use of low-powered transmitters placed along traffic routes or throughout an urban area. The transmitters continously emit their location address code, which is received by an equipped vehicle as it comes within close range of the emitter.
3. *Time and Frequency Techniques.* These may be separated into two categories:

a. *Hyperbolic.* A hyperbolic system makes use of receivers which measure the two time differences between the signals from 3 stations in a master-slave transmitter chain. These time differences then determine intersecting hyperbolic lines of position.

b. *Range-Range.* Range-Range systems determine vehicle location by measuring the time it takes for a radio signal to travel between a transmitter and the vehicle or between vehicle and a distribution of receivers. Using arrival times of transmitted pulses, a central computer can determine the location of the vehicle from the data.

The U. S. Department of Transportation (DOT) has sponsored a number of AVM feasibility studies with varying fundamental objectives in mind. Four DOT experiments have been conducted recently in the Philadelphia, Pa. area, and three of them utilize time and frequency technology, one incorporating LORAN-C [1, 2].

In recent years, it has been shown that the television communication system in the United States (transmitter to home receiver, studio-to-transmitter link, cross-country network paths, studio wiring, etc.) is exceptionally stable when used for high-accuracy timing [3, 4]. If an atomic clock is available at a television studio, it is possible to encode an unused portion of the video format with accurate time and frequency information. The short-term instability (1 sec) has been shown to be less than 3.0 ns. The long-term accuracy of a decoder locked to the reference is as good as the atomic standard feeding the time code generator at the studio.

In the TvTime System developed by the National Bureau of Standards in Boulder, Colorado, the video signal is actively encoded with time and frequency information. If the user can observe signals from three or more TV stations having synchronized time codes, then he can calculate his location. This use of the TvTime System has already shown promise for geodetic surveying [5].

The standard television format in the U. S. calls for 525 horizontal lines which generate one picture. At its present stage of development, the TvTime System code is inserted on line 21 of each television picture. This line is part of the vertical interval (the black bar which may be seen as the picture rolls from top to bottom). Consequently, the code does not interfere with TV viewing. Fig. 1 shows how the code would appear on the TV screen and gives a waveform

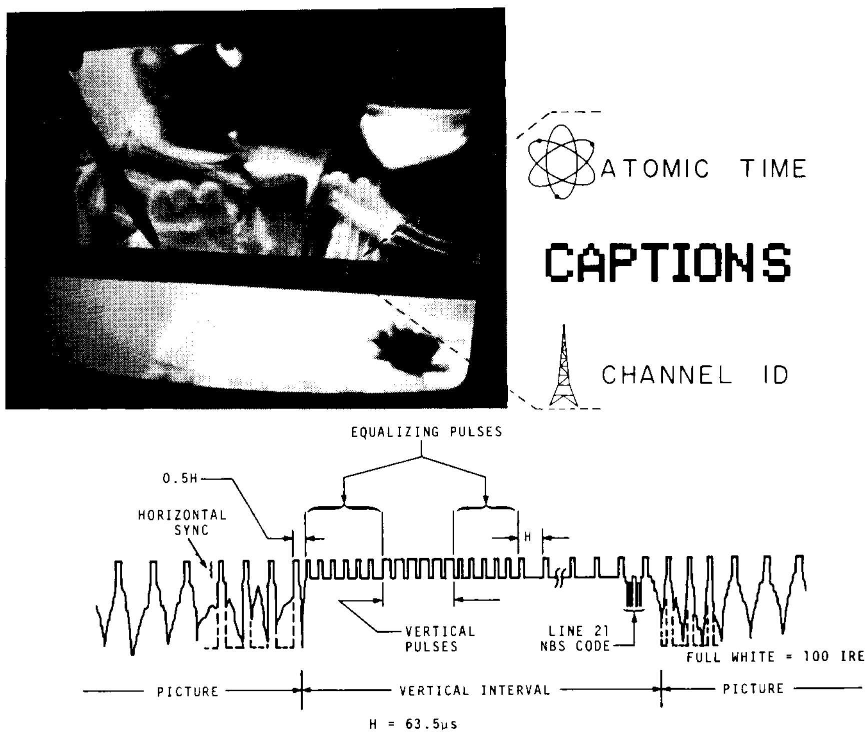

Fig. 1—Television stations transmitting the NBS code will have among other things accurate time-of-day information in digital form located in the vertical interval, the black bar between picture frames.

