principle of classical categorization [10]. This approach assumes that the property of a parent class of any given class is inherited by its child concept (s). Based on Subsumption based reasoning OWL DL provides strong capabilities for such taxonomy based representations.

Several ontologies based on this approach in the geospatial domain can be found in [11], [12]. Two important issues in such ontologies include

- Need to develop common top level ontologies in order to connect between concepts [13]
- Avoiding non consistent *is-a* relations between concepts by applying tests of identity, rigidity and unity [14]

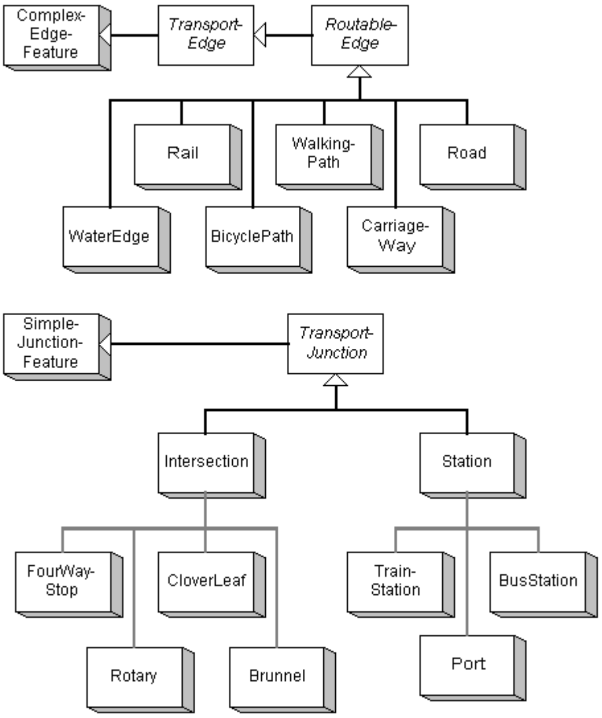


Fig. 3 UNETRANS Model for transportation

Actions or function hierarchies in geospatial space

Function Representation [15] is a framework in which to represent an agent's understanding of how some device works. Often, when people understand 'how things work," they give information of the following three types: (i) what the device is intended to do (function), (ii) the causal process by which it does it, and (iii) how the process steps are enabled by the functions of the components of the device, the way they are connected together and the underlying domain laws.

Soon and Kuhn [16] and Kuhn [17] have reported use of such entailment relation for spatial task or function based ontologies. Figure 4b shows the action hierarchies based on similar entailment relationships reported by Kuhn [17]. Such ontologies can be modeled by specifications which treat functions as first class citizens and algebraic specifications as discussed by Sen [18]. Task hierarchies have been explored extensively by time geographers who explore human activity [19]. Knowledge of such hierarchies is crucial to model geographic entities with reference to human activities. Description logics (DL) based function based ontologies have been widely reported as well [20]. The Hozo ontology editor which considers relationships and roles as a fundamental aspect of ontologies is a useful tool to develop such ontologies [21] [22]

It is important to note that function based hierarchies help to structure geospatial things based on the actions in geospatial space. Entities in this space are attached to such functions.

Need for integration

Both taxonomy based hierarchies and action hierarchies represent knowledge about the geospatial domain. While conventional taxonomy based systems are important in view of natural categories of geospatial entities, it can be argued that for man-made artifacts such as roads bridges etc it is imperative that functions (both the intentional and the ones it affords) are important to convey its semantics. Clearly there is a need to integrate these approaches (as shown by Loos and Porzel [23]) and we do so in the subsequent section based on an algebraic specification approach and a probabilistic approach based on BayesOWL [24].

Algebraic Specifications

Algebraic specifications have been used to specify domain models in the geospatial domain by a number of researches [25], [26], [27] and use of the functional programming language Haskell to develop executable specifications has been reported to have the following important advantages [28].

1. allows executable specifications, which allow verification
2. Advanced polymorphic type system with multiple parameter type classes which allow parameterized multiple inheritance

Algebraic specifications of road network ontology

Based on the work of Raubal & Kuhn [29] and Sen [18] we specify a preliminary ontology of road networks consisting of three concepts - road elements, footpath elements and motorway elements from the Highway Code of the UK[3]. We also specify a crosswalk element as a fourth concept and this is taken from the New York Driver's Manual[4].

