

# 全球衛星定位即時線上應用程式之研究與設計

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摘要

全球衛星定位係結合衛星與無線通訊的一種導航系統，可即時提供GPS接收器所量測的三維定向座標、載具速度及時間資訊，便捷與準確地讓使用者能夠不受限於地域、時區等因數影響。

本文的研究則根據全球航海電子學會(NMEA)所頒佈之NMEA-0183規範；配合地標資訊系統(GIS)所律定之橢球體( $\varphi, \lambda, h$ )與直角體(x, y, z)座標轉換運算式，採取LabVIEW圖控介面程式及Matlab計算模組的設計軟體，併行整合實用的即時線上應用程式，讓一般GPS使用者皆能測量其地理方位。

總括言之，文中對所擷取到的地理資訊亦特別提出新穎的雙向濾波設計模組，預作前置平滑處置虛擬測距誤差(Pseudo-range error)與降低載波相位偏異誤差(Carrier Phase-delay)的影響，確保量測精度的品質提昇與減少外在雜訊的干擾。經由一設計製作的簡易串列介面電路，可直接與個人電腦連線操作與應用，大幅改善全球衛星定位系統的實用性與降低商品化成本。

**關鍵詞：**全球航海電子學會(NMEA)、全球定位系統(GPS)、地理資訊系統(GIS)、世界大地基準(WGS)、台灣大地基準(TWD)。

# Design of a Real-time and On-line Prototype Software in GPS/GIS Application

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## Abstract

Global Positioning System (GPS) is a satellite-based radio positioning/navigation system providing accurate, three-dimensional, common grid position, velocity and time information to unlimited users and areas. In this paper, a virtual instrumentation-based technology was adopted to construct the prototype software for GPS/GIS applications. Including NMEA specification and GIS technology, this study combines the flexible GUI functions of LabVIEW with the advanced analysis programming of MATLAB to develop a novel real-time and on-line prototype software for the pseudo-range position measuring and geodetic coordination transforming.

Indeed, the primary software features of this system is considered in its all aspect of low-cost, flexibility, and graphic-user-interface concepts on the PC-based platform. It functionally acquires and decodes NMEA-0183 information sentence, and then GPS user could not only simply integrate the geodetic data into positioning and navigation applications, but it also allows researchers do their developing on versatile programs.

**Keywords:** NMEA (National Marine Electronics Association), GPS (Global Positioning System), GIS (Geographic Information System), WGS (World Geodetic System), TWD (TaiWan Datum) ◦

## 1. INTRODUCTION

Each GPS satellite broadcasts signal continually that says, "According to its atomic clock, the time is now  $t$ ", and each satellite periodically broadcasts a current, precise estimate of its orbital elements. The elements are determined by the ground processing, using precise observations of the satellite by a global network of the tracking station whose locations have been precisely surveyed. In addition, each satellite timing clock is monitored and regularly calibrated by ground based processing [2,3]. All of these estimates and calibrations are regularly uploaded to satellite, which in turn regularly broadcasts them to users.

Thus, in effect, GPS receiver hears a message; "At that time  $t$ , by its clock, its 3-dimensional position was  $P$ ." It means a typical user is in the directing line-of-sight of several GPS satellites simultaneously, and these positioning data, which are received from several satellites almost simultaneously.

Conclusively, those straightforward computation on the time-difference is sufficient to calculate the user position quite accurately, but the user's receiver gets time-of-arrival signal inaccurately. However, these error aren't significant, because it is consistent across satellite. The algorithm is built into the receiver estimates the user's clock error along with the user's 3-dimensional position. All that required is a good simultaneous view of at least four GPS satellites.

For the users with commercial GPS receivers, the main sources of error in computing 3-dimensional position are listed as follows [4]:

1. Bias errors, even after the regular calibration in the satellite clocks; at calibration, the satellite clock biases begin a random walk which, after a certain hours, dominates the error,
2. Errors in ground estimates of those satellite orbital elements,
3. Signal propagation delay error due to the tropospheric and ionospheric effects,

4. Relativity effects of large satellite velocities relative to the users,
5. Earth tide, which is slight distortion of the solid earth due to tidal forces from the sun and moon, and
6. Signal measurement error occurs in GPS receiver.

