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System of Coordinate for Road Networks

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Abstract - the coordinate systems are so important for many civil engineering projects especially in road and railway projects. Universal Transverse Mercator projection with 6 degrees (UTM 6°) is used all over the world. Some problems may occur, one of these problems is increasing in distance distortion along the roads.

This paper presents a new coordinate system for road networks using the theory of united projections "compound projection". A road connecting Sydney and Albury in Australia has been chosen for this study. The results obtained show a big improvement in the coordinates accuracy riches millimetre compared with the results obtained with UTM projection system.

keywords: compound projection, coordinate system, Universal Transverse Mercator projection

I. Introduction

The coordinate systems are so important for many civil engineering projects especially in road and railway projects. Mercator projection with 6 degrees (UTM 6°) is used all over the world. Some problems may occur, one of these problems is increasing in distance distortion along the roads. The other problem when the road crossing two or more projection zones specially in overlap area between the zones where the maximum distortion is occurred. The increasing of use the road maps by the public sector, become very important to develop a new coordinate system to eliminate those problems, and increase the accuracy of maps.

Study has been carried to improve the coordinate system along the roads using the united coordinate system method with compound projection (Mercator and Lambert projection). This method give very precise results, with accuracy riches millimetre.

II. Methodology

The methodology applied for the new maps projections has standard parallels for any zones with two new scale factors $k_1+k_2=1$ [1]. In this research the projections of Lambert and Mercator has been used for creating new algorithms, which give name (compound projection); it has special properties for distortion scale factor, where all projections (Mercator, Lambert, Russell and Lagrange) haven't these properties.

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Compound projection algorithms created from direct algorithms Lambert and Mercator and each one has a new scale factor, as following [1,2].

First: direct algorithms of Mercator projection

$$C_1=\frac{m_0.c.\cos B_0}{V}, \qquad C_2=-\frac{C_1.\sin B_0}{2},$$
$$C_3=\frac{C_1.\cos^2 B_0}{6}(\tan^2 B_0-V^2),$$

$$\begin{aligned}C_{12} = \frac{C_1 \sin B_0 \cos^{10} B_0}{479001600}\big(& 2702765 - \\ & -17460701\tan^2 B_0 - 189410408\eta^2\tan^2 B_0 - \\ & -\tan^{10} B_0 + 16889786\tan^4 B_0 + \\ & +11272037\eta^2 + 517812174\eta^2\tan^4 B_0 + \\ & +44281\tan^8 B_0 - 2819266\tan^6 B_0 + \\ & +41248981\eta^2\tan^8 B_0 - \\ & -285183772\eta^2\tan^6 B_0);\end{aligned} \qquad (1)$$

Second: direct algorithms of Lambert projection "Eq. (2)"

$$C_j = \frac{C_1}{j!}(-1)^{(j-1)}(\sin B_0)^{(j-1)},,, \text{J} = 1,2,\ldots,\text{n}.$$

$$C_1 = C_1 \qquad ,C_2 = -\frac{C_1}{2}\sin B_0 \qquad ,$$
$$C_3 = \frac{C_1}{6}\sin^2 B_0 \qquad ,C_4 = -\frac{C_1}{24}\sin^3 B_0,.... \qquad (2)$$

Compound projection uses two scale factors and the summation of it must be equal one. If k_1= 0.5 , k_2 =0.5 projection of Russell created; using other new values of two scale factors, a different geometric figures is created "compound projection". To get the two scale factors area adjustment by least square method observation should be used [3,4]

$$m\cdot 0+k_1\cdot 1+k_2\cdot 1=1$$

$$m\cdot 1+k_1\left(-\frac{\Delta X_1^2}{2m_0R_0^2}\right)+k_2\left(-\frac{\Delta Y_1^2}{2m_0R_0^2}\right)=m_0$$

$$m\cdot 1+k_1\left(-\frac{\Delta X_2^2}{2m_0R_0^2}\right)+k_2\left(-\frac{\Delta Y_2^2}{2m_0R_0^2}\right)=m_0$$

$$m\cdot 1+k_1\left(-\frac{\Delta X_n^2}{2m_0R_0^2}\right)+k_2\left(-\frac{\Delta Y_n^2}{2m_0R_0^2}\right)=m_0$$