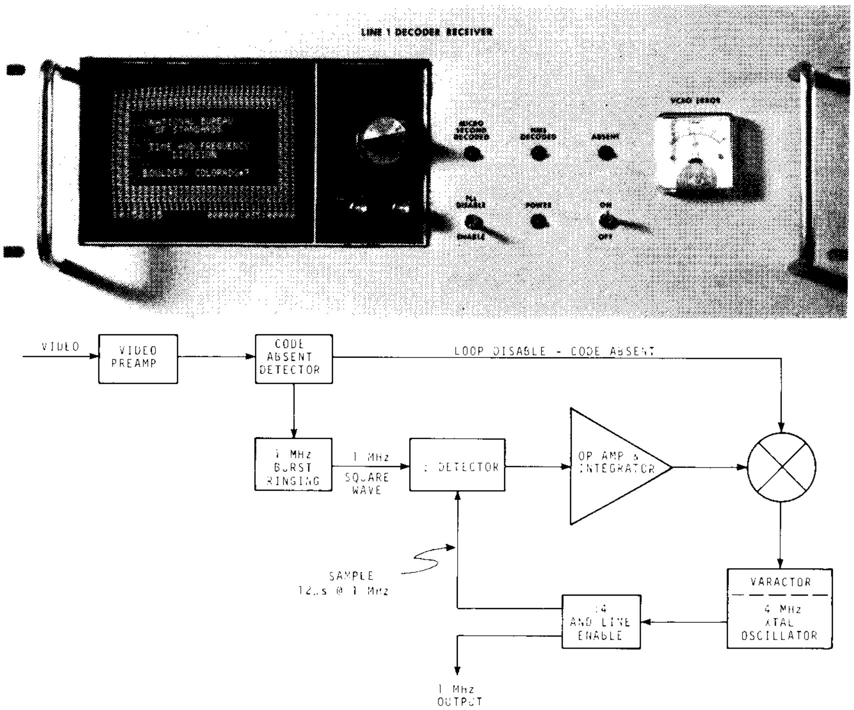

Fig. 2—The high-resolution TV time decoder-receiver costs about $1000 for parts and can resolve time to one nanosecond.

diagram of this line's relationship with respect to the picture transmission. Each line 21 is made up of 16 microseconds of a 1 MHz sinewave followed by a 22 bit binary code at a 1 MHz bit rate. This code is referenced to the 1 MHz output from an atomic frequency standard. Better than 85% of the number of line 21's have no time code. During this time additional coding for captioning of TV programs and station ID's may be sent if required.

A decoding device similar to that shown in Fig. 2 is used to process the information which has been encoded on line 21. The particular decoder shown here has a television screen display option. The option merely takes the alphanumerics information from line 21 and writes them on the screen. The display device may be turned off without affecting the operation of the rest of the decoder. The time of day in hours, minutes, and seconds is displayed in the lower left hand corner of the screen. The time code updates these digits each second. The decoder also has the facility to display the difference between the decoded time and a local clock input. This number, displayed to the nearest nanosecond in the lower right corner of the screen, is primarily a function of distance from the transmitter and hence is a measure of the propagation delay. An additional feature of this decoder is the ability to phase lock a crystal oscillator to the 1 MHz sinewave of the time code. Included in Fig. 2 is a block diagram of this phase-lock circuitry.

TV/AVM Systems

We should consider now possible AVM systems which incorporate the TV technique. The basic design of most AVM systems calls for each vehicle in the fleet to be equipped with a position detecting device and a central dispatch which gathers data from the fleet (Fig. 3). Transmission of the position data is usually via a multiplexing scheme included in conventional mobile communication channels. A computer at the central dispatch location will determine the location of the vehicle. This information can be displayed in various forms for use by the dispatcher. More advanced concepts include reverse data transmission for display in the vehicle [1].

Ideally, three or more television transmitters, each sending the code, should be located around the greatest area of concentration of the vehicles. Each vehicle would carry a television receiver which could automatically receive a signal having a prescribed identification code. A decoder and phase-locked oscillator would derive time and frequency signals from the video format. A small computing and controlling circuit would be necessary to drive the basic data within the vehicle, although final position computation would be completed by the central computer. The central computer would also have access to local TV decoders which could continuously monitor the time and frequency signals and correct vehicle position computations based on any changes of the transmitted codes.

Hyperbolic System

A hyperbolic system would be the least expensive to implement. This system requires only that a computer compare the time or phase between successive pairs of three TV transmitters received at the vehicle (Fig. 4). With information from one pair of transmitters, the car's position is surmised to be a point along a hyperbola. Intersecting lines-of-position are obtained from two pairs of transmitters.

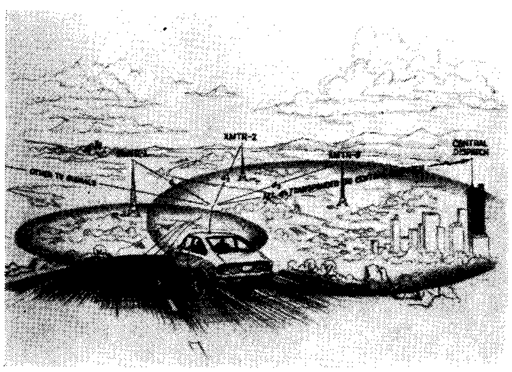

Fig. 3—In the basic TV/AVM configuration, distance-to-transmitter information is computed in the vehicle. This data is transponded via conventional mobile channels to a central dispatch where the actual position of the vehicle is determined.

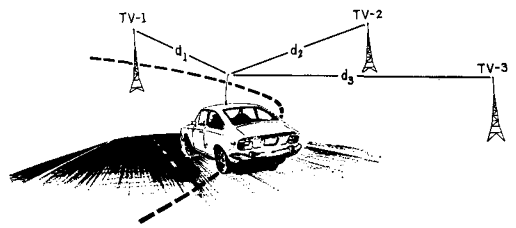

Fig. 4—In the hyperbolic system, the vehicle equipment measures [$d_1 - d_2$]. This quantity discloses that his position is anywhere along a locus of points generating a hyperbola. Using a third television transmitter, [$d_3 - d_2$] is measured to determine the vehicle's location on the hyperbola.

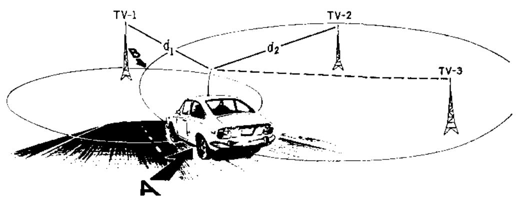

Fig. 5—In the range-range system, the vehicle equipment measures d_1 and d_2 (absolute values) using an on-board, calibrated portable clock. Thus, vehicle's position is either point A or point B, the intersects of two circles about transmitters 1 and 2 with radii d_1 and d_2, respectively. An antenna direction finder or a third television signal may be used to resolve position ambiguity.

The unit cost of the vehicular equipment could be kept to a minimum. Receivers without picture displays are available from manufacturers for as little as \$35/unit. Experimental precision decoders like the one in Fig. 2 have a cost of about \$1000 using discrete components and common TTL integrated circuits. For large scale application special large scale integrated circuits could be developed and the cost could fall to \$100/unit. The position computer and control would have a price tag of \$100–\$1000 depending upon the position determination technique.

Range-Range System

In the range-range (trilateration) navigation system, time or frequency data received from television stations are compared to a clock or oscillator carried in the vehicle. With this technique, one is able to measure the distance from a TV transmitter by observing the absolute path delay of the transmitted signal. With one pair of transmitters, the location of the observer can be calculated to be one of two possible points, the intersects of two circles. With a third transmitting source or with a direction finding antenna, one can easily surmise his position without ambiguity (Fig. 5). With advancing design and manufacturing methods in the area of precision crystal, rubidium, and cesium oscillators, it is conceivable that equipping each vehicle in a fleet with a calibrated standard and using a range-range system may be feasible in the near future. Ruggedized rubidium oscillators showing one part in 10^{12}/s statistical stability are now available in small packages [6]. Cesium oscillators with 6 inch beam tubes are in the prototype stages of development by some manufacturers and may cost less than $5000/unit. In fact, data taken for this paper (Section III) utilized a portable cesium oscillator. Its present cost is much too great to be considered for each vehicle of a range-range system; however, it is a completely portable, self-contained unit. Equal performance may be obtained at a much lower cost in the not too distant future. A systematic method would need to be established in which each vehicle, upon arrival at a central dispatch point, would have its portable oscillator recalibrated with respect to a master standard; the better each vehicle's oscillator, the less frequent the calibrations.

Potential Problems

All characteristics of present TV systems are not favorable for the AVM application in many urban areas. Most television services are not 24-hour operations. One solution to this is for the TV transmitters simply to stay on the air. This carries with it the necessity to perhaps purchase standby transmitting equipment, the cost of which might need to be borne by AVM users.

Geometric dilution of precision (GDOP), which is a function of the spatial separation of the transmitters, is probably the biggest factor limiting the usefulness of the system. GDOP is a term used to describe the loss of position resolution due to the obliqueness of the angle formed between two lines of position. Unfortunately, ideal location of the TV transmitters rarely exists. Because the home viewer usually equips himself with a directional antenna, it is a common practice for television transmitters to be located relatively close together. We certainly do not advocate the movement of the location of TV transmitters to appropriate positions for the benefit of ideal vehicle monitoring; the system as it stands can provide accurate, useful information when used in conjunction with other AVM methods.

To a large extent, the accuracy and resolution of AVM techniques are directly related to the amount of money invested in the system. By utilizing cost facilities the TV/AVM technique can provide the potential for good accuracy and resolution at a relatively low cost. In an area where the TV transmitters are poorly sited for AVM, it may be effective to use an additional technique. A special transmitter site could be set up to emit signals from another location which would enable precise location fixes. Or a simple dead reckoning or signpost system might be sufficient to complement a TV system plagued with high GDOP. The use of signals carried by FM radio stations to aid position location is currently being explored by the NBS.

The problems of noise and multipath associated with an urban environment still exist with the use of TV transmitters. However, transmitter power, antenna type, and location in most instances have been chosen to minimize the effect of a highly cluttered environment. In an urban area, "ghosting" is usually not entirely avoidable. Reducing "ghosting" in TV picture reception, however, reduces AVM errors due to multipath. Low user cost, small equipment space requirements, and widespread availability, too, are aspects of the system which are attractive for vehicle location plans.

Passive System Using Existing Broadcast Facilities

It is possible to devise an AVM system using television signals that do not transmit an active code. The NBS first became aware of the usefulness of TV signals applied to precise time calibration by using one of the horizontal lines (line-10 is usually used) in the raster display as a passive time transfer. Using a common television transmitter, the time of arrival of line-10 in the video format at two locations may be compared. The difference between the times of arrival is equivalent to the difference in the TV signal's path delay at the two locations. If one knows the path delays, one can accurately measure the time synchronization. Conversely, suppose one location is moving relative to the other. If the two points are continuously monitoring a TV signal and are maintaining joint communication, one can measure the movement from changes in the path delay. Using three or more transmitters, relative position can be determined unambiguously. The advantage of this method is that the television stations would not need to be concerned about the transmission of a special code. They are passive participants in the scheme. This method, however, would require considerably more computation before a position fix could be calculated, so the added benefit might be offset by the need for more complicated computer hardware [7]. Problems of transmitter siting would be similar.

Experimental Results

In order to evaluate the position locating capabilities of the TvTime System, several field trips were made in the area of Denver, Colorado. The field gear consisted of a van equipped with a TV time decoder and antenna, a portable cesium clock and an AC generator. The locations at which measurements were made are shown in the map of Fig. 6. These locations represent first or second order geodetic markers and, consequently, their positions are well known. The three TV transmitters from which delay measurements were made, shown in Fig. 6, also have known positions. The theoretical path delay may be easily computed from the velocity of propagation and the distance between the transmitter and receiving site.

The theoretical path delay was compared to the experimental delay measurement to determine the position locating accuracy of the TV system. From this data, the accuracy of a range-range position locating system is estimated to be within 42 m (60 m for a hyperbolic system) with 95% confidence. As expected because of multipath effects in an urban environment, the data taken in Denver limit the overall estimated accuracy of the system. The rural data is two to three times more accurate than the urban data. These multipath effects, however, appear to be constant at a particular location. By mapping multipath bias at each location, the system precision can be markedly improved. With this modification to our data, the range-range accuracy for the urban environment was within approximately 15 m (22.5 m for the hyperbolic system) with 95% confidence.

Conclusion

This study was part of an effort by the National Bureau of Standards to examine other

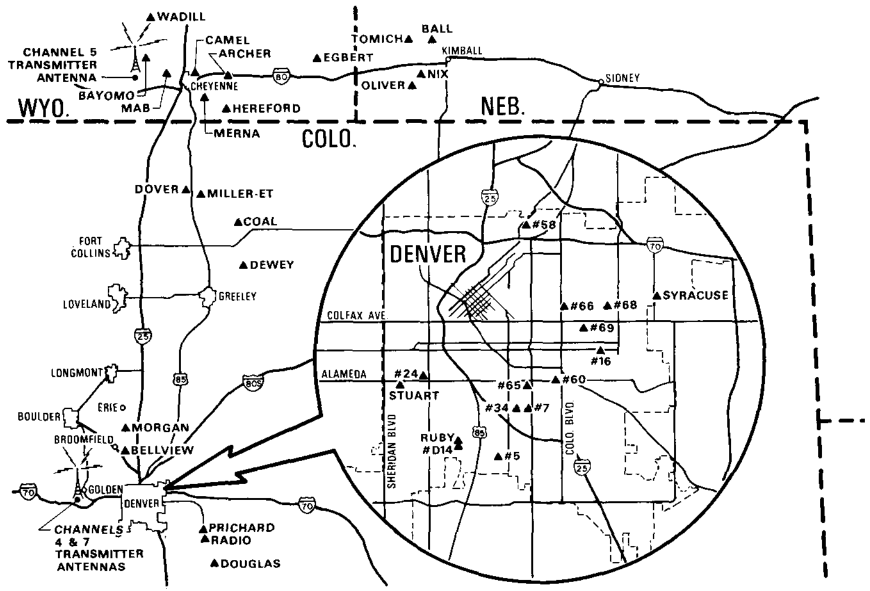

Fig. 6—Maps of observing sites and transmitters.

areas of research which would benefit by the implementation of the TvTime System. Several industries have been concerned with the need for applied research in AVM techniques, and the Department of Transportation has proposed one program goal calling for a location accuracy of 150 m with 95% confidence [2]. The TvTime System has the potential to achieve accuracies of 42 to 60 m, with this confidence, using a three-transmitter range-range or hyperbolic technique in a typical urban environment with the transmitters widely spaced to minimize GDOP. The cost per vehicle for equipment using the hyperbolic navigation method is estimated to be between $500 and $1000. This does not include the cost of a computer at the central dispatch which would be used to translate each vehicle's raw data into a usable form. A range-range method would cost the same plus the cost of high quality oscillators carried by each vehicle.

There have been several alternate AVM systems proposed in the past, but few have been actually tried. The cost of the proposed equipment has been a severe limitation. It is hard to envision the cost per vehicle of a practical system being equal to or greater than the cost of each vehicle itself and still consider the system beneficial. It is clear that the technology is available and successful AVM systems could be implemented, but the deployment of such systems becomes a question of economics.

Of the time and frequency methods, a TV/AVM system, if fully implemented, offers great cost effectiveness; however, there are two aspects governed by the television stations themselves which will directly affect the merit of the system for a given area. The first is that most TV facilities are not now 24-hour operations. This is not a problem because the television stations could stay on the air at all times if the extra cost of operating in this manner is absorbed by those needing the signals. The second aspect represents a more serious problem. The ability to compute precise vehicle positioning is restricted in many urban areas by the number of widely spaced TV transmitters. In heavily populated regions, there are usually a limited number of favorable locations for TV transmitting antennas which provide good coverage. It is not uncommon to have nearly all the antennas on a single building, hill or in an open space.

One solution is to allow AVM users to install additional transmitters on unused channels. This is probably a rather short-sighted solution which would pose frequency allocation policy questions about the use of broadcast spectrum for non-broadcast use. A more practical solution, might be to extend the concept of frequency distribution from television to existing facilities which are more widely spaced, such as AM and FM broadcast transmitters. The use of a highly stabilized 19 kHz pilot signal, contained in stereo FM broadcasts, for car locating is presently being investigated by the NBS. It is clearly an important objective to see if a system using only existing facilities can be devised so as to conserve the radio spectrum and eliminate the need for the additional transmitters which have been proposed in alternative systems.

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