A NEW PARADIGM FOR HIGH ACCURACY ORBIT DETERMINATION AT THE CENTIMETER LEVEL

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Abstract

Traditionally, satellite positions are determined by earth monitoring stations and their ephemeredes are given with respect to earth coordinates. As centimeter accuracies are anticipated, we realize that the dynamics of the earth's variations in spin rate and radius (solid earth tides) are several centimeters from day to day. A satellite constellation having centimeter accuracy would provide a robust opportunity to view the earth for the first time from an independent, local-inertial, reference frame.

Given the recent developments in atomic clocks and other relevant technologies, a new paradigm is developed herein utilizing currently available technology. This paradigm leads us to believe that real-time centimeter accuracies are potentially achievable. This new paradigm takes advantage of the fundamentals in orbital physics to provide the necessary orthogonality and independence needed to potentially arrive at the desired robustness and accuracy, as well as independence for an orbiting constellation.

Introduction

This paper provides an introduction to the concepts needed to determine satellite orbits with accuracy on the order of a centimeter and gives an idea of the fundamental physics involved. The theory has broad applicability and many detailed studies would be necessary for any given application. We have used GPS orbits as an example.

About five years ago the ideas contained herein were conceived, and a patent application was filed jointly with support from Allan's TIME, Inc, Hewlett Packard Company, and the University of Colorado. The patent proceedings were discontinued due to an unusual set of circumstances, and the authors have chosen at this point in time to share the ideas – so that they may be more broadly used. The abstract and the claims for this patent application are listed in Appendix A as filed some five years ago.

In view of the accuracy desired from the solution, the effects of relativity must be carefully considered. In the simulations performed in conjunction with the patent application, the relativity equations were calculated at the centimeter level. We will briefly discuss other effects that could affect such a satellite constellation at this level of accuracy.

The Physics Needed and the Concept for this New Paradigm

First, we need the first-order Doppler equation, and we will write it in a very simple form: $y = v/c$, where "y" is the normalized, Doppler-shifted, frequency offset as received at a monitor station coming from the atomic frequency standard on board a particular satellite (SV), "v" is the relative velocity between the SV and the same monitor station clock at a well surveyed point on the earth or otherwise, and c is the speed of light. Of course, if all the relativity effects are calculated and accommodated correctly, "y" will be zero when "v" is zero as specified in the equation. These zero values will occur uniquely at the point of closest approach – in principle, providing a fiducial marker for the orbit.

In Figure 1 we show a simple diagram of the effect on this equation when measuring a Doppler frequency for an observer that is in line with the frequency of transmission. When the transmitter goes through the observer's position, two notable things happen: 1) the Doppler shift goes through zero, and 2) the derivative of the Doppler frequency offset, dy/dt, is a delta function. These distinctive characteristics of the Doppler transition, allow it to provide a fiducial marker for that point in time.

We can carry this concept into space with a highly accurate atomic clock on board a space vehicle (SV). Again, the Doppler frequency will be zero at the point of closest approach, and this point becomes a fiducial marker for the SV orbit.

The delta function from our initial case turns into a Doppler frequency slope, dy/dt, which will be a function of the SV's orbital geometry. As shown in Figure 2 for a GPS like orbit, this slope is dy = 1×10^{-13} per dt = 175 microseconds. Five years ago, this level of accuracy was easy to achieve. Now one can do much better. Frequency stability of 1×10^{-14} is commonly available on the new GPS block 2R rubidium clocks in space.

Next, we may simplistically write Kepler's third law in the following way:

$$T^2 = \frac{4\pi^2}{GM_e} r,^3 \qquad (1)$$

Where T is the period of the orbit, G is the universal gravitational constant, M_e is the mass of the earth, and r is the radius from the center of the earth to the center of the SV. Now, we recognize in this simplistic circular orbit that the motion of the spacecraft is orthogonal to the radius vector. Hence, in Kepler's third law a natural orthogonality is built into the physics.