Several of the errors can be partially compensated by the position estimation algorithm within the user's receiver, but residual errors are still remained. The significant factor in the final result is how these satellite ephemerides have been estimates and how the satellite clocks have been calibrated recently. If the upload estimates are not refreshed at least daily, the resulting navigation accuracy for precision users degraded. Using a fixed GPS receiver in precisely surveyed position, or Differential GPS (DGPS) can then correct the relative instantaneous bias errors in the clocks of all the GPS satellites in view. The effect of this method is to compensate not only for the SA noise, but also for the related errors that are originated

from the tropospheric and ionospheric transmission delays, earth tides and etc. However, as a user moves away from the based receiver, viewing a different combination of GPS satellites than are viewed by the referred receiver, the accuracy of DGPS sharply degrades. Some of GPS users have long desired generalization of DGPS, that it could provide superb navigational accuracy over a wide geographical area. The reminder of this paper discusses this concept further, and it also describes a particular real-time prototype of such a system being studied in LabVIEW and MATLAB [5,6].

## 2. PSEUDO-RANGE

Position calculations are generally made of using triangulation algorithm. GPS signals from at least four satellites are required in order to calculated the 3-dimensional position information. A receiver computation is based on signal transmission delays, and is decided to measure the distance between user and

satellites. Moreover, these distances are called pseudo-ranges and is written as  $R_1 = C\Delta T_1$ ,  $R_2 = C\Delta T_2$ ,  $R_3 = C\Delta T_3$ , and  $R_4 = C\Delta T_4$ . Wherein C denotes the speed of light  $\Delta T_1$ ,  $\Delta T_2$ , and  $\Delta T_4$  present the time-of-arrive delays that encounter in reaching the receiver upon transmission from satellites 1, 2, 3 and 4 [7]. Conclusively, user's position in Earth Centered Earth Fixed (ECEF) coordinates Xu, Yu, and Zu can be computed by the following equations:

$$(X_i - X_u)^2 + (Y_i - Y_u)^2 + (Z_i - X_u)^2 = (R_i - R_{bi})^2, \quad \text{for } i=1,2,3,4 \quad (1)$$

where  $X_i$ ,  $Y_i$ , and  $Z_i$  respectively are satellite positions, and  $R_b = CT_b$  is due to clock bias,  $T_b$  and  $R_i$  are included as a range correction, which is caused by offset between the satellite and receiver clock with the respect to GPS time (see Figure 1). In this study, the algorithm is considered to avoid the aforementioned ambiguity of Eq. (1) by utilizing the adjacent-in-time difference phase with a linearized filter to

observation model in matrix, which is given by [8]

$$\begin{bmatrix} P_n - \hat{P}_n \\ \delta\Phi_n - \hat{\delta}\Phi_n \end{bmatrix} = \begin{bmatrix} 0 & A_n \\ -A_n & A_n \end{bmatrix} \begin{bmatrix} \delta x_{n-1} \\ \delta x_n \end{bmatrix} + \begin{bmatrix} e_n \\ \varepsilon_n \end{bmatrix}. \quad (2)$$

Herein  $P_n$  and  $\hat{P}_n$  are the pseudo-range measured and related predicated value;  $\delta\Phi_n$  and  $\hat{\delta}\Phi_n$  are the delta carrier-phase measurement and the related predicated value;  $\delta x_n$  is an estimated correction at epoch n; and  $A_n$  is the measured partial derivatives for epoch n;  $e_n$  and  $\varepsilon_{n-1}$  are the system errors respectively, which is associated with their carrier phase and pseudo-range measured. [9,10]

Many significant algorithms are in use today; none of them can meet all the basic requirements (i.e. mobile, low cost, accuracy, short range, reliable) [1]. For Example, GPS may acquire a static accuracy of  $\pm 16$  cm, however in the relatively combined positioning mode, the accuracy is reduced to 1.2 m. But GPS is not self-contained positioning system and its system accuracy could be degraded by

the availability and anti-spoofing [2]. Navigation system such as Loran C, DECCA, and ILS can't either achieve submeter accuracy over a range of 6 Km [3, 4].

A novel approach to determine absolute position with a high degree of accuracy and it is suited for real time range estimation. Herein we implement the Wiener-Kolmogorov model and the Spectral Prony Algorithm (SPA) with a priori of the system, then a wide class of signal estimation will be lead to a solution of optimum linear estimation problems of GPS application.