We skip an introduction to the steps of algebraic specification of ontologies which are available from Ruether *et al* [30]. Our specification assumes top level ontologies of path schema as suggested in Kuhn and Raubal[2004] and we build our specifications on level zero where we specify persons on foot (or pedestrians) as

```
data PersonOnFoot = PersonOnFoot Node deriving
(Eq, Show)

type PersonsOnFoot = [PersonOnFoot]
```

Similarly a Car is specified as

```
data Car = Car Node deriving (Eq, Show)

type Cars = [Car]
```

In level one the behaviors of Cars are defined as

```
instance Path RoadElement Car where

move (RoadElement edge) (Car node) = Car (other
edge node)

instance Path Crosswalk Car where

move (Crosswalk edge) (Car node) = Car (other edge
node)
```

Thus cars can *move* on *RoadElements* and *Crosswalks*. At the same time *PersonsOnFoot* can move only on *Footpaths* and *Crosswalks*.

```
        instance Path Footpath PersonOnFoot where

        move (Footpath edge) (PersonOnFoot node) =
PersonOnFoot(other edge node)

        instance Path Crosswalk PersonOnFoot where

        move (Crosswalk edge) (PersonOnFoot node)
= PersonOnFoot(other edge node)
```

Testing executable specifications

We test the above specifications to check how an instance of a *Motorway* would fit in the above definitions of road network elements. We know that a Motorway would have the same behavior as a *RoadElement* and will allow only *drive* and not *walk*. Thus

```
        instance Path Motorway Car where

        move (Motorway edge) (Car node) = Car (other
edge node)
```

Now if we try to move an instance of the *Car* on the *Motorway* it moves to the end of the Motorway but gives an error for a *PersonOnFoot*.

```
> move theMotorway theCar

Car (Node "end")

> move theMotorway thePersonOnFoot

ERROR - Type error in application

*** Expression      : move theMotorway
                      thePersonOnFoot

*** Term            : thePersonOnFoot

*** Type            : PersonOnFoot

*** Does not match  : Car
```

This behavior is same for a *RoadElement* instance but not for instances of *Crosswalk* or *Footpath*. Hence we are able to say that in this case *RoadElements* are similar (equivalent) to *Motorway*.

There is a limitation that a probabilistic inference is not possible in the current method of overloading the functions of *drive* and *walk*. We plan to work on partial overloading based on the approach shown by Navratil [31].

The full Haskell code of the example discussed here is available for download at http://ifgi.uni-muenster.de/~sumitsen/Hcode.zip.

Bayesian ontologies

The term BayesOWL has been used by Ding et al. [24] to characterize their mechanism of expressing OWL ontologies as Bayesian networks. The important steps to construct such ontologies are as below:

Construction of the DAG: The entity classes to be used are listed first and the topmost (most universal) concept is added to the top of the DAG as a node. Child concepts of this concept are added below the parent concept as individual nodes and the complete DAG is created by constructing the links. Each node has only 2 states (True, False)

Regular Nodes and L Nodes: The nodes created above are called Regular nodes. There are another category of nodes called L Nodes which help in constructing Union, Intersection, Disjoint and Equivalent relationships. Since we do not use any of these relationships in our ontologies we shall ignore construction of L Nodes.

Allocating conditional probabilities: Regular nodes (other than the top node) have one conditional probability value each for its parent node. It is suggested that such conditional probability values are learnt from text classification techniques. We use the relatedness values from WordNet similarity modules to derive these values.

Applying IPFP iterations to impose P Space: Finally with given CPT values it is important for the network to learn the real values given the probability constraints to arrive at a condition where all LNodes are true. This is achieved by a iterative proportional fitting procedure [24]. In case there are no L Nodes to be considered this iterative step can be overlooked

The Bayesian network DAGs for Highway code text and NY driver's manual is shown in figure 4 and 5 respectively

The Bayesian Network files are available for download at http://ifgi.uni-muenster.de/~sumitsen/BNont.zip.