Second step:

$$Q_e = AQA^T,,,,,Q=1$$

$$A=\begin{bmatrix} 1 & 1 & \cdots & 1 & 0 \\ -\dfrac{\Delta X_1^2}{2m_0R_0} & -\dfrac{\Delta X_2^2}{2m_0R_0} & \cdots & -\dfrac{\Delta X_n^2}{2m_0R_0} & 1 \\ -\dfrac{\Delta Y_1^2}{2m_0R_0} & -\dfrac{\Delta Y_2^2}{2m_0R_0} & \cdots & -\dfrac{\Delta Y_n^2}{2m_0R_0} & 1 \end{bmatrix},$$

$$K = Q_e^{-1}F$$

$$F = [m_0 \quad m_0 \quad \ldots \quad 1], \qquad (3)$$

$$V = A^{T}K$$

$$V = [m \quad k_1 \quad k_2].$$

III. AREA OF STUDY

A road connect the city of Sydney and the city of Albury that lie into deferent zones (zone 55, and zone 56), figure 1.

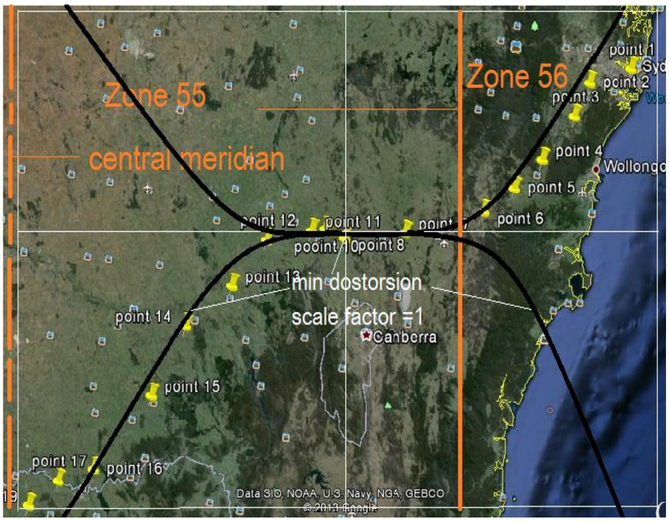

Fig.1: The Road Location

The road is located in New South Wales (NSW). This state uses a number of projection types for creating maps like (UTM6, MGA Map Grid of Australia, MGA zone boundaries across NSW, GDA Lambert), fig.2 [5]

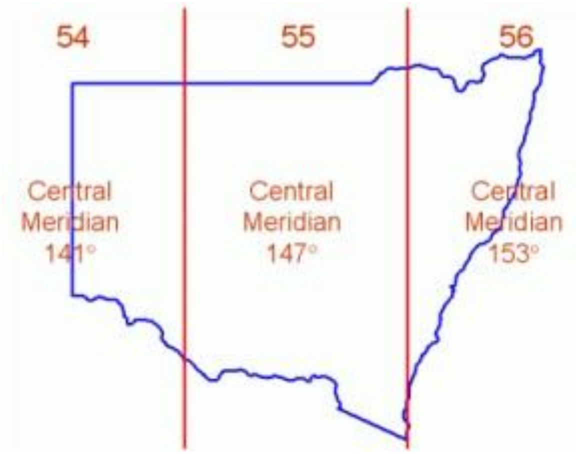

Fig.2: The administrative boundaries of NSW state

The road length is about 500km. For the compound projection, the two zones were merged in one zone with standard parallel 34.8 S, and central meridian 149.1 E and the two scale factors are (k_L=1.688498, k_M=-0.688498) [4].

IV. RESULT ANALYSES

table (1) illustrates the distortion scale factor for UTM projection and compound projection, where distortion scale factors are fixed and stable also gives very good results for compound projection compared with the results obtained by UTM projection where gives very good results only in some points.

distortion scale factor is very important for distances measurements by rectangular coordinates in zones or in overlap area between two zones.

TABLE I: The compassion between UTM and compound projection

Points	Geographic coordinates		UTM			Compound projection in one zone		
			X	zone-Y	Scale factor	X	Y	Scale factor
1	33°55´43.35″S	151°9´9.43″E	3755788.180	56-329244.779	0.99995945	3757716.797	189792.886	0.9998881
2	34°0´20.38″S	150°50´2.03″E	3764899.067	56-299960.388	1.00009331	3765686.877	160181.087	0.9999434
3	34°11´27.49″S	150°42´47.22″E	3785694.729	56-289264.272	1.00014746	3786049.550	148691.372	0.9999072
4	34°25´48.38″S	150°27´48.37″E	3812765.241	56-266913.349	1.00026972	3812227.348	125317.275	0.9999017
5	34°35´9.48″S	150°15´1.50″E	3830566.478	56-247804.027	1.00038402	3829268.203	105541.258	0.9999172
5	*34°35´9.48″S*	*150°15´1.50″E*	*3831933.566*	*55-798149.464*	*1..0006958*	3829268.203	105541.258	0.9999172
6	34°42´33.22″S	150°00´39.63″E	3844866.442	56-226244.233	1.00052380	3842714.467	83454.787	0.9999430
6	*34°42´33.22″S*	*150°00´39.63″E*	*3844926.636*	*55-775772.884*	*1.00053746*	3842714.467	83454.787	0.9999430
7	34°48´54.17″S	149°25´5.72″E	3855198.735	55-721188.248	1.00020305	3854120.588	29118.071	0.9999929
7	*34°48´54.17″S*	*149°25´5.72″E*	*3858384.327*	*56-172351.322*	*1.00092338*	3854120.588	29118.071	0.9999929
8	34°49´45.33″S	148°57´33.59″E	3855858.858	55-679174.993	0.99999569	3855660.001	-12868.066	0.9999988
9	34°47´55.16″S	148°52´24.88″E	3852314.711	55-671395.542	0.99996208	3852279.370	-20720.131	0.9999964
10	34°46´24.96″S	148°48´58.81″E	3849439.477	55-666208.706	0.9999405	3849513.125	-25966.200	0.9999945
11	34°46´45.98″S	148°42´57.04″E	3849925.335	55-657000.885	0.99990381	3850191.469	-35162.493	0.9999896
12	34°49´11.82″S	148°22´17.75″E	3853933.911	55-625438.261	0.9997939	3854860.008	-66638.467	0.9999624
13	35°3´50.31″S	148°5´44.15″E	3880686.437	55-599899.272	0.99972299	3882146.733	-91616.618	0.9999467
14	35°16´22.61″S	147°44´0.13″E	3903559.066	55-566698.805	0.99965482	3905714.867	-124339.432	0.9999263
15	35°38´59.42″S	147°26´36.93″E	3945202.202	55-540155.983	0.99961987	3947915.502	-150017.001	0.9999948

16	36°2´41.70″S	146°58´7.93″E	3988930.835	55-497195.869	0.9996001	3992539.906	-192084.357	1.0000864

Table (2) illustrates the distances measured directly from the rectangular coordinates using UTM and compound projections and compared with the same distances measured by geodetic problems [2]. The distance mean error was 1.691m for compound projection, but it was 21.924 m for UTM projection for the short distances.

All calculations use WGS84, the world geodetic system which provides coordinate frame for the earth.

TABLE 2: The comparison results

Distance by UTM meters	Distance by compound Pr. meters	Distance by geodetic problems meters
25875.301±15.919 $S_{5\text{-}6}$ Zone55	25857.575±1.807 $S_{5\text{-}6}$	25859.382 $S_{5\text{-}6}$
25871.098±11.716 $S_{5\text{-}6}$ Zone56		
55542.763±20.217 $S_{6\text{-}7}$ Zone55	55520.971±1.575 $S_{6\text{-}7}$	55522.546 $S_{6\text{-}7}$
55562.389±39.843 $S_{6\text{-}7}$ Zone56		

V. CONCLUSION

The coordinate system by compound projection with case of parabola is better than of old coordinates systems by UTM and other of traditional coordinates system used for Australia. The results follow:

- scales factors for all points by compound projection, they are fixed and stable, compared with the results obtained by UTM projection;
- compound projection has only one zone for the entire road, while UTM projection has two zones for the same road;
- The mean error in the compound projection for the short distances 20000.00- 60000.00 m was ±1.691m; while in UTM was ±21.924m.

From the above, it appears that the compound projection system is more suitable for road maps.

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