We can now ask the question, using a GPS orbit for example, if we know the SV's circular position to 175 microseconds out of a period of about 12 hours, how well do we know the radius vector, r? By taking the derivative of the above equation, we obtain the following:

$$\frac{dr}{r} = \frac{2}{3}\frac{dT}{T}, \qquad (2)$$

where we can take dT = 175 microseconds, T is one orbit period of a GPS SV (about 12 hours), r is the radius vector from the center of the earth to the SV, and we solve for dr = 7 cm. This value of dr is an uncertainty on the absolute distance from the center of the earth to the center of the SV, and is totally independent of atmospheric delay variations to the extent that they are symmetric about the point of closest approach. Hence, we see the tremendous leverage factor this equation provides in determining the radius vector. This is illustrated in Figure 3. Also, we see that the improvement scales as the accuracy of the frequency standard in the SV. So if we had an SV frequency standard with an accuracy of 1×10^{-14}, then dr would be reduced to 7 mm. The technology currently exists to place this high level of accuracy in space. There are numerous other effects that need to be accounted for to prevent degradation of this level of accuracy, but in concept one sees the tremendous advantage of this approach.

Some Practical Considerations

Because of the four dimensional nature of this high accuracy problem, one also has to deal with the estimations of all six of the orbital parameters: the semi-major axis, the eccentricity, the initial longitude, the angle of perigee, the inclination angle, and the angle of ascending nodes - in addition to the relativistic considerations. At least two monitoring stations are needed in order to avoid ambiguities in determining these parameters.

In principle, all of the computations could be done in the SV. This would avoid having to communicate data from several monitor stations on the ground, which is currently a large segment of the overhead for GPS operation. For practical reasons, one may chose to perform the computations on the ground and then pass them up to the SV or to perform them independently in both locations for redundancy.

One of the biggest practical considerations is to ensure that Equation 1 is valid. From a current science perception, this equation will be valid as long as the relativistic calculations are performed correctly and if the SV has no other forces than the gravitational force acting upon it. This can be accomplished to good approximation by having a "drag free" sensor at the center of mass of the SV, and then having small trim jets to keep it in a "drag free" state – as has been done in other tests and as is planned for the "Gravity Probe-B" space experiment soon to be launched.

Error Analysis

In Table 1 we have made a preliminary error analysis of the various contributing factors. We have specifically made an estimate of the theoretical limit. As can be seen, most of the errors are of the order of a centimeter. The largest one being the error in the speed up and slow down of the earth's spin – causing errors of several centimeters over the course of a day. The variations in the movement of the earth is, of course, one of the several measurements that one would like to study from this independent-local SV inertial frame. By looking at correlations across the constellation, one could sort out what the earth was doing versus what the errors were in the SV's positions. The earth rotates, at the equator, a centimeter in 22 microseconds. This would be resolvable, in principle, with an SV clock having an accuracy of 1×10^{-14}.

If the drag-free error contribution is given by $\frac{1}{2} a t^2$, and acceleration error "a" is given by $5 \times 10^{-12} g$, then in order to keep this error at one centimeter, the value of "t" is about 20,000 seconds – less than six hours. Hence, the acceleration detectors would have to be updated about four times per day to contribute no more than one centimeter to the SV ephemeris error.

In typical satellite tracking, the vertical error component is the most difficult one to minimize. In this new paradigm, the vertical error component is the easiest. Currently, the center of the earth is not known with an accuracy of one centimeter. This new paradigm would significantly assist in improving the accuracy of this measure.

Clocks

The atomic clocks that are being used, or that are being considered for space applications and that would be useful for this new paradigm approach, are cesium beam, rubidium gas-cell, and hydrogen maser designs. We will briefly touch on what we consider to be the best approach for each of these three types – picking from the best of the technology that is currently available.

About a decade ago, Hewlett Packard (Len Cutler, Robin Giffard, and colleagues) developed a revolutionary commercial, cesium-beam, frequency standard and clock, the model HP 5071A. As a result of the outstanding performance of this clock, the primary timing centers throughout the world have acquired them, and this type of clock now makes up 85 % of the weight of International Atomic Time (TAI) and of the official civil time (UTC) for the world. It has extremely high accuracy and typically negligible frequency drift. This technology has the potential to improve the performance of space cesium clocks by about an order of magnitude. There is no fundamental limiting reason why this technology couldn't be utilized in space. This technology provides outstanding long-term stability of the clocks and is the fundamental reason why these clocks have such a high weight in international timing. This same technology is now beginning to make a very important contribution to avionics positioning – augmenting GPS. However, the short-term stability gives some limitation; it is about $6 \times 10^{-12} \tau^{-1/2}$. This implies that one would have to average the frequency for about four days to have an uncertainty of about 1×10^{-14}. There are ways to improve the short-term stability and those are being pursued. Because of the $\tau^{-1/2}$ behavior of the clock noise, whatever factor of improvement is gained, the square of that factor will be the decrease in time necessary to integrate to a particular level. In the above example, if $6 \times 10^{-12} \tau^{-1/2}$ were divided by a factor of 3 to a level of $2 \times 10^{-12} \tau^{-1/2}$, then it would only take 1/9 th of four days (less than 11 hours – one GPS orbit) to reach an integrated level of 1×10^{-14}. Fortunately, for this kind of noise (white-noise FM), one does not need to continuously monitor the time of the clock. In fact, the optimum estimate of the frequency is given by $(x(t + \tau) - x(t))/\tau$, where $x(t)$ is the time deviation of the clock at time t. These time deviation measurements could be one orbit apart if the precision of measurement was not a limiting factor ($\tau = 12$ hours).