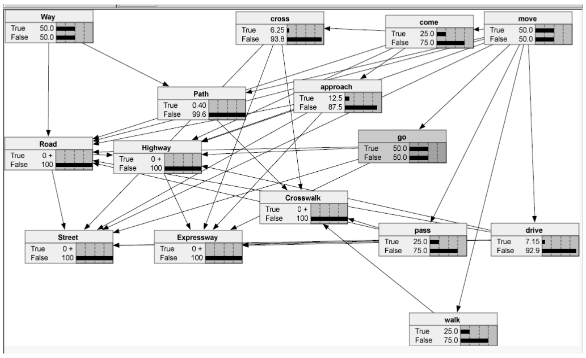


Fig. 4:DAG extracted from the NY Driver Manual text

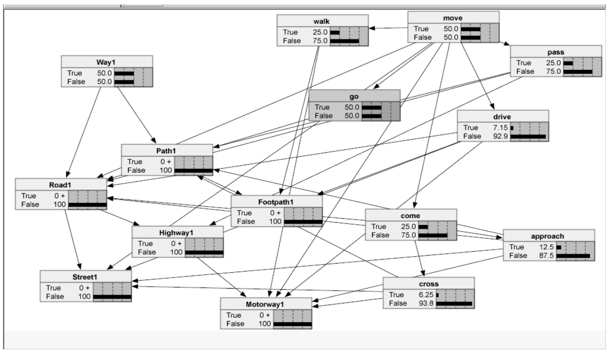


Fig.5: DAG extracted from the UK Highway code text

Inferences in a Bayesian geospatial ontology

The following inference tasks are carried out based on the proposals of BayesOWL [24]

- Concept Satisfiablity: if a concept based on certain states of given nodes in the network can exist. This is defined by verifying if P (e|t) = 0, where e is the given concept. For example in our networks a concept where *move*=False and *walk*=True is not satisfiable because P (e) = 0
- Concept Overlap: the degree of overlap between a given concept and any other concept in the network is determined by *P* (*e*|*C*,t). Thus the concept overlap between *approach* by *move* is 0.25.
- Concept similarity: The advocated measure of similarity is based on Jaccard coefficient provided by Rijsbergen [32] as $M = \frac{2D \cap Q}{D + Q}$

Following the example in algebraic specification, we decide to set values of walk = False and drive=True in the HWC DAG and obtain the following results

Concept ruled out		Concepts valid	
HWC	**NYDM**	**HWC**	**NYDM**
Footpath	Crosswalk	Rest	Rest

This shows that the *Footpath* in HWC behaves most similar to a *Crosswalk* in the context of the NYDM.

Discussion

We have shown two approaches of geospatial ontology specification. Both approaches treat functions of geospatial entities as first class citizens. The advantage of the Bayesian approach is that it allows the use of probabilistic linkages.

While algebraic specifications have been in use for geospatial ontologies for sometime (see [33] and [28]). The BayesOWL presents a new approach to geospatial ontology specification. However the most significant contribution of the specifications in this paper is the relative significance given to functions of geospatial entities which speaks for equal (if not higher) importance given to the hierarchies of actions in geospatial space

Geospatial entities for human activities

Our Argument that geographic information (GI) deals with both actions and entities in geospatial space builds a direct correspondence between entities and their functions. At the same time it has been argued by Kuhn [17] that increased complexities of human actions leads to increased complexities of conceptualization of the environment around them. This leads to the hypothesis that concepts of entities themselves are formed after the concept of the action has been established.

The approaches presented in this paper allow the use of such a presumption. It also allows a task based approach to ontologies which allow human activities to be linked to the geospatial data used. Such connectivity to human activities is expected to provide the link to greater usage of GI based on increased interoperability. The facilitation of translations across domains which have different semantics for geospatial entity classes provides opportunity of greater data and application sharing [1]. The work in this paper should be viewed with this perspective.

Future work

Some of the future work in this area, are outlined as below

1. Attempt probabilistic extensions to the algebraic specifications (as shown by Navratil [31]). This would allow composite overloading of functions which means a *Crosswalk* could be used for both *walk* and *drive* to certain extent but its function of *walk* will be restrictive as compared to that of a *Footpath*.
2. For the BN approach there is a need to validate results with human subject testing and to understand the possibilities of a automated or semi-automated translation framework which mimics the human translation process.
3. Finally both the two approaches need to be compared to the traditional approaches of taxonomies of geospatial entities in absence of their functional properties. We need to evaluate if these two approaches are more applicable in the case of manmade entities (or artifacts) as compared to natural categories.

Acknowledgements

The author acknowledges the help from members of Insititute of GeoInformatics and specially to Dr Werner Kuhn for ideas presented in this paper. Financial support from Ordnance Survey is also acknowledged.