Conclusively, this study constructs a general description of the relevant SPA analysis, then an advanced model will be demonstrated. Finally we will discuss the features with the simulation results to make positive remarks as well as orientation of future research.

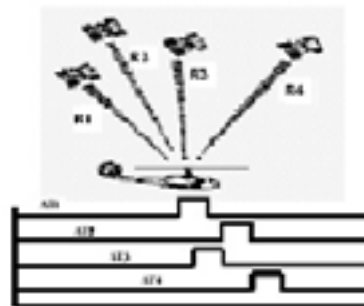


Figure 1: Pseudo-range and position-based calculation.

However, the optimized estimation for Eq. (2), in a least-square sense, is

$$\begin{bmatrix} \hat{x}_{n-1} \\ \hat{x}_n \end{bmatrix} = \begin{bmatrix} x_{n-1} \\ x_n \end{bmatrix} + \begin{bmatrix} A_{n-1}^T C_{\delta p_n}^{-1} A_{n-1} & -A_{n-1}^T C_{\delta p_n}^{-1} A_n \\ -A_n^T C_{\delta p_n}^{-1} A_{n-1} & A_n^T (C_p^{-1} + C_{\delta p_n}^{-1}) A_n \end{bmatrix}^{-1} \times \begin{bmatrix} -A_n^T C_{\delta p_n}^{-1} W_{\delta p} \\ A_n^T C_p^{-1} W_p + A_n^T C_{\delta p_n}^{-1} W_{\delta p} \end{bmatrix} \quad (3)$$

$C_{\delta p}$  and  $C_p$  are the covariance matrix and  $W_{\delta p}$  and  $W_p$  are the disclosure vectors for the pseudo-range and time difference carrier phase.

### 3. TRANSFORMATION ALGORITHMS

First, a three-dimensional geometry is used to derive coordinate conversion transforming the measured geodetic latitude, longitude and spheroid altitude

into the Cartesian coordinates or vice versa [11,12].

3-1. Transformation using the

Molodensky-Badekas Model

In the geodetic context, the general transformation model is often referred to as the Bursa-Wolf model. But it is invoked for small network; its rotation parameters are highly correlated with the translation calculation. Therefore we choose the alternative Molodensky- Badekas model to avoid this correlation problem [13] and to compute the 3-D transformation difference. As we know TWD97( $X_A$   $Y_A$   $Z_A$ ), which is based on GRS80 ellipsoid. Therefore we had to convert data ideally through ITRF94 intermediately, and then calculated it under ECEF (Earth-Center Earth Fixed) system into WGS84( $X_B$   $Y_B$   $Z_B$ ) by using the following formulas:

$$\begin{bmatrix} X_B \\ Y_B \\ Z_B \end{bmatrix} = \begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} + \begin{bmatrix} Tx \\ Ty \\ Tz \end{bmatrix} + \begin{bmatrix} D & -R3 & R2 \\ R3 & D & -R1 \\ -R2 & R1 & D \end{bmatrix} \begin{bmatrix} X_A \\ Y_A \\ Z_A \end{bmatrix} \quad (4)$$

Hereinafter we must also realize that

TWD97 is based on GRS80 geodetic ellipsoid but ECEF is corresponding to WGS84 geodetic ellipsoid. In this study, it simply adopts parameters as three translation ( $T_x$   $T_y$   $T_z$ ), one distortion  $S$ , and three rotation ( $R1$   $R2$   $R3$ ) factors listed in table 1, which were official published by IERS [14].

	$T_x$	$T_y$	$T_z$	$D$	$R1$	$R2$	$R3$
<b>Solution</b>	<i>cm</i>	<i>cm</i>	<i>cm</i>	<i>ppm</i>	<i>.001"</i>	<i>.001"</i>	<i>.001"</i>
ITRF 97	0.67	0.61	-1.85	1.55	0.00	0.00	0.00
ITRF 96	0.67	0.61	-1.85	1.55	0.00	0.00	0.00
ITRF 94	0.67	0.61	-1.85	1.55	0.00	0.00	0.00
ITRF 93	1.27	0.65	-2.09	1.95	-0.39	0.80	-1.14
ITRF 92	1.47	1.35	-1.39	0.75	0.00	0.00	-0.18
ITRF 91	2.67	2.75	-1.99	2.15	0.00	0.00	-0.18
ITRF 90	2.47	2.35	-3.59	2.45	0.00	0.00	-0.18
ITRF 89	2.97	4.75	-7.39	5.85	0.00	0.00	-0.18

**Table1: Conversion factors deviated from ITRF2000 to previous frames.**

Conclusively, the calculated difference between the two coordinate frames was the philosophy of how an inertial datum should be defined, and was ignored by all but a handful of geodesics that are working at the extraordinary levels of accuracy. The transformation based on the above derived

difference of plus or minus few centimeters, Therefore, as long as proceeding is recognized, it can be stated that WGS84 and TWD 97 are based on same ellipsoid as commercial applications.

### 3-2. Transverse Mercator Mapping to geographical conversion

The inverse formulas for the TM map projection, as shown in Figure 2, were taken directly from the Dept. of Defense World geodetic system [15], and the conversion algorithm will be duplicated in this study. However, it is worth emphasizing, the geographical constants used must be those of the spheroid associated with the mapping datum. In the case of the Map Grid of Taiwan, the geographical flattening and semi-major axis length of the TWD97 are required

### 3-3. Ellipsoid to Cartesian conversion

In Figure 2, the three-dimensional geometry will be used to derive the conversion formulas from a spheroid

coordinates  $(\psi, \lambda, h)$  to the Cartesian coordinates, which are centered on the same spheroid and its axes are aligned with the minor and major axes of that ellipsoid. The formulae used in this package are those given in [16].

### 3-4. Cartesian to geographical datum conversion

Rearranging the specified equations, we can derive the conversion formulas between the Cartesian coordinates and the geographical coordinates. However, There is at least one difficulty, which is the geographical latitude, it inevitably presents on both sides of one of inverse equations. This necessitates that some form of rotation be used for its solution.

(A) Ellipsoidal (WGS84  $\psi, \lambda, h$ ) to Cartesian (ECEF  $X, Y, Z$ )

$$X = (N + h) \cos \phi \cos \lambda \quad (5.1)$$

$$Y = (N + h) \cos \phi \sin \lambda \quad (5.2)$$

$$Z = [N(1 - e^2) + h] \sin \phi \quad (5.3)$$

$(\psi, \lambda, h)$ : WGS84 Latitude, Longitude and



**Height**

(X, Y, Z): ECEF Cartesian Coordinates

$$N = \frac{a}{\sqrt{1 - e^2 \sin^2 \phi}} : \begin{matrix} \text{Curvature radius in} \\ \text{prime vertical} \end{matrix}$$

(B) Cartesian (ECEF X, Y, Z) to Ellipsoidal

(WGS84  $\phi, \lambda, h$ )

$$\phi = \tan^{-1} \left( \frac{Z + e'^2 b \sin^3 \theta}{p - e^2 a \cos^3 \theta} \right) \quad (6.1)$$

$$\lambda = \tan^{-1} \left( \frac{Y}{X} \right) \quad (6.2)$$

$$h = \frac{P}{\cos \phi} - N \quad (6.3)$$

a : Semi-Major Axis or Equatorial Radius

b : Semi-Minor Axis or Polar Radius

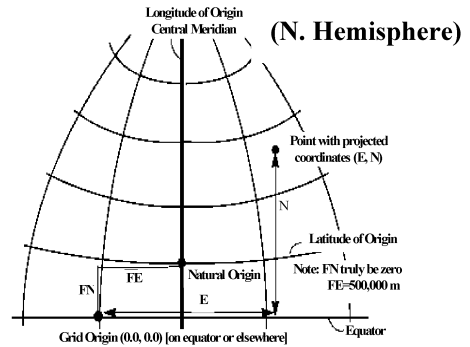
$$P = \sqrt{X^2 + Y^2} \quad \begin{matrix} \text{Horizontal Positioning} \\ \text{Range,} \end{matrix}$$

$$\theta = \tan^{-1} \left( \frac{Za}{Pb} \right) \quad \begin{matrix} \text{Ellipsoidal Compensated} \\ \text{Angle,} \end{matrix}$$

$$e^2 = 2f - f^2 \quad \text{First Eccentricity Square,}$$

$$e'^2 = \frac{a^2 - b^2}{b^2} \quad \begin{matrix} \text{Second Eccentricity} \\ \text{Square, and} \end{matrix}$$

$$f = \frac{a-b}{a} \quad \text{Flattening Parameter.}$$



**Figure 2: Coordinate of Transverse Mercator Projection**

In this study, we also provide a simplified formulas allowing user make the suitable conversion transformation between WGS84 and TWD97 datum, which adopts GRS80 ellipsoid data and refers to ITRF (International Terrestrial Reference Frame). Furthermore, there are two main schemes being considered in this study; one is to design a control and acquisition system using a friendly GUI (Graphic-User-Interface) software for processing GPS signal; another is to build-up the conversion algorithm for concisely coordinate transforming and dealing with factor compensation.

## 3-5. UTM map projection

The formulae used for the UTM projection were again taken from the Defense Image / Mapping Agency [18]. The eastern and northern reference are now matched with the Map Grid of Taiwan, which is the UTM projection of geographical coordinates on TWD97 datum. Since TWD97 datum uses the Geocentric Reference System (GRS80) spheroid, the flattening factor and its semi-major axis

length of GRS80 must be used as geometrical constants.

UTM provides coordinates on a world wide flat grid for the simple computation. UTM divides the world into 60 zones, each being  $6^\circ$  longitude wide, and extending from  $80^\circ$  south latitude to  $84^\circ$  north latitude. The first zone was started at the International Date-Line proceeding eastward and it excludes the both polar-regions.

Coordinate Transformation of Transverse Mercator Projection [18]

$$E' = K_o v \left[ A + \frac{(1-T+C)A^3}{6} + \frac{(5-18T+T^2+72C-58e'^2)A^5}{120} \right] \text{ and} \quad (7.1)$$

$$N' = K_o \left\{ M + v \cdot \tan \phi \left[ \frac{A^2}{2} + \frac{(5-T+9C+4C^2)A^4}{24} + \frac{(61-58T+T^2+600C-330e'^2)A^6}{720} \right] \right\}, \quad (7.2)$$

wherein  $E'$  and  $N'$ , derived as shown in Figure 2, are the projected Easting and Northing coordinates with  $K_o = 0.9996$ ,  $\lambda_o = 123^\circ$ ,  $T = \tan^2 \phi$ ,  $C = e'^2 \cos^2 \phi$ ,

$$A = \cos \phi (\lambda - \lambda_o), \quad v = \frac{a}{\sqrt{1 - e'^2 \sin^2 \phi}}, \text{ and}$$

$$M = a \left[ \left( 1 - \frac{e^2}{4} - \frac{3e^4}{64} - \frac{5e^6}{256} - \Lambda \Lambda \right) \phi - \left( \frac{3e^2}{8} - \frac{3e^4}{32} - \frac{45e^6}{1024} - \Lambda \Lambda \right) \sin 2\phi + \Lambda \Lambda \right]. \quad (7.3)$$

## 4. SOFTWARE

### DEVELOPMENT

National Instruments<sup>®</sup> LabVIEW<sup>™</sup> (version 6i) programming language was implemented for this project because of its flexibility to communicate through RS-232 or USB and to acquire signal transferring from GPS receivers, which are easily constructed with automating environment for personal computers. LabVIEW's software also enables the designer using the object-oriented GUI (Graphic User Interface) program in the operations that it occurs whenever an object-task is activated. As a result, the transformation algorithm be discussed earlier is effectively transparent to the user and only a little understanding of mathematical relation between different geodetic datum is required.

The majority of the transformation parameter sets between datum (stored as a ASCII file, named Datum.dat that accompanies this software). In Taiwan, a national-wide set of transformation

parameters is derived here and has been stored in "Datum.dat". If they are refined in future reasonably which is likely as researcher derives its own representative transforming parameter, Datum.dat file can be manually edited using any WINDOW's text editor. This feature also allows the transformation is user-defined.

## 5. GPS RECORDING

Since the LabVIEW's simulation is matured, timing benchmarks showed that the process time (on a Pentium IV machine) was considerably less than these time being simulated. Thus we believe that the proposed algorithm could be implemented in real time. In April 2002, our group recorded that live signals over a two-hour period by using the Garmin GPS-25LP receiver, and then began to adopt the algorithms from the simulation mentioned above to process this recorded sensor data.

Reading the NMEA-0183 sentences (seen as table 2) by LabVIEW and converting information into WGS84, the

gedoditic position format turned out, as we expected, not to be difficult.

3-5. Table 2: NMEA0183 samples

reading through a RS-232 channel

```
$GPGGA,052735.2405.7244,N,12042.7885,
E,1,04,9.2,80.3,M,16.7,M,,*71
$GPGSA,A,2,06,,15,17,,23,,,,,9.2,9.2,*18
$GPGSV,3,1,09,06,23,235,48,09,48,174,,10,
30,078,15,25,321,36*71
$GPGSV,3,2,09,17,44,322,43,18,19,306,,23,
33,321,38,24,16,146,35*79
$GPGSV,3,3,09,26,53,012,,,,,,,,,,,,,*41
$GPRMC,052735,A,2405.7244,N,12042.7885
,E,000.0,000.0,230402,003.1,W*66
```

NMEA-0183 Standard is used to define the electrical signal requirements, data transmission protocol and timing specific sentence. It formats for a 4800 baud-rate serial data bus and is based on RS232 interface. Moreover, NMEA information of GPS set is transmitted from Satellite Vehicles to any receiver with a maximum length of 80 character.

In particular we analyzed the GPS signal by using its spectrum adopting MATLAB. It surprises us to learn the similar second order's Power Spectrum Density (PSD) contour is existed (see

Figure 3), can be described as:

$$\Phi(s) = \left[ \frac{k(s+a)}{s^2 + 2\zeta\omega_o s + \omega_o^2} \right]^2, \quad (8)$$

where  $\zeta$  and  $\omega_o$  are corresponded to the GPS receiver's performance character and  $a$  is the unknown-decay coefficient. Therefore, the interfering error can be eliminated by using a low-pass filtering technology.

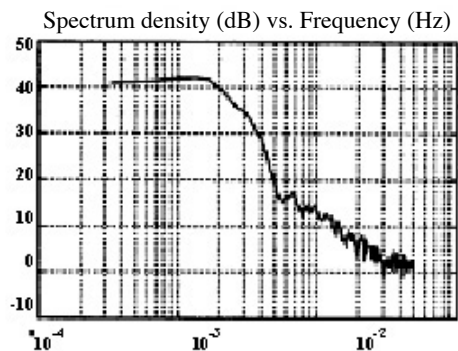


Figure 3 : Power Spectrum density of measured Latitude error.

Having successfully demonstrated this proposed algorithm with recorded data, we could turn our attention to develop a demonstration system. With an analytic state equation, a 2<sup>nd</sup> order model can be set up to re-process the data before the

positioning calculated.

Thus special software was written and checked on a personal computer at GPS test-bench. It controls the receiver, acquires data at one-second intervals, selects the data of interest and formats it into ASCII formats. Then data will be transmitted to main programming loops over LabVIEW interfaces by means of a standard communication package.

In order to execute the measured GPS coordination transformation, this study is simply focused on deriving an optimized set of conversion parameter, which is between TWD97 or TWD96 and WGS84 for Taiwan users by using a Molodensky-Badekas model and a multiple regression skill to pre-evaluate GPS signals as needed.

## 6. CONCLUSION

This prototype software allows the received GPS positioning signal to be smoothed, and to be transformed from a spheroid Cartesian coordinates and/or the existing TaiWan Datum to Ellipsoid

Cartesian of World Geodetic System.

It can handle reasonably large data sets quickly and efficiently and a few extensive tests have showed that results in round-off errors does not affect the transformed coordinates at sub-meter level. However, users should be aware that the calculation accuracy strongly depends on the parameter used.

The friendly environment of the LabVIEW and MATLAB will provide graphic-oriented operation, as shown in Figure 4.

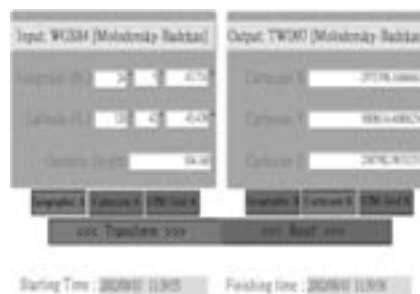


Figure 4 : Sample of Datum-mapping of coordinate-transformation.

Most importantly, such a fundamental program is of practical use to those who wish to transform geodetic datum between

the different coordinate system. The main benefit derived from studying such a software in-house is that it is optimized for special requirements of popular users, and the effort overcomes some unknown reliance, which appears to be all too common unfortunately to be used nowadays.

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