The GPS Block 2R rubidium clocks have been engineered to an astounding level – given the limiting physics associated with rubidium gas-cell technology. Their short-term stability is about $2 \times 10^{-12} \tau^{-1/2}$, which is about an order of magnitude better than most of the SV cesium clocks. Additionally, the flicker floor is lower than that for cesium – at about 1×10^{-14}. However, as can be expected from the fundamental physics of the devices, the frequency drift of the rubidium clocks is significantly higher than that of the cesium clocks. Despite this fact, the frequency drift of the rubidium clocks has been made remarkably low with very careful engineering. From the fundamental physics of the clocks, one would expect the long-term stability of the cesium-beam clocks to almost always be better than that of rubidium, gas-cell clocks. The next generation rubidium clocks planned for the GPS III program have even better short-term stability – about $7 \times 10^{-13} \tau^{-1/2}$, which means that in a single pass ($\tau = 10{,}000$ s) one could integrate the clock noise down to a level of 1×10^{-14}. This would be nearly ideal for this new paradigm concept for providing centimeter level accuracies for the SV orbits. However, the frequency drift would have to be very carefully calibrated with respect to the monitor station reference frequency standard, and each of the monitor station frequency standards would need an accuracy of 1×10^{-14}.

Only one hydrogen-maser clock has flown in space. This was the special clock built by Robert F. C. Vessot and colleagues for one of the finest tests of special and general relativity that has ever been conducted. The Swiss are proposing to provide a passive hydrogen-maser clock to be space qualified for the Galileo program. It will be very interesting to see how this program turns out. The short-term stability of active hydrogen masers can be made exceptionally good at about $1 \times 10^{-13} \tau^{-1}$. This far out-performs any other commercial clock in the short-term and has some significant benefits in some applications – as in the current new paradigm. However, this is not what is being proposed, and wisely so, because making a space-qualified, active, hydrogen-maser clock with very reliable long-life performance is no small task. The Swiss proposal is much more reasonable, but has the disadvantage that the short-term stability is not nearly as good as for the active maser. It is nominally comparable to the current GPS block 2R rubidium clocks.

Summary

Below we list some of the advantages and needs of this new paradigm.

ADVANTAGES:

- Real time accuracies approaching a centimeter.
- Potential for Autonomy; calculations could be performed onboard the SV.
- Requires only a minimum of two tracking stations.
- Has natural – heretofore under-utilized orthogonality from fundamental physics.
- Is based on proven technologies.
- With some of the new anticipated developments, this new paradigm has some very interesting application opportunities (see Appendix B).

NEEDS

- Utilize the current high accuracy atomic clock technology
- Utilize current "drag-free" technology

Perspective

There are numerous applications where centimeter accuracy is desired, but the situation is limited by the accuracies afforded by current system architectures. GPS, as delivered now in real time, without other corrections, is pushing hard to approach one meter of accuracy. By differencing and double differencing the data with respect to known fixed points, which requires post-processing the data, then centimeter level accuracies are possible. By making use of this new paradigm and other new technologies now being developed, real-time accuracies at the centimeter level – without other correction factors being needed – will be possible.

Frequency can be measured more accurately than any other quantity. The length of the "second" (defined by a unique frequency in the cesium atom) is the most accurate measurement known to man. This new paradigm takes advantage of this fact. This new paradigm mitigates to a significant degree the large problem now facing most satellite tracking systems – determining the absolute delay through the atmosphere. This delay is highly variable and unpredictable and is carrier-frequency dependent. If the uncertainty in this delay could be circumvented to some degree, this, by itself, would be a significant advantage. This new paradigm offers this circumvention to a significant degree.