References

1. Kuhn, W. (2005) Geospatial Semantics: Why, of What, and How? In Journal on Data Semantics III,
2. Agarwal, P. (2005) Ontological considerations in GIScience. International Journal of Geographical Information Science Vol 19. No. 5 501-536
3. Bishr, Y. A. (1997). Semantic Aspects of Interoperable GIS. Enschede, NL, ITC Publication No. 56.5. Ogden, C.K. and I.A. Richards.: The Meaning of Meaning. Harcourt, Brace & World.
4. Probst, F., & Lutz, M. (2004): Giving Meaning to GI Web Service Descriptions, 2nd International Workshop on Web Services: Modeling, Architecture and Infrastructure (WSMAI-2004).
5. Ogden, C.K. and I.A. Richards (1946) The Meaning of Meaning. Harcourt, Brace & World.
6. Kuhn, W.(2003) Semantic Reference Systems. International Journal of Geographic Information Science (Guest Editorial). 17(5): pp. 405-409.
7. Guarino, N. and Welty, C. (2004) An Overview of OntoClean in S. Staab, R. Studer (eds.), Handbook on Ontologies, Springer Verlag.
8. Câmara, G. M., A.M.V.; Paiva, J.A.C; Souza, R.C.M. (2000). Action-Driven Ontologies of the Geographical Space. In M. Egenhofer (ed),GIScience 2000, Savanah, GA, USA
9. OGC (2004) OpenGIS® Geography Markup Language (GML) Implementation Specification, (Document number ISO/TC 211/WG 4/PT 19136 N 005r3) available at http://www.opengis.net/gml
10. Laurence, S. and Margolis. E.: Concepts and Cognitive Science. Concepts: core readings. E. Margolis and S. Laurence. Massachusetts, Bradford Book: (1999). 4-81
11. Hiramatsu, K. and F. Reitsma.: GeoReferencing the Semantic Web: ontology based markup of geographically referenced information. Joint EuroSDR/EuroGeographics workshop on Ontologies and Schema Translation Services, Paris, France. (2004).

12. Curtin, K., Valerian, N., Goodchild, M. and Grise, S.(2001) ArcGIS Transportation Data Model. ESRI

13. Gangemi, A., Guarino, N., Masalo, C., and Oltramani, A. (2001) Understanding top-level ontological distinctions. In Proceedings of the IJCAI-01 Workshop on Ontologies and Information Sharing, Seattle, USA. Pp 26-33

14. Guarino, N. and Welty, C.(2004) An Overview of OntoClean in S. Staab, R. Studer (eds.), Handbook on Ontologies, Springer Verlag

15. McGinnis, B. D. & Ullman, D. G.(1992) The Evolution of Commitments in the Design of a Component, Journal of Mechanical Design, Vol. 114, pp. 1-7.

16. Soon, K., and Kuhn, W.: Formalizing User Actions for Ontologies. Egenhofer, M., Miller, H. and Freksa, C. (eds.), Proceedings of the International Conference on Geographic Information Science. MA (2004):

17. Kuhn, W.: Ontologies in support of activities in geographical space. International Journal of Geographical Information Science, 15 (2001) 613-631.

18. Sen, S.: Ontologies of One Way Roads In Proceedings of Workshop on Foundational aspects of Ontologies (FONT05), Koblenz, Germany 2005

19. Miller, H. J.: "What about people in geographic information science?" in P. Fisher and D. Unwin (eds.) Re-Presenting Geographic Information Systems, John Wiley, (2005) 215-242.

20. Kitamura Y, Sano T, Namba K, Mizoguchi R.: A Functional Concept Ontology and Its Application to Automatic Identification of Functional Structures. Advanced Engineering Informatics 16(2): (2002) 145-163.

21. Kitamura, Y., Koji, Y. and Mizoguchi, R.: An Ontological Model of Device Function and Its Deployment for Engineering Knowledge Sharing In Proc. of the First Workshop FOMI 2005 - Formal Ontologies Meet Industry, Castelnuovo del Garda (VR), Italy, 2005

22. Kozaki, K., Kitamura, Y., Ikeda, M., Mizoguchi, R.: Hozo: An Environment for Building/Using Ontologies Based on a Fundamental Consideration of "Role" and "Relationship", Proc. of EKAW2002, (2002) 213-218

23. Loos, B. and Porzel R.: Towards Ontology-based Pragmatic Analysis In: Proceedings of DIALOR'05 (Ninth Workshop on the Semantics and Pragmatics of Dialogue (SEMDIAL)), LORIA Nancy, France. June 9 - 11 2005

24. Ding, Z.; Peng, Y.; and Pan, R. (2005) BayesOWL: Uncertainty Modelling in Semantic Web Ontologies. In Soft Computing in Ontologies and Semantic Web, Springer-Verlag.

