

東海大学大学院平成 2 5 年度博士論文

**Study of Vehicle Vibration for Forward Prediction of
Land Mobile Satellite Tracking for Telemedicine**

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1. Summary

This doctoral thesis was written on the basis of the original article published in “International Journal of E-Health and Medical Communications“. I got permission for the submission of the doctoral thesis to the institutional repository of Tokai University in addition to reuse of my article in my doctoral thesis.

In cases in which emergency personnel in an ambulance need to administer medical treatment, the triage officer, a full-time physician assigned to a prefectural or equivalent emergency medical center, can provide appropriate instructions if he or she can identify the patient’s status via a fast data connection. (Note that certain current legal restrictions need to be addressed before this is permissible.)

Transmitting patient biometric information and instructions between a moving ambulance and a doctor located at a hospital via communication satellite requires an ambulance capable of tracking the communication satellite continuously via tracking beacon radio waves from the satellite, in addition to transmitting and receiving radio waves for patient information and doctor’s instructions. Unfortunately, tracking beacon radio waves from communication satellites are weak, and vehicle vibrations caused by rough road surfaces often destabilize satellite tracking. In urban environments, buildings and trees also impair reception of the tracking beacon and make stable tracking still more difficult. Tracking instability can generate tracking failures and freezing/disruption of information flow between the ambulance and the doctor.

To address tracking instability, we draw on the concept of forward prediction. First, we let an ambulance move over the road, collecting data on vehicle vibrations relative to road positions and data on the tracking antenna relative to road positions. We can obtain this data from ambulances in service. Additionally, we can obtain data on the effects of roadside obstacles on satellite visibility. Satellite visibility is a rate of probability of obstacles blocking view of a satellite over a certain period of time. This data is used as forward prediction reference data. Generating a database of reference data requires collecting the data mentioned above on many roads over which ambulances may travel.

Suppose the tracking of an ambulance traveling on a road becomes unstable due to vehicle vibrations or roadside obstructions. If the ambulance can constantly detect its own position in real-time, it can identify its location instantaneously when tracking is suddenly rendered unstable, allowing it to obtain reference data on the tracking antenna near the actual location of the ambulance. This makes it possible to adjust the tracking antenna based on the reference data obtained immediately after the ambulance passed the point at which tracking became unstable, allowing tracking to resume with virtually no disruptions.

In this study, the method is characterized by real-time measurements of the vibration sustained by a vehicle due to rough road surfaces, comparisons of measured data to vibration data stored in a database, and use of convolution and cost functions. In addition, we measured the vibration (pitch angle) caused by the rough road surfaces with a vehicle and verified that we can estimate vehicle location. The vehicle was driven in Takaoka, Toyama, to measure the pitch angle vibration sustained by the vehicle. Moreover, measured pitch angle vibration data was evaluated statistically.

Regarding the convolution-based estimates, we have clarified that vehicle location can be sufficiently estimated if the real-time vibration data that the vehicle acquires is 30 seconds or longer.

Regarding the cost-function-based estimates, we extracted the reference partial vibration data including the point estimated by GPS close to the GPS position of the measured vibration data, and calculated the cost function based on the measured vibration data and reference partial vibration data. We demonstrated that the current location of the measurement vehicle on the road can be estimated to within 0.1 m based on the reference vibration data by adjusting the position of the measured vibration data with the position data corresponding to the minimum value of the cost function. Our efforts also showed that cost-function-based estimates of the current location of the measurement vehicle on the road are valid if a P-P amplitude, or the difference between the maximum value of the vibration peak in the vibration data and the minimum value of the adjacent vibration, is over 0.3.

Our efforts also demonstrate that accurate estimates of the location of the vehicle allow predictions of future vehicle location, which can then be used to predict tracking antenna angles and to reconfigure antennas subject to unstable tracking in a real-time manner.

Tracking instability is sometimes caused by blockage of tracking beacon radio wave by roadside obstructions, including buildings and trees. Therefore, satellite visibility was experimentally evaluated.

To measure the satellite visibility toward a target communication satellite, the sky including the roadside was picture-recorded in three different areas (in the area of Ginza, Tokyo; in the area near the Sendai Station in Miyagi Prefecture; in the city area of Takaoka in Toyama Prefecture) by use of a fish-eye lens mounted on a moving vehicle. Based on the results of these measurements, we newly introduced the urban space factors (Kitano's urban space factors) for these areas. We also proved that these urban space factor allowed us to estimate the satellite visibility toward each of geostationary satellites such as SUPERBIRD C , SUPERBIRD D and JC-SAT 3 , JC-SAT 4.

Maximum value of the satellite visibility by the space diversity consisted of two geostationary satellites is acquired by simulation from combination of all two satellites which are located in any place on the geostationary satellite orbit in each city of Japan. From these simulation results, it was found that there was a limit of the satellite visibility by the space diversity which uses two geostationary satellites. The limit of this improvement depends on the city.

Moreover, the angle of elevation of the quasi zenith satellite which the satellite visibility exceeds the limit value of two geostationary satellites was acquired, and these angles of elevation were compared between each city of Japan. As a result, it became clear that more than 68 degrees of an elevation angle of the quasi zenith satellite is necessary to exceed a maximum satellite visibility of two geostationary satellites.

The fundamental technology required to receive a weak tracking beacon radio wave from a communication satellite with land mobile satellite tracking system and use this tracking beam for tracking the communication satellite is crucial to reducing tracking instability based on forward prediction. We will perform experiments to evaluate an onboard satellite tracking system

Using the developed quadrant detector, the Ku-band geostationary satellite is tracked from the moving land mobile. The tracked geostationary satellite is N-SAT-110 and the frequency is 12.7 GHz. The measuring ground places are two of Takaoka City Toyama Prefecture in Japan. Both include several bending parts of about 90 degrees. At the first proving ground place the measurement vehicle ran about 1.6 km road at a speed of 40 km/h and 50 km/h and at the second place the measurement vehicle ran an about 2.5 km road at a speed of about 44 km/h.

At each place the time dependency of the azimuth angle of the tracking antenna and the geostationary satellite and the time dependency of the power level of the center detector have been measured. From these experimental results, even when the measurement vehicle is bent in each curve spot of approximately 90 degrees, the tracking of the satellite is continued. Finally the tracking performance is also evaluated by using measured search time for tracking of antenna and dead time of output power.

From above result, it can be thought that using forward prediction method can reduce the tracking instability.

2. Objective

The objective of this theses for a doctorate is to study a key technology for the land mobile satellite tracking system which is used for the tele-medicine That is, the forward prediction is proposed for the reduction of the tracking instability. The key technology to estimate the real-time location of the running ambulance by the vehicle vibration with the road surface roughness and to readjust the tracking antenna is studied. Moreover, in relation to the forward prediction the blocking of electric wave

from the satellite by the obstacles is evaluated and land mobile satellite tracking system is experimentally evaluated.

3. Backgrounds and Introduction

In cases in which emergency personnel in an ambulance need to administer medical treatment, the triage officer, a full-time physician assigned to a prefectural or equivalent emergency medical center, can provide appropriate instructions if he or she can identify the patient's status via a fast data connection. (Note that certain current legal restrictions need to be addressed before this is permissible.)

Various methods have been proposed to transmit patient biometric information (including video images) from the ambulance to the hospital, including mobile phones, wireless LAN, and satellite communications. Several examples involving mobile phones have been reported, including third-generation phones used mainly in Asia, including Japan and Korea, third-generation UMTS phones used mainly in Europe, and second-generation GSM phones still in use in Europe.

These mobile phones represent a convenient way to transmit patient biometric information, including video images, from the ambulance to the hospital. On the other hand, they are ill-suited to capturing and transmitting high-definition video; reliable coverage tends to be restricted to urban areas; and emergency communications are likely to be disrupted due to congestions in times of serious disasters, such as earthquakes.

Wireless LANs allow connection to the Internet from access points via radio waves typically in the 2.4-GHz and 5-GHz bands. While the technology's broadband performance makes it suitable for transmitting high-definition video, there are limits on the feasibility of installing the number of access points needed to ensure seamless communication and continuous transmission of high-definition video while the ambulance is in motion. Additionally, due to the linearity of high-frequency radio waves, communications will often be impaired by buildings in urban areas.

By contrast, satellite communication accommodates high-definition video transmission and covers all of Japan, with relatively little interference from structural clutter in urban areas. One option is to use land mobile satellite services (LMSS) including services provided by geostationary satellites such as Inmarsat in the L band and N-Star and ETS-VIII in the S band. However, since video biometric information entails significant data volumes, the Ku band with its superior broadband performance is the most suitable.

Transmitting biometric information from the ambulance to the hospital requires technology to track the communication satellite from the moving vehicle. Tracking methods for Ku-band communication satellites include conical scanning, track-while-scanning, step tracking, monopulse, and quadrant detection. Several reports have described these methods, including their functional features.

The conical scanning method captures the target at the center of the rotational axis by rotating the electron beam and maintaining constant intensity for reflections from the target. The step tracking method compares received signal levels while slightly oscillating the antenna direction, gradually moving the antenna in the direction that strengthens the signal. The track-while-scanning method moves the antenna to the angle calculated from information on waves reflected from the target obtained while scanning the area including the communication satellite. The monopulse method uses two different antenna patterns obtained with two antennas to detect the phase difference of the signals received by the antennas, converting this information to angular data and adjusting the antenna angle based on this information.

The quadrant detection method places four (2 x 2) horn antennas at the receiving part of a Cassegrain antenna and moves the Cassegrain antenna so that signal intensity is equivalent at each of the four horn antennas. Since the strength of the radio waves from geostationary satellites is extremely weak (approaching the noise floor), the quadrant detection method is most effective, as it compares the signal intensity for tracking. We selected the quadrant detection method to develop a new tracking system and are currently undertaking studies to explore this technology.

Given the numerous geostationary satellites placed in orbit at intervals as narrow as 2 degrees, which implies a need to reduce interference issues with adjacent satellites in the Ku-band, the system requires narrower and more precisely directional transmission of waves from the ambulance. Unfortunately, tracking radio wave from geostationary satellites is weak, and the vehicle vibrations caused by rough road surfaces often destabilize satellite tracking. In urban environments, buildings and trees also impair reception of the tracking radio wave and make stable tracking still more difficult. Tracking instability can generate tracking failures and freezing/disruption of information flow between the ambulance and the doctor.

In this paper, to address tracking instability, I draw on the concept of forward prediction. Real-time estimates method of ambulance location on the road has been investigated. This technology is a key part for reducing tracking instability based on forward prediction. The present study proposes a new method that performs feature extraction from previously acquired data to select points with large amplitudes of vibration caused by uneven road surfaces. And it applies convolution or cost functions to synchronize data with vibrations measured by the ambulance to accurately calculate and identify the current position of the ambulance. The study also confirms the feasibility of synchronization based on a comparison of the reference pitch angle vibration data stored in the vehicle database with pitch angle vibration data measured as the vehicle passes over rough road surfaces.

Tracking instability is sometimes caused by blockage of tracking radio wave by roadside obstructions, including buildings and trees. The measurement vehicle measures vehicle vibration in real-time as it moves. It also obtains information on satellite visibility affected by roadside obstructions near the vehicle. This allows stable tracking based on forward prediction, even if satellite visibility falls below a predetermined threshold. Our research goal is to evaluate satellite visibility through such studies to help realize the aforementioned technology.

Lastly, in addition to reduction of tracking instability by using forward prediction, the establishment of the basic technology is important for receiving of weak electric wave

from the communications satellite by the land mobile satellite tracking system, and for tracking a geostationary satellite. We will perform experiments to evaluate an land mobile satellite tracking system. Specifically, we will evaluate the geostationary satellite tracking performance by using the Ku-band system equipped at the measurement vehicle.

4. Materials and Methods

4.1 Necessity of forward prediction

Transmitting patient biometric information and instructions between a moving ambulance and a doctor located at a hospital via communication satellite requires an ambulance capable of tracking the communication satellite continuously via tracking beacon radio waves from the satellite, in addition to transmitting and receiving radio waves for patient information and doctor's instructions. Unfortunately, tracking beacon radio waves from communication satellites are weak, and vehicle vibrations caused by rough road surfaces often destabilize satellite tracking. In urban environments, buildings and trees also impair reception of the tracking beacon and make stable tracking still more difficult. Tracking instability can generate tracking failures and freezing/disruption of information flow between the ambulance and the doctor.

To address tracking instability, we draw on the concept of forward prediction. First, we let an ambulance move over the road, collecting data on vehicle vibrations relative to road positions and data on the tracking antenna relative to road positions. We can obtain this data from ambulances in service. Additionally, we can obtain data on the effects of roadside obstacles on satellite visibility. Satellite visibility is a rate of probability of obstacles blocking view of a satellite over a certain period of time. A satellite visibility of 1.0 means the total absence of roadside obstructions. This data is used as forward prediction reference data. Generating a database of reference data requires collecting the data mentioned above on many roads over which ambulances may travel.

Suppose the tracking of an ambulance traveling on a road becomes unstable due to vehicle vibrations or roadside obstructions. If the ambulance can constantly detect its own position in real-time, it can identify its location instantaneously when tracking is

suddenly rendered unstable, allowing it to obtain reference data on the tracking antenna near the actual location of the ambulance. This makes it possible to adjust the tracking antenna based on the reference data obtained immediately after the ambulance passed the point at which tracking became unstable, allowing tracking to resume with virtually no disruptions. Additionally, if tracking becomes unstable, patient biometric information from the ambulance is temporarily stored in memory on the ambulance side, while instructions from the doctor are stored in memory on the doctor's side; after the tracking antenna is adjusted and tracking resumes, the stored data is retrieved from memory, preventing frozen or disrupted communications.

The study focuses on the fundamental technologies required to reduce tracking instability and quickly resume tracking. Specifically, the research focuses on the following tasks: 'Estimates of vehicle location for forward prediction'. Next as related study for forward prediction, the research focuses on the following task 'Evaluation of satellite visibility' and 'Experimental evaluations of land mobile satellite tracking system'.

4.2 Study for forward prediction

(1) Estimates of vehicle location for forward prediction

Studies of real-time estimates of ambulance location on the road represent a key part of the technology for reducing tracking instability based on forward prediction. Our research evaluates the feasibility of estimating vehicle location based on data on vehicle vibrations caused by rough road surfaces. To do this, we will mount a three-dimensional attitude measurement instrument in a measurement vehicle and measure vehicle vibrations as the vehicle moves over the surface of the road. We will then statistically evaluate the measurement data. Next, we will extract a set of real-time measurement data and reference data. Real-time measurement data refers to data gathered by the moving measurement vehicle. Using this set of data, we will simulate the task of estimating vehicle location using convolution and the task of estimating vehicle position using a cost function. We then use these simulation results to evaluate the feasibility of estimating vehicle location.

(2) Evaluation of Satellite visibility

Tracking instability is sometimes caused by blockage of tracking beacon radio wave by roadside obstructions, including buildings and trees. The reference data contains data on satellite visibility and vehicle vibrations at given road positions. The measurement vehicle measures vehicle vibration in real-time as it moves and draws on the reference data to estimate vehicle location. It also obtains information on satellite visibility affected by roadside obstructions near the vehicle. This allows stable tracking based on forward prediction, even if satellite visibility falls below a predetermined threshold.

Our research goal is to evaluate satellite visibility through such studies to help realize the aforementioned technology. Specific measures include mounting a fisheye lens on the roof of the measurement vehicle and capturing hemispherical images with the zenith as the apex and the lens mounting surface as the horizontal plane. We will then binarize the image data: black for obstructions and white for clear space. Next, we will perform simulations to calculate and evaluate the visibility of the target communication satellite from the measurement vehicle. Since satellite visibility varies depending on the particular point of the road over which the ambulance is moving, we will evaluate the dependency of satellite visibility on road width. We will also propose methods to improve satellite visibility based on the space diversity scheme and use of a quasi-zenith satellite system.

(3) Experimental evaluations of land mobile satellite tracking system

The fundamental technology required to receive a weak tracking beacon radio wave from a communication satellite with an onboard satellite tracking system and use this tracking beam for tracking the communication satellite is crucial to reducing tracking instability based on forward prediction. We will perform experiments to evaluate an onboard satellite tracking system. Specifically, we will evaluate the geostationary satellite tracking performance of the Ku-band satellite tracking system on board the measurement vehicle.

5. Discussion

5.1 Discussion of Estimates of Vehicle Location

The cost-function-based estimates of vehicle location use road surface data for positions where the amplitude of the measured and reference vibration is sufficiently large. This is because small vibration amplitude appears in many locations on the road surface, making it difficult to identify vehicle location. Here, we define P-P amplitude as the difference between the local maximum value (positive peak) of the vibration and the local minimum value (negative peak) of the adjacent vibration. When P-P amplitude is greater than a certain value, the minimum value of the cost function of Equation (4) derived from the measured and reference partial vibration data exists in the integration range. In this case, we can estimate vehicle location. On the other hand, when P-P amplitude is less than a certain value, the minimum value of the cost function is at the upper or lower limit of the integration range, and the local minimum cannot be obtained. In this case, it may be difficult to estimate vehicle location.

P-P amplitude has been defined. P-P amplitude is indicated by data, in which the horizontal axis is P-P amplitude and the vertical axis is cumulative number of appearances of P-P amplitude. P-P amplitude appearing in the vibration data is divided into bins with a width of 0.05. The cost function is prepared based on the measured partial vibration data containing each bin as the maximum value and the reference vibration data. The broken line shows the cumulative value of P-P amplitude when the minimum value of the cost function is at the upper or lower limit of the integration range, indicating the condition which makes it difficult to estimate vehicle location. According to data, when P-P amplitude is 0.3 or less, the minimum value of the cost function may be at the upper or lower limit of the integration range, and in such a case, the cost-function-based estimates of the current location of the measurement vehicle on the road may fail. This result shows that the estimates of the current location requires P-P value of over 0.3. The simulation results for the position corresponding to P-P amplitude of 0.6 and cumulative value of 1 in a P-P amplitude distribution.

The result of cost-function-based estimates of the position corresponding to P-P amplitude of 0.4 and cumulative value of 1 was obtained. The measured vibration data

is prepared with the vibration data of length 20 m preceding the 173-m point along the route over which the vehicle passes, and the cost function is calculated with the reference partial vibration data, including the position estimated by GPS. The cost function provided a minimum value. By adjusting the measured vibration data with the minimum value of the cost function, we can make the peak point, P1, of the measured vibration data and the peak point, Q1, of the reference vibration data approximately agree.

The results of estimates of the position corresponding to a P-P amplitude of 0.35 and cumulative value of 1 was obtained. Moreover, estimates of the position corresponding to P-P amplitude of 0.3 and cumulative value of 4 was obtained. These results were obtained by preparing the measured vibration data with the vibration data of length 20 m preceding the 205-m and 565-m points, respectively, along the route where the vehicle passes and calculating the cost function with the reference partial vibration data including the position estimated by GPS. The peak point P2 of the measured vibration data approximately agreed with the peak point Q2 of the reference vibration data. Similarly, the peak point P3 of the measured vibration data approximately agreed with the peak point Q3 of the reference vibration data. As shown in these examples, when P-P amplitude in the amplitude distribution is over 0.3, we can synchronize the position of the reference vibration data and the position of the measured vibration data with a cost function and estimate the current location of the measurement vehicle on the road.

If an ambulance has a database storing data on road-induced vibration and correct tracking antenna angle setting at each point on a road previously traversed by a vehicle, we can reconfigure the tracking antenna with the algorithm below when tracking becomes unstable due to road-induced vibration. First, the current location at which tracking became unstable is estimated by the method described earlier. Then, the tracking antenna angle setting data for distance D_0 ahead of the current location is read in from the database. The distance, D_0 , is determined by the product of the time, T_0 , required to modify the tracking antenna angle setting mechanically and the estimated speed, V_0 , of the ambulance at the current location. When the ambulance has traveled the distance, D_0 , in the time, T_0 , from the current location where tracking became

unstable, the tracking antenna is thus reconfigured in real-time to the correct angle. In this manner, estimating vehicle location enables the forward prediction of the tracking antenna angle setting at distance D_0 ahead. In the future, we will provide the measurement vehicle with the firmware incorporating the algorithm to estimate vehicle location as discussed earlier and this algorithm for forward prediction and will evaluate the performance of the reconfiguration of the tracking antenna when tracking becomes unstable due to road-induced vibration.

5.2 Discussion of Related Study for Forward Prediction

5.2.1 Discussion of Evaluation of Satellite Visibility

(1) Satellite Visibility

From the results of the satellite blocking rate measurement obtained in three Japanese urban areas, it became clear that the satellite blocking rate expressed in a logarithmic scale reduces almost linearly with respect to the elevation angle expressed in a linear scale. The portion reducing almost linearly is approximated and shown by a straight dashed line.

The approximation equation of the satellite blocking rate for the straight dashed line in the area of Ginza, in Tokyo is expressed as follows, where X is the elevation angle.

$$B_s = 100 \cdot 10^{-0.010 \cdot X} \quad (15)$$

So, the satellite visibility V_s is expressed as follows from Equation (6)

$$V_s = 100 \cdot (1 - 10^{-0.010 \cdot X}) \quad (16)$$

Similarly, the approximation equation of the satellite-blocking rate for the straight dashed line in the area near the Sendai Station, Miyagi Prefecture is expressed as follows, where X is the elevation angle.

$$B_s = 100 \cdot 10^{-0.018 \cdot X} \quad (17)$$

So, the satellite visibility V_s is expressed as follows.

$$V_s = 100 \cdot (1 - 10^{-0.018 \cdot X}) \quad (18)$$

Similarly, the approximation equation of the satellite-blocking rate for the straight dashed line in Takaoka district area in Toyama Prefecture is expressed as follows, where X is the elevation angle.

$$B_s = 100 \cdot 10^{-0.052 \cdot X} \quad (19)$$

So, the satellite visibility V_s is expressed as follows.

$$V_s = 100 \cdot (1 - 10^{-0.052 \cdot X}) \quad (20)$$

Considering the fact that, at the elevation angle of 0 degree, the satellite blocking rate in those three urban areas are of almost same values of 100%, the approximation equations (15), (17), (19) of the straight dashed lines may be put together into a single general equation as follows:

$$B_s = 100 \cdot 10^{-C_f \cdot X} \quad (21)$$

And the satellite visibility V_s is expressed as follows, where X is the elevation angle.

$$V_s = 100 \cdot (1 - 10^{-C_f \cdot X}) \quad (22)$$

Wherein, C_f is a newly introduced urban space factor (Kitano's urban space factor). The urban space factor is a factor peculiar to an individual urban area, and indicates quantitatively the state of the urban area space. From the equation (22), the urban space factor C_f allows the estimation of the satellite visibility in each urban area. The value of C_f is 0.010 in Ginza in Tokyo; 0.018 in the area near the Sendai Station in Miyagi Prefecture; and 0.052 in the city area of Takaoka Area in Toyama Prefecture.

The urban space factor C_f for a city seems to have some relation to the population of the urban area. This is because the dimensions of the urban area as well as its circumstances relating to the buildings, trees, utility poles, etc. standing along the roadside roughly depend on its population. From data which shows the relationship between the urban space factor C_f and the population of a city which includes urban area, it can be seen that the approximate urban space factor for a certain city can be estimated from the population of the city.

The typical geostationary satellites for use in the communication between an ambulance and a hospital are SUPERBIRD C, SUPERBIRD D, JCSAT 3, JCSAT 4, etc. The elevation angles at which these geostationary satellites can be viewed are different in different cities. From the elevation angles, these geostationary satellites can be viewed in such cities as Tokyo, Sendai, and Toyama near Takaoka. As for the elevation angle toward any one of these satellites, the upper limit thereof lies in the area near

Kagoshima City and the lower limit thereof lies in the area near Wakkanai City, Hokkaido. The values of the upper and lower limit elevation angle toward respective satellites are also shown.

The relationship between the satellite visibility V_s and the urban space factors C_f for the SUPERBIRD C was obtained. The satellite visibility is obtainable by substituting the elevation angle X into Equation (22). The dashed line is obtained by substituting the value of the upper limit elevation angle in Kagoshima City for the elevation angle X into Equation (22). The solid line is obtained by substituting the value of the lower limit elevation angle in Wakkanai City for the elevation angle X into Equation (22). The satellite visibilities in the area of Ginza, Tokyo, in the area near the Sendai Station, Miyagi Prefecture, and in the city area of Takaoka City, Toyama Prefecture were obtained.

The satellite visibilities in these areas are shown in range of the dashed line and the solid line. For the other Japanese areas, the urban space factor may be estimated from the population of a specific city. Then, the satellite visibility in that area may be estimated from its urban space factor. The satellite visibility in that area may be estimated to be a value included between the dashed line representing the value of the lower limit elevation angle and the solid line representing the value of the upper limit elevation angle. In addition, when a area such as Tokyo, Sendai, or Takaoka is specified, the satellite visibility will be determined more accurately from the elevation angle to the target geostationary satellite. Therefore, by substituting both the elevation angle and the urban space factor estimated from the population of the area into the equation (22), the more accurate satellite visibility can be obtained.

The relationship between the satellite visibility V_s and the urban space factor C_f for SUPERBIRD was obtained. The relationship between the satellite visibility V_s and the urban space factor C_f for JC-SAT 3 and JC-SAT 4 were also obtained. These results are similar to the previous result which shows the relationship between the satellite visibility and the urban space factor for SUPERBIRD C. In the case of JC-SAT 3 and JC-SAT 4, the elevation angles toward each geostationary satellite slightly differ in

different areas and, accordingly, the satellite visibilities toward each geostationary satellite becomes almost same. The difference in the elevation angles between JC-SAT 3 and JC-SAT 4 is as small as 1 degree or 2 degree in each city, as shown in Table 3. Therefore, the average value of the elevation angles toward JCSAT 3 and JC-SAT 4 is obtained.

(2) Improvement of satellite visibility

The use of the quasi zenith satellite has been reported as the way of more improving the satellite visibility. The quasi zenith satellite is a system which the satellite always exists in the high angle of elevation near the zenith by using more than one orbiting satellite. The geostationary satellite exists only on the orbit. The satellite visibility of the space has a limit in each city. Therefore the quasi zenith satellite can improve the satellite visibility compared with the spatial diversity case.

The angle of elevation of the quasi zenith satellite which exceeds a limit of the satellite visibility of the space diversity can be obtained as follows. Now, It assumes that the quasi zenith satellite always exists in the opposite cone of which the top is the ground and an axis is the direction of the zenith. The oblique angle to the ground level in the opposite cone surface is the elevation angle of the quasi zenith satellite. The satellite visibility which the satellite exists in the azimuth from 0 degrees to 360 degrees at the constant angle of elevation is calculated by the simulation. The angle of elevation of the quasi zenith satellite is the angle when at any azimuth angle the satellite visibility of the quasi zenith satellite exceeds a limit value of the satellite visibility.

Data to seek the angle of elevation of the quasi zenith satellite in Ginza Tokyo is obtained. The transverse is an azimuth of the quasi zenith satellite, the vertical axis is satellite visibility and the parameter is the angle of elevation of the satellite. The parallel solid line to the transverse is a limit value of the satellite visibility of the space diversity 74.8 % in Ginza Tokyo. When the angle of elevation is equal to or more than 68 degrees to all azimuths, the satellite visibility exceeds 74.8 % of limit value of Ginza Tokyo. Therefore, in case of Ginza Tokyo the elevation angle of the quasi zenith satellite is necessary to be more than 68 degrees.

Data to seek the angle of elevation of the quasi zenith satellite in Hiroshima City is obtained. A limit of the satellite visibility of the space diversity is 92.8%. When the angle of elevation is equal to or more than 70degrees to all azimuths in Hiroshima City, the satellite visibility exceeds 92.8% of limit values of Hiroshima City. Therefore, in case of Hiroshima City the elevation angle of the quasi zenith satellite is necessary to be more than 71 degrees.

A similar simulation was accomplished about Sendai City in Miyagi Prefecture, Kochi City in Kochi Prefecture, Takamatsu City in Kagawa Prefecture, Fukuoka City in Fukuoka Prefecture and Wakkanai City in Hokkaido and Naha City in Okinawa Prefecture in addition to Ginza Tokyo and Hiroshima City.

The transverse shows a limit value of the satellite visibility of the spatial, and the vertical axis shows the angle of elevation of the quasi zenith satellite which exceeds a limit value of the spatial diversity. When the limit of the satellite visibility of the spatial diversity reaches until 90%, the angle of elevation of the quasi zenith satellite is approximately constant of 68 degrees. When the limit of the satellite visibility exceeds 90 %, the angle of elevation increases rapidly. When the limit of the satellite visibility becomes 100%, the angle reaches 90 degrees.

The city within area A where the angle of elevation of the quasi zenith satellite becomes constant of approximately 68 degrees is a great city like Ginza Tokyo, Sendai City. The city within area B where the angle of elevation is increasing is a middle city like Fukuoka City, Takamatsu City and Kochi City. The city within area C where the angle of elevation becomes from 80 degrees to 90 degrees is a small city like Naha City, Wakkanai City. In this way, it let's be possible to say that a city in Japan is generally classified into the great city in area A, the middle city in area B, the small city in area C.

The satellite visibility of Tokyo Ginza has periodicity to the azimuth among angle of elevation from 65 degrees to 69 degrees. That is, the satellite visibility becomes bigger

around 70 degrees and 250 degrees of azimuths and becomes smaller around 160 degrees of and 310 degrees of azimuths. Hiroshima City case doesn't show periodicity as much as Ginza Tokyo. The azimuth is not the direction of the running vehicle and is the absolute direction. Therefore, in case of Ginza Tokyo, the vehicle seems to be running to the direction of mainly east and west. Also, the higher buildings are in the north and south direction and the satellite visibility seems to degrade for this reason. On the other hand, in case of Hiroshima City, there is little bias to the running direction of the vehicle and there are few high buildings. Therefore, the satellite visibility seems to be little azimuth dependence.

The reason why the angle of elevation of the quasi zenith satellite is approximately constant of 68 degrees in the city of area A is that the city within the area A is a typical great city in Japan and has the almost same city structure composed of the almost same road width and the almost same height buildings. The reason why the angle of elevation is approximately increasing within the city of area B is that the city within area B is a typical middle city in Japan, and that the height of the building is lower compared with a great city. The reason why the angle of elevation becomes approximately 90 degrees at the city of area C is that the city within area C is a typical small city in Japan, and that there are few the high buildings.

5.2.2 Discussion of Evaluation of Tracking System with Quadrant Detector

An expanded figure of the azimuth angle figure at spot A part is shown. In this data, the solid line is the azimuth angle of the geostationary satellite and the dotted line is the azimuth angle of the tracking antenna. A search time for tracking of the antenna is obtained. At spot A, the search time for tracking is 10.0 seconds. A bend angle of the moving vehicle is also obtained. At spot A the bend angle is 90.0 degrees.

An expanded figure of the output power figure at spot A part is shown. From this data, a dead time of output power is also obtained. The dead time is difference between time which output power falls off at beginning of curve part and time which output power recovers at ending of curve part. At spot A the dead time is 12.9 seconds. It was found that the time change of the azimuth angle of the tracking antenna and the geostationary

satellite and the time change of the output power of the center detector coincide approximately.

Additional running data of 40km/h and new running data of 50 km/h were acquired. The search time for tracking, the bend angle of the moving vehicle and the dead time of output power were acquired. As a result, relation between the search time for tracking and the dead time of output power was obtained. It was found that the dead time of output power is 2 or 4 seconds longer than the search time for tracking.

The relation between the search time for tracking and the bend angle of the moving vehicle is shown. From this data, the search time for tracking is 6 to 12 seconds regardless of the bend angle of the moving vehicle. This is because the tracking antenna always re-acquisitions the satellite by the re-starting of the scanning at the beginning of curve, regardless of the bend angle. The search time for tracking depends on the direction where the tracking antenna lost sight of the satellite. Therefore, this search time has time width and becomes 6 to 12 seconds..

5.3 Medical Application of Vehicle Vibration Measurement Technology

For medical application of the vehicle vibration measurement technology, a vibration-free bed in the ambulance with function of ghost canceller can be considered. In this section, a new vibration free bed is discussed as compared with the conventional technology which was used in practice.

(1) Vibration-free bed by using conventional technology

At present an air-suspension type vibration-free bed, a magnetic spring type vibration-free bed and a vibration-free bed with an acceleration sensor and so on are used in practice.

As for the air-suspension several papers are reported. In reference paper 36, the vibration of the floor surface and the vibration of the bed were compared when the various ambulance passed on the hose bridge which was placed in the road surface. As a

result, it has become clear that vibration amplitude of bed was 1.5-5 times larger than that of floor surface. Therefore in this paper it was concluded that a coil-spring was necessary for reduction of vibration. The vibration-free performance of several main-stretcher on air-suspension and on floor surface was compared. As a result, high performance main-stretcher was selected and effectiveness of air-suspension was confirmed. The design method which optimize the air-suspension structure for vibration-free by modeling of vehicle suspension structure, had been proposed when the ambulance passed through the hump (This was semi-cylinder type prominence which was put on purpose on the road surface for reduction of the traffic accident). Based on these study results, in the latest ambulance the air-suspension is adopted as follows.

At TOYATA HIMEDIC the air-suspension type made by ShinMaywa Industries, Ltd is adopted. ISUZU SUPERMEDIC a vibration-free bed (AM-500) with a latest function is adopted. This vibration-free bed reduces the lateral acceleration at the vehicle rolling by using the air-suspension. At NISSAN PARAMEDIC the air-suspension type vibration-free bed is adopted.

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As for the magnetic spring several papers are also reported. The design method for reduction of vibration of the bed in the ambulance by using the magnetic spring had been proposed. The development result was used in practice and partially adopted as a vibration-free bed, which was called MEDIA MASTER as product name at a high-quality ambulance. This uses a repulsion force of a permanent magnet.

Recently, an actively controlled bed, which reduces vibration by compensating the vehicle vibration measured by an acceleration sensor, had been reported. By the acceleration sensor mounted in the vehicle, the acceleration of front-back direction and the acceleration of right-left direction are measured in real-time. The oblique angle and the rotation angle of the bed are fixed by the computer-controlled motor according to the acceleration level. Therefore, the actively bed is the two-degree-of- freedom type bed which is two-dimensionally controlled. It was reported that in the case of the actively controlled bed compared with uncontrolled bed the acceleration of front-back direction became $1/3$ and the acceleration of right-left direction became $1/4$. However

even this actively controlled bed could not enough eliminate effect of the vehicle vibration.

(2) New vibration-free bed which vehicle vibration measurement technology is applied

The air-suspension, the magnetic spring and the acceleration sensor, which are used for the vibration-free bed, are used for reduction of force to the bed which is effected by the vehicle vibration. Therefore there was a limit in the reduction of the vibration of the bed. In contrast, it can be considered that the vibration-free bed with function of ghost canceller has high quality of dumping of vibration by cancellation of vibration itself compared with the conventional vibration-free bed such as the air-suspension type and the magnetic sprig type and acceleration sensor type.

Namely, the vibration measurement equipment is put at near front wheel and at first the vibration of the front wheel is measured by this measurement equipment. The bed for a patient, which is put near at the rear wheel, is affected by the vibration from the rear wheel.

When the ambulance runs at a speed of 40km/h the vibration due to rough road surface at first occurs at front wheel, and then occurs at rear wheel after about 0.3 seconds. Therefore inverting the vibration of the front wheel and adding this inverting vibration to the vibration of the rear wheel can cancel the vibration at the bed. The principle of the ghost canceller is shown. In this data, the vibration of the rear wheel and the inverting vibration of the front wheel and add vibration of both vibrations is shown respectively. Finally, add vibration is the amplitude of zero. Key technology of this vibration-free bed is a equipment for inverting vibration which occurs at the front wheel. For this equipment the new programmable vibration generator will be necessary. But this new equipment will be possible to realize by improving conventional vibrator.

(3) Simple design for new vibration-free bed

A simple block diagram for the new vibration-free bed which uses the vehicle vibration measurement technology is shown. The new bed is constructed by a three-dimensional

vibration measurement equipment, a vibration phase shifter, a vibration phase inverter, a variable delay generator and a external signal control type three- dimensional vibration generator. The three-dimensional vibration measurement equipment measures the vibration near the front wheel.

The bed is affected by vibration from the rear wheel and by a little vibration from the front wheel. The vibration from the rear wheel is almost canceled by the vibration phase inverter, the variable delay generator and the external signal control type three-dimensional vibration generator. Its cancellation procedure is as follows.

The phase of the vibration data measured at the front wheel is inverted by 180 degrees by the vibration phase inverter. Next, the variable delay generator delays the phase-inverted vibration signal. This delay time depends on the vehicle speed. The delayed vibration signal is converted to mechanical vibration signal by the external signal control type three dimensional vibration generator. This mechanical vibration is applied to the bed. As a result, the bed vibration affected by the rear wheel is almost cancelled by the vibration, which is applied by the external signal control type three-dimensional vibration generator.

On the other hand, the vibration from the front wheel is almost canceled by the vibration phase shifter and the external signal control type three- dimensional vibration generator. Its cancellation procedure is as follows. The vibration phase shifter delays the phase of the vibration from the front wheel by 180 degrees. The vibration generated by the external signal control type three- dimensional vibration generator, to which the 180 degrees delay signal is input, is applied to the bed. As a result, the vibration of bed from the rear wheel is almost canceled like an echo canceller by the vibration from the external signal control type three- dimensional vibration generator.

As above explanation, the vibration of the bed in the ambulance is almost cancelled by using system.

Moreover, among each component, next condition is necessary. It supposes that the vibration, which occurred at the front wheel, occurs at the rear wheel after T seconds.

T is expressed as

$$T = D / V \quad (23)$$

, where D is distance between center of the front wheel and the center of the rear wheel and V is the vehicle speed.

And next equation is necessary,

$$T_p + T_d + T_g = T \quad (24)$$

, where T_p is a delay time of the vibration phase inverter, T_d is a delay time of the variable delay generator and T_g is delay time of external signal control type three-dimensional vibration.