As an example of current high accuracy measurements, the last six GPS block 2R rubidium clocks have long-term stabilities of about 1×10^{-14}. At this outstanding level of performance, they are all experiencing common instabilities of about 2×10^{-14} with periods of the frequency instability of the order of three weeks and with what appears to be close to a second harmonic is evident as well. However, it isn't a second harmonic because it isn't tied to the fundamental period. These observations appear to be common across the six most recently launched satellites. The searching question is what could be causing this phenomena? As we approach real-time centimeter accuracies, these kinds of questions will undoubtedly arise, and they may have very revealing answers.

Conclusion

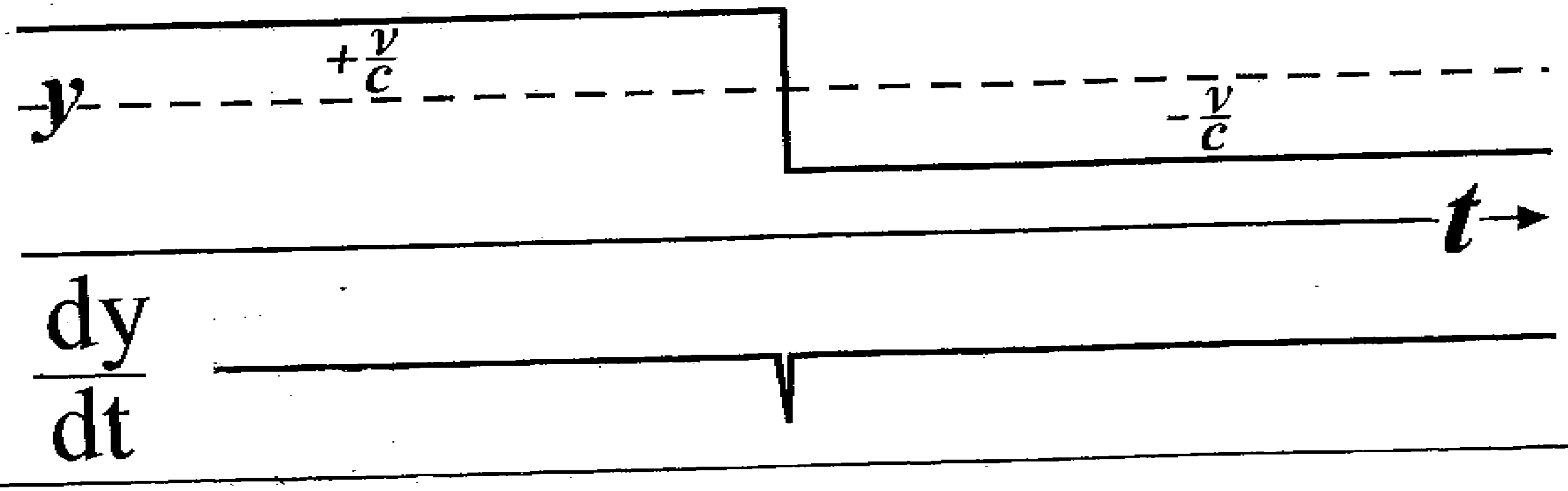
This paper was given as a last-minute invited, fill-in paper to help take the place of those who could not come to ION GPS 2001 because of the horrific attack on the United States on 11 September by terrorists. Hence, there has not been time to do a full development of the material herein. It is our desire to give enough information so that the interested investigator can pursue this new paradigm efficiently and well.

When we performed the investigations for the patent application, relevant technology had not progressed as far as is now available. The current state of technology makes this new paradigm even more promising. It is believed by the authors that pursuing the improved levels of accuracy promised by this type of approach will greatly benefit the user community and also add significantly to scientific understanding of questions which were previously unanswerable.