25. Kuhn, W., and Raubal. M. (2003) Implementing Reference Systems. In Proceedings of Fifth AGILE Conference, Lyon, France.

26. Frank, A.U.(2003): 'Ontology for spatio-temporal databases'. In Spatiotemporal Databases: The Chorochronos Approach. (Koubarakis, M., et al., eds.), Lecture Notes in Computer Science, Berlin, Springer-Verlag, pp: 9-78.

27. Kuhn, W., & Frank, A.U.(1999) The Use of Functional Programming in the Specification and Testing Process. In Interoperating Geographic Information Systems. (Goodchild, M.F., et al., eds.), International Series in Engineering and Computer Science, Vol. 495, Boston, Kluwer.

28. Raubal, M. and Kuhn, W.(2004) Ontology-Based Task Simulation. Spatial Cognition and Computation, Vol. 4, No. 1

29. Ruther, C., Kuhn, W. and Bishr, Y. (2000) An Algberaic Description of Coomon Ontology for ATKIS and GDF, 3rd AGILE conference, Helsinki, Finland.

30. Navratil, G. (2006) Error Propagation for free? In Proceedings of Fourth international Conference on Geographic Information Science - GIScience 2006, Münster, Germany.

31. Rijsbergen, V. 1979. *Information Retrieval.* London:Butterworths, 2nd Edition

32. Frank, A.U., & Medak, D. 1997. 'Executable Axiomatic Specification Using Functional Language - Case Study: Base Ontology for a Spatio-Temporal Database', Institute for Geoinformation, TU Vienna.

About Author

Sumit Sen is Graduate from the Institute of Geoinformatics, University of Muenster, Germany. He is pursuing his Ph.D. studies at the institute under Prof. Dr. Werner Kuhn. He obtained his Masters in Geographic Information from City University, London and his Bachelor of Engineering from VRCE, Nagpur, India. He also has work experience of over 7 years in the software Industry with Tata Infotech Limited in India. During his tenure he has worked on projects related to Geoinformatics, simulation and optimization. He has also been involved with NSDI India projects. His main research interests are in the area of semantic interoperability, process simulation and optimization. His recent work has been focused on functions of geospatial entities and their specification in geoontologies. He has experimented with Bayesian Network based ontologies of the transportation domain. Such ontologies allow probabilistic linkages between hierarchies of entities and their functions. This provides a framework for semantic translation of GI.

Anthropogenic Land Subsidence Monitoring Using Global Positioning System

Parul R. Patel[1]**, Madhav N. Kulkarni**[2] **and Anand D. Hiroji**[3]

Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400 076, India
E-mail : p5parul@iitb.ac. in

Abstract

Anthropogenic land subsidence is associated with the removal of subsurface material and withdrawal of natural resources like water, oil, and gas. Over the last several decades, man made subsidence has caused problems in urban, rural and unpopulated areas of the world. Most of the major subsidence areas around the world have been developed in the past half-century at accelerated rates due to rapidly increasing use of ground water, oil and gas etc. with increase in population. The type of hazards associated with subsidence is different from that caused by sudden and catastrophic natural events like floods and earthquakes, because surface sinking is a slow event. Uniform subsidence of the whole area does not create problems but the heterogeneous subsidence in urban areas produces damages in buildings and in other man-made structures such as bridges, canals, highways, electric power lines, railroads and underground pipes etc. Hence careful monitoring and measuring of land subsidence is required for the safety of the infrastructure lying above the subsidence area.

Many geodetic techniques like levelling, Synthetic Aperture Radar Interferometry (InSAR), Global Positioning System (GPS) are available to monitor land subsidence. Conventional levelling was used for monitoring land subsidence till late eighty. But for the large area, levelling technique is time consuming, uneconomical and tedious hence with the development of new space technology, land subsidence is now increasingly being measured with the Global Positioning System (GPS). Global Positioning System is satellite-based radio navigation system for determination of precise position and time using radio signals from the satellites. GPS technology has numerous applications including measurement of land subsidence.