Under condition of Equation (2), next equation is necessary

$$ABS(P_r) = ABS(P_g) \quad (25)$$

, where P_r is an amplitude of vibration which occurs at the rear wheel, P_g is an amplitude of the vibration of the external signal control type three-dimensional vibration and ABS means absolute value.

(4) Future Direction

In the future, system design and fabrication of the vibration-free bed will be carried out. After that a simple experiment will be done.

Moreover, by assuming that the small unevenness of the road surface is a signal noise, the vibration of the ambulance will be discussed in more detail by using Noise-Equivalent-Angle (NEA) theory which is used in small signal analysis of communication theory.

6. Conclusion

The quality of data including video images transmitted from the moving ambulance to the hospital via a communication satellite is ensured by tracking the signal transmitted from the communication satellite with the ambulance. However, the tracking signal from the satellite is extremely weak, and the road surface on which the ambulance travels is uneven, causing vibrations in the tracking antenna, disturbing tracking of the satellite.

To address tracking instability, we draw on the concept of forward prediction. This makes it possible to adjust the tracking antenna based on the reference data obtained immediately after the ambulance passed the point at which tracking became unstable, allowing tracking to resume with virtually no disruptions.

In this study, the method is characterized by real-time measurements of the vibration sustained by a vehicle due to rough road surfaces, comparisons of measured data to vibration data stored in a database, and use of convolution and cost functions. In addition, we measured the vibration (pitch angle) caused by the rough road surfaces with a vehicle and verified that we can estimate vehicle location. The vehicle was driven in Takaoka, Toyama, to measure the pitch angle vibration sustained by the vehicle. Moreover, measured pitch angle vibration data was evaluated statistically.

Regarding the convolution-based estimates, we have clarified that vehicle location can be sufficiently estimated if the real-time vibration data that the vehicle acquires is 30 seconds or longer.

Regarding the cost-function-based estimates, we extracted the reference partial vibration data including the point estimated by GPS close to the GPS position of the measured vibration data, and calculated the cost function based on the measured vibration data and reference partial vibration data. We demonstrated that the current location of the measurement vehicle on the road can be estimated to within 0.1 m based on the reference vibration data by adjusting the position of the measured vibration data with the position data corresponding to the minimum value of the cost function. Our efforts also showed that cost-function-based estimates of the current location of the measurement vehicle on the road are valid if a P-P amplitude, or the difference between the maximum value of the vibration peak in the vibration data and the minimum value of the adjacent vibration, is over 0.3. Our efforts also demonstrate that accurate estimates of the location of the vehicle allow predictions of future vehicle location, which can then be used to predict tracking antenna angles and to reconfigure antennas subject to unstable tracking in a real-time manner.

Tracking instability is sometimes caused by blockage of tracking beacon radio wave by roadside obstructions, including buildings and trees. Therefore, satellite visibility was experimentally evaluated.

To measure the satellite visibility toward a target communication satellite, the sky including the roadside was picture-recorded in three different areas (in the area of Ginza, Tokyo; in the area near the Sendai Station in Miyagi Prefecture; in the city area of Takaoka in Toyama Prefecture) by use of a fish-eye lens mounted on a moving vehicle. Based on the results of these measurements, we newly introduced the urban space factors (Kitano's urban space factors) for these areas. We also proved that these urban space factor allowed us to estimate the satellite visibility toward each of geostationary satellites such as SUPERBIRD C , SUPERBIRD D and JC-SAT 3 , JC-SAT 4.

Maximum value of the satellite visibility by the space diversity consisted of two geostationary satellites is acquired by simulation from combination of all two satellites which are located in any place on the geostationary satellite orbit in each city of Japan.

From these simulation results, it was found that there was a limit of the satellite visibility by the space diversity which uses two geostationary satellites. The limit of this improvement depends on the city.

Moreover, the angle of elevation of the quasi zenith satellite which the satellite visibility exceeds the limit value of two geostationary satellites was acquired, and these angles of elevation were compared between each city of Japan. As a result, it became clear that more than 68 degrees of an elevation angle of the quasi zenith satellite is necessary to exceed a maximum satellite visibility of two geostationary satellites.

The fundamental technology required to receive a weak tracking beacon radio wave from a communication satellite with land mobile satellite tracking system and use this tracking beam for tracking the communication satellite is crucial to reducing tracking instability based on forward prediction. We will perform experiments to evaluate an onboard satellite tracking system

Using the developed quadrant detector, the Ku-band geostationary satellite is tracked from the moving land mobile. The tracked geostationary satellite is N-SAT-110 and the frequency is 12.7 GHz. The measuring ground places are two of Takaoka City Toyama Prefecture in Japan. Both include several bending parts of about 90 degrees. At the first proving ground place the measurement vehicle ran about 1.6 km road at a speed of 40 km/h and 50 km/h and at the second place the measurement vehicle ran an about 2.5 km road at a speed of about 44 km/h.

At each place the time dependency of the azimuth angle of the tracking antenna and the geostationary satellite and the time dependency of the power level of the center detector have been measured. From these experimental results, even when the measurement vehicle is bent in each curve spot of approximately 90 degrees, the tracking of the satellite is continued. Finally the tracking performance is also evaluated by using measured search time for tracking of antenna and dead time of output power.

From above result, it can be thought that using forward prediction method can reduce the tracking instability.

Finally medical application of vehicle vibration measurement technology has been discussed. The vibration-free bed with function of ghost canceller has been investigated. This has high quality of dumping of vibration by cancellation of vibration itself compared with conventional type of the air-suspension type and the magnetic-floating type.