Doppler

Doppler Equation: $y = \frac{\nu}{c}$

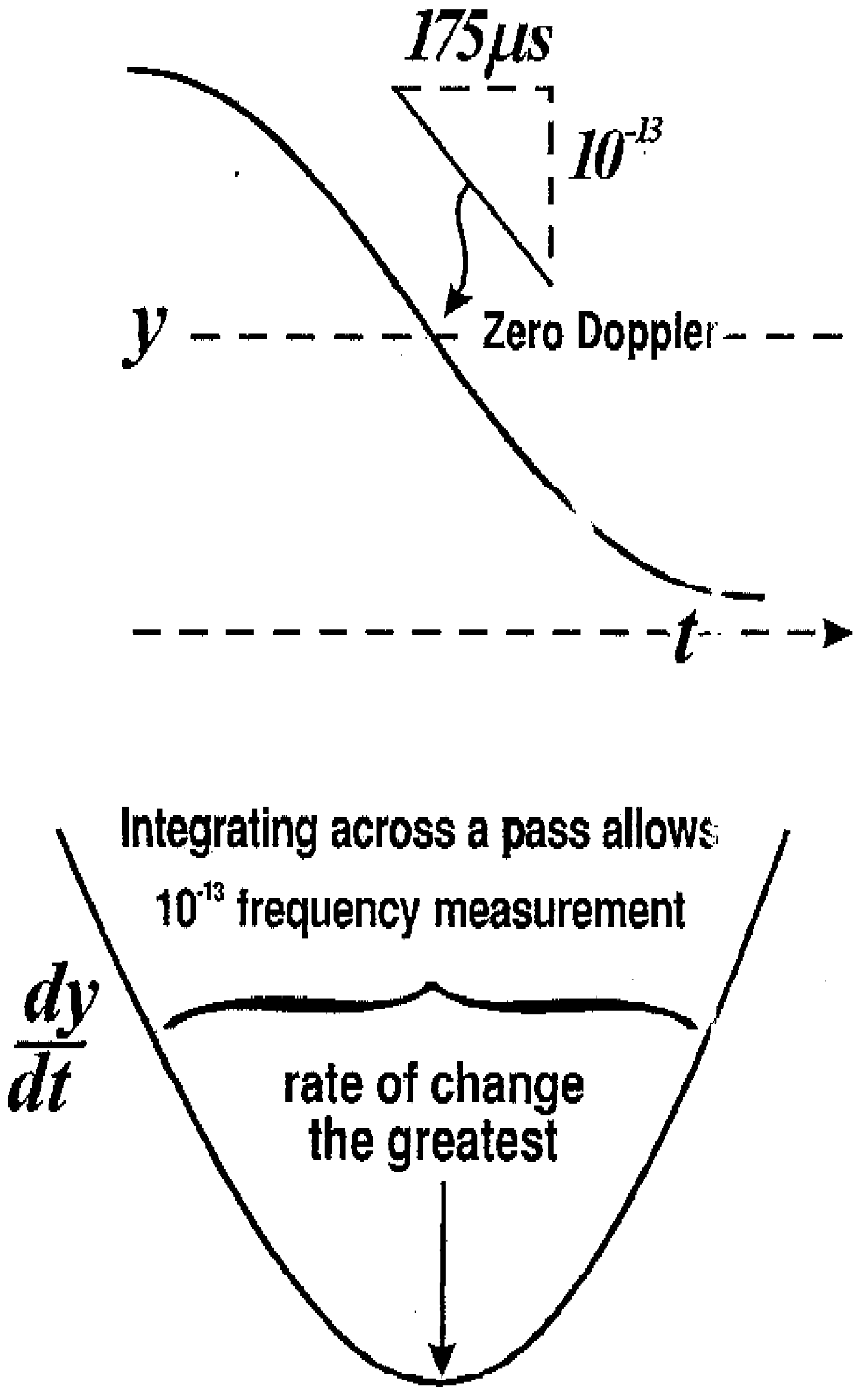
In–line example:



Point of maximum rate of change is point of closest approach

Figure 1

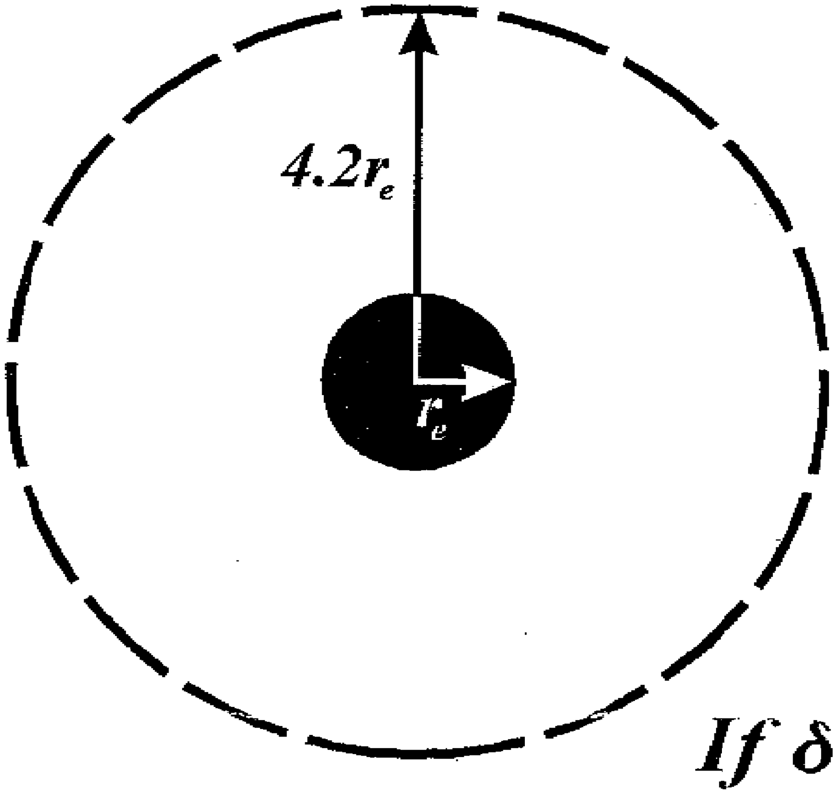
Example at GPS Orbits



Integrating across a pass allows 10^{-13} frequency measurement

Figure 2

GPS Orbit



$$T^2 = \frac{4\pi^2}{GM_e} r^3$$

$$\frac{\delta r}{r} = \frac{2}{3}\frac{\delta T}{T}$$

$$If\ \delta T = 175\ \mu s, \delta r = 7cm$$

$T \equiv$ **Period of orbit**
$r \equiv$ **Distance from center of mass**
$M_e \equiv$ **Mass of the Earth**

Figure 3

ACCURATE ORBIT ERROR SOURCES	**THEORETICAL ERROR LIMIT**
EARTH SPIN IRREGULARITIES	4 cm/12 hrs.
POLAR MOTION	~ cm
IONOSPHERE	~ cm
TROPOSPHERE	~ cm
CLOCK FREQUENCY ACCURACY	< cm
CLOCK FREQUENCY STABILITY	< cm
ZERO-g UNCERTAINTIES	$t^2 \times 2.5 \times 10^{-11}$ m/s^2
GRAVITATIONAL EFFECT OF MOON	7×10^{-16}
GRAVITATIONAL EFFECT OF SUN	4×10^{-17}
EARTH TIDES	~ cm
MULTIPATH	~ cm
RECEIVER DELAY VARIATIONS	~ cm
MONITOR STATION CLOCK	< cm
MONITOR STATION LOCATION	1 to 2 cm
MEASUREMENT UNCERTAINTIES	~ cm
ALTITUDE OF SATELLITE Involves trade-offs between several factors: clock noise, integration time, Kepler's 3rd law leaverage factor, geometry of satellites with monitor stations, method of measuring ionosphere and troposphere and other factors.	~ cm

Table 1

Appendix A: Navigation and Timing Accuracy at the 30 Centimeter and Sub-Nanosecond Level

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ABSTRACT

Past and current navigation systems using clocks in orbiting satellites require earth-based monitor stations which are used to estimate the space clocks' times and frequencies as well as the satellites' velocities and positions (orbital elements or ephemerides). The geometries and atmospheric delays limit current technology such that the best navigation accuracies are several meters for real-time systems. Better accuracies, after the fact, can be calculated with large amounts of averaging. Differential GPS delivers very good accuracies, but is a much more complicated approach, and it is not conveniently available globally.

This invention combines three technological realities in a way that provides navigation accuracies more than ten times better (sub 30 cm) - than are currently available. These three technologies are as follows.

First, atomic clocks are now being made whose frequencies in space can be known without calibration or reference to an earth monitor station. Having an independent frequency standard in space being measured with an earth monitor station frequency standard of comparable accuracy provides frequency Doppler shift information which can be used for very accurate orbit period determination.

Second, the poor geometries limiting current navigation systems can be bypassed if the satellites' basic equations of motion are truly followed. For example, the period of orbit of a satellite is directly relatable to its radius vector from the center of mass of the earth. We can utilize the significant advantage that the satellite moves at right angles to the radius vector -- giving an optimum geometrical view. Hence, if the orbit period is well known, the radius is well known. Using the Doppler shift relationships, the period can be determined very accurately, and its uncertainty is not limited by atmospheric delay uncertainties. Thus, both the geometric limitations and the atmospheric delay uncertainties causing most of the inaccuracies in current navigation systems are circumvented with this invention.

Third, the basic equations of motion will be followed if compensation can be made for effects perturbing the satellites' orbits. These include, but are not limited to solar winds and pressure, radiation pressure, and atmospheric drag. Drag-free systems have been developed and tested in space which compensate for these effects. In well designed systems, the residual forces cause accelerations significantly less than 10^{-11} g, where "g" is the gravitational acceleration on the surface of the Earth. For GPS orbits, 10^{-11} g would amount to an 8 cm error in one orbit.

As an illustration of combining the three technologies outlined above, consider Kepler's second law: $T^2 = (2\pi)^2 r^3/GM_e$, where "T" is the satellite's orbit period, "r" is the distance from the satellite to the center of mass of the Earth, "G" is the universal constant of gravitation, and "M_e" is the mass of the Earth. Each time the satellite's clock is observed from a monitor station's clock, one can conceptualize that point where the Doppler shift will be zero: the satellite clock's frequency and that of the monitor station agree with proper relativistic terms included. This can be viewed as a fiducial point in the satellite's orbit. Hence, from pass to pass the Doppler frequency behavior can be used to determine the orbit period. For example, if the orbit period could be determined with an uncertainty of 175 μs, then the uncertainty on the absolute length of the radius vector to the satellite from the center of mass of the Earth would be 7 cm at GPS altitudes. This level of uncertainty would be available using the Doppler effect if the accuracy of the satellite's clock frequency were 10^{-13}. This approach effectively bypasses the need of having an accurate measurement of the time-of-flight of the satellite's signal through the ionosphere and troposphere. Rather, it is based on the constancy of the gravitational constant and of the mass of the Earth -- along with the fact that gravitational fields are not perturbed by the atmosphere,

This invention provides that by having two or more monitor stations, or by having one with the satellites in non-synchronous sidereal orbits, the position and the velocity are determinable in real-time for each of the satellites configured with this invention. Accurate time and frequency information are natural bi-products.

Utilizing current technology, and experience gained from previous navigation and timing systems, we have the opportunity, using this invention, to improve accuracy for navigation and timing by about an order of magnitude over current GPS numbers. The simulated accuracies are about 30 cm and less than a nanosecond for timing.

It may also be possible to simplify system management. For example, as compared to GPS, only one monitor station is needed, and even if two or more are used for redundancy and robustness, data do not need to be communicated to one central location for the calculation of satellite ephemerides . The satellite can broadcast its position in real-time, and each pass over a monitor station provides a slight correction update. Neither is communication between the satellites necessary as is designed into the next generation of GPS Block 2-R satellites, which will deliver 3 meter accuracy.

CLAIMS:

1. Potential to provide real-time navigation accuracies better than one meter for avionics and terrestrial vehicles, and to reach accuracies better than 10 centimeters. For example, this invention could provide sub one meter precision approaches which are so important in blind conditions for aircraft.

2. Potential to provide root mean square (RMS) errors for satellites' orbital elements of 10 centimeters or better available in real-time. This level of accuracy can be achieved with state-or-the-art cesium-beam frequency standards.

3. Potential to provide an international time reference with sub-one-nanosecond accuracy.

4. Potential to provide normalized frequency-transfer uncertainties between any two timing centers on the surface of the Earth such that the full accuracy of the best primary frequency standards involved may be realized.

5. Potential to provide an independent inertial reference from which fine detail of Earth dynamics may be studied: short-term UT1 variations; Earth and ocean tides; ocean currents; polar motion; Earth core-mantle slippage; correlations of Earth dynamics with earthquakes and as a potential element in earthquake prediction.

6. Potential to provide collision avoidance assist for land, sea and aircraft.

7. Potential to provide harbor control and avoidance of sea craft collisions with natural hazards: reefs, rocks, shallow areas (correlating tides, ocean currents and underwater objects for safety purposes).

8. Taken to its practical limit with currently available technology, the invention could reach less than 1 cm navigation accuracies. This could be done with hydrogen maser clocks in the satellites and in the monitor station(s) calibrated using timing signals to assure accuracies of both at the 10^{-14} level. Because of the excellent short-term stabilities of H-masers, the frequency during one pass can be resolved to this accuracy level. By way of example, at GPS orbits the radius could be resolved to 7 mm.

9. This invention has the potential to provide an external-to-the-Earth inertial-reference frame. Any long-term drift in this frame could be calibrated using Very Long Baseline Interferometry (VLBI), which can reference fixed radio stars in space. These two methodologies taken together could open up some very important opportunities in our understandings of Earth dynamics. The Earth has day-to-day random variations amounting to about 7 cm (a point at the equator speeding up or slowing down, in an RMS sense, this amount). VLBI can resolve earth movements, but this invention pushes the accuracy another factor of ten better in the short-term, and could, potentially, be much more convenient and cost effective. There is the very real possibility that these movements could be correlated with earthquake phenomena and Earth plate tectonics. Understanding the Earth's dynamics as a whole system could be extremely useful. This could also open up increased understanding of the higher order moments describing the mass distribution within the Earth as well help observe Earth core-mantle slippage.

10. Potential to provide high-accuracy orbital elements for satellites which are semi-independent of the signal delay through the atmosphere. In other words, most other satellite systems, such as GPS, depend on measured time delay through the atmosphere. Given a fixed and unknown delay, the frequency, which this invention uses, does not change.

Appendix B: The following was presented as an invited talk in September 2000 at the Civil GPS Service Interface Committee – Timing Subcommittee.

Overview of a New Unified Field Theory with a New Model of Gravity

By

David W. Allan

A new theory of gravity as well as a unified field theory (UFT) are being proposed, showing how the four force fields work together, implicating also a fifth field. A main feature of this new model is the proposal of the existence of diallel, gravitational-field lines that emanate from every entity. For the earth, for example, they emanate radially from its center. These diallel lines provide a conduit for combined particle and wave flow and exchange beyond the speed of light, and they have quantum states similar to the atom. On the web site, we present a general field equation showing the importance of energy density in this new UFT. We also present a new gravitational force equation, that has as a special case the commonly accepted gravitational equation.

As we have been working on this new theory, we have been amazed at insights, applications and heretofore unexplained phenomena to which it applies. On the web site we list a large number of such phenomena, and the list continues to grow from information often supplied by others.

The Brigham Young University Physics and Astronomy Department has been very supportive of our research by letting us use their laser laboratory facilities and by also loaning us some excellent students to help with the research efforts. During private conversation with him, Dr. Leonard S. Cutler of Agilent Technologies learned of our need for a UV spectrometer, and he loaned us a UV monochrometer, which would very nicely allow us to do the spectrometry over the UV spectral region – expected according to the theory and according to other external experimental evidence.

We have conducted four experiments to date to differentiate the new theory from traditional thinking, and we have obtained affirmative results on all four. The first one demonstrated pendulum clock slowing as a result of introducing high energy-density sources underneath the clock as predicted by the new UFT. The second experiment showed evidence that these diallel lines for the earth define the local vertical. We were able to bend the local vertical slightly using high energy-density sources. In the third experiment we obtained pulsed UV emissions from diallel-line electrons that had been placed in an excited state. Most recently (9 Sept. 2000) we obtained continuous diallel-line quantum emissions at 420 nm. In this same experiment we also observed blue shifted He-Ne 631 nm photons, as predicted by the theory and as they interacted with the diallel-line excited electrons. Papers are in preparation documenting the above, and some additional information is available on the web site.

While we are confident of the general model and we see great ramifications coming from the theory, we nevertheless sense our inadequacy to relate it clearly and accurately to the manifold areas to which it is sure to find application. That is why we are anxious to garner the interest of other researchers and theorists who can help flesh out the theory, expand the equations, and probe the manifold applications and ramifications.

Our web site www.allanstime.com is designed to be a catalyst to encourage others to participate in developing the theory and in doing experimentation. We trust you will be patient with our exuberance at times as we may tend to overextend the applications in some cases, and reveal our lack of professional knowledge of other areas outside our field of expertise. We also hope you will be understanding of the need we feel to go ahead and make this unfolding theory – and very different way of viewing nature – available publicly prior to its being published in a peer-review journal so that others may participate in the pioneering.

We would like to thank all our friends and colleagues who have thus far helped and facilitated the development of this theory and the experimentation to go with it. Its many manifestations as well as applications for the benefit of society are very motivational to us. And we would like to invite all who are interested to join with us as we continue this exciting pursuit. The fifth force field is particularly exciting as it appears to couple beyond the physical. We call it – following Gustaf Stromberg (Franklin Institute Journal, Vol.272, 1961, p134) – the Eternity Domain. Our work could not have progressed as it has without the hand of Providence – to whom we are most grateful, first and last.