Indian Institute of Technology Bombay (IITB) GPS team has carried out land subsidence study over the shallow gas reservoir field, near Surat in Gujarat. A GPS monitoring network was established in February 2004 with four reference stations and 27 deformation stations, 5 deformation stations were added in May 2006. Repeat observations have been carried out over this network to study land subsidence, over 9 campaigns at approximately 4-5 months gap during February 2004 to July 2006. The reference stations were continuously running during the entire field campaign of GPS data collection. At each deformation station, five hours of continuous GPS data was collected. The precision of few mm levels is estimated, using geodetic dual frequency receivers, precise ephemeris and processing the data in post processing mode with scientific data processing software. This paper highlights the results of nine GPS campaigns. Correlations of land subsidence with other factors are also discussed in this paper.

Key words: *Land Subsidence, GPS.*

Introduction

Land subsidence is a gradual settling or sudden sinking of the earth's surface owing to subsurface movement of earth materials either by man made activities or by natural activities. The term "subsidence" is as old as "modern geology." Land subsidence is one of the most varied forms of ground failure affecting from broad regional lowering of the land surface to local collapse. On the regional scale, geological reasons including tectonic or volcanic activities are the main causes of land subsidence. On the other hand, localized phenomena are caused by either natural or man-made reasons. Natural causes are those which occur with shallow-holes or sink holes in lime stone areas, while man-made reasons are associated with the removal of subsurface material such as, under ground mining operations and withdrawal of natural resources like water, oil, gas, under ground construction etc (Sharif et al., 1997, Mosavi et al., 2001). Due to extraction of natural resources such as oil, gas and water the pore pressure reduces in the production zone, which leads to increase in effective load from the overlying strata and compaction of compressible beds take place. This compaction of beds at depth can result in subsidence at the land surface (Gibeaut et al., 2000). Anthropogenic land Subsidence is considered as one of the major problems because of financial loss due to urban infrastructure and property damage. Hence accurate measurement and monitoring of land subsidence is required, to predict land subsidence in future and to protect infrastructure lying over the surface. It also helps in designing infrastructures, by viewing possible effects of land subsidence in future and to recommend methods for a sustainable use of the underground resources.

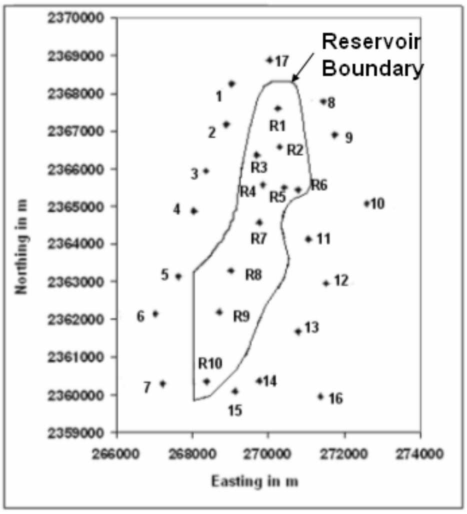
Extensive researches have been done in monitoring and measuring land subsidence but mainly focused on the subsidence due to ground water extraction. However, an accurate characterization of subsidence due to oil and gas production is rare due to various reasons, one of which is the difficulty of measuring surface subsidence precisely, with high resolution, over a large area, and in a timely fashion. Subsidence caused, by ground water withdrawal and hydrocarbon production have certain similarities, but they occur in distinct geologic environments. Ground water withdrawal for civil and industrial usage usually takes place at shallow depth, where the porous media are soil or soft rocks. These media are characterized by large porosity and permeability. Hydrocarbon production usually takes place at greater depth. Where, the porous media are consolidated or unconsolidated rocks. These media has less porosity and permeability than those of at shallower depth. The temperature and pressure at greater depth are also much larger. The geological structure at greater depth are also often more complicated. Additionally, direct measurements of compaction and related parameters are easier to conduct at shallow depth than at greater depth (Xu Haibin, 2002).

Many techniques are available to measure and monitor the land subsidence. Most common techniques used to measure the land subsidence are conventional levelling, GPS, InSAR, radioactive markers, Bore hole extensometer etc. Although the accuracy of geodetic levelling is very high, in many applications, it is time consuming, tedious, labour intensive and expensive operation. With the development of new space technology, land subsidence is now being measured with GPS technology. The Global Positioning System (GPS), a satellite based navigation and surveying system for determination of precise position and time using radio signals from the satellites, is very widely used for numerous applications, including the study of crustal motion and subsidence (kulkarni et al., 2005). The accuracy of GPS derived coordinates is 4-5 mm in the vertical direction and 3-4 mm in the horizontal direction. This accuracy is adequate to detect and monitor subsidence rates that are usually measured in the magnitude range of centimeters per year. Due to advantages of GPS survey over conventional methods, currently the most convenient method for measuring land subsidence is GPS method. Hence GPS technology has been implemented to monitor and measure land subsidence over the study area, total nine campaigns have been carried out by IIT Bombay GPS team during February 2004 to May 2006.

GPS Network for Monitoring Land Subsidence and GPS Monumentation

To monitor land subsidence in area of 19 km^2, total 31 subsidence monitoring stations were selected. Out of 31 stations, 4 stations have been established as reference stations. Reference stations are comparatively stable. Out of 27 deformation stations, 10 deformation stations are within the reservoir boundary and rests are out side the reservoir boundary as shown in Figure 1. The total study area is divided in to three zones, Critical zone, deformation zone and reference zone. Critical zone is a reservoir boundary, which is more liable to subsidy. Deformation zone is a zone around the reservoir boundary, which is likely to be deformed but the deformation would be less compared to deformation of critical zone. The reference zone is a zone, in which all the four reference stations are located. This zone is stable zone and very far from the study area. For this study IITB permanent GPS station is also used along with the other reference stations.

To achieve mm-level precision in detecting land subsidence, it is important to erect proper monumentation at each GPS station. GPS pillar must be rest on a firm ground, and in case of alluvial, it should be founded on firm strata. For this study, iron rod of 12 mm diameter was lowered up to 20-22 feet below the ground level. Concrete column of 1 m height was constructed below the ground level and about 0.75 m above the ground level (see Figure 2). Pipe fencing is erected around the pillar for the security of the GPS station point. Force centering



R1 to R10 Deformation Stations within Reservoir Boundary

1 to 17 – Deformation Stations outside the Reservoir Boundary

Fig 1: Local Network for Deformation Stations Showing Reservoir Boundary

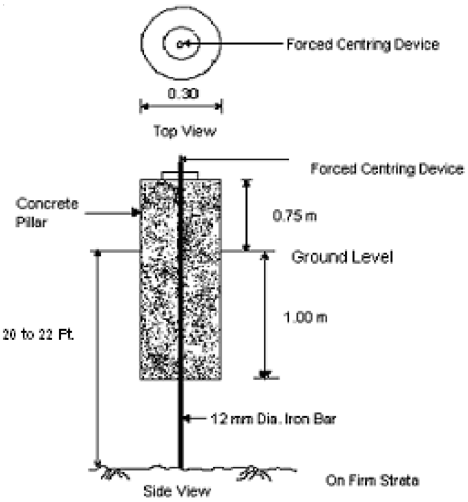


Fig: 2 GPS Monumentation

devices is provided over which GPS antenna is placed during the data collection.

Data Collection and Processing

Total nine campaigns have been carried out over this network to study land uplift and subsidence during February 2004 to May 2006 at an interval of 3 to 4 months. Each fieldwork period is spanning approximately one week. Geodetic dual-frequency GPS receivers, Trimble 4000 SSi with choke ring antenna and Trimble 5700 with zephyr geodetic antenna were used to collect the data. The reference stations were continuously running during the entire field campaign of GPS data collection. At each deformation station, minimum five hours of continuous GPS data was collected. The data were collected with a 15 second interval and elevation mask was kept 15 degree. Position Dilution of Precision (PDOP) Cut-off was set as 4.

The collected data and base lines were processed in the World Geodetic System 84 (WGS 84) reference system. Three International GNNS Service (IGS) stations were selected for constraining the solutions in the International Terrestrial Reference Frame 2000(ITRF 2000). IGS data files as well as precise ephemeris files were downloaded from IGS data bank, which were used for post processing the data. In addition to these, IITB reference station data is also used.

Collected data were processed with scientific GPS data processing Software Bernese Version 4.2, which has been developed by the Astronomical Institute of the University of Berne. This software is a sophisticated tool meeting highest quality standard of geodetic and further application using GPS as well as GLONASS (Hugentobler et al. 2001).

In first step, precise coordinates were obtained from IGS website for three nearby IGS stations, namely LHAS, BAHR and IISC. By tightly constraining these three stations, the precise coordinates of all the four reference stations along with IIT Bombay permanent reference station were calculated. After computing the reference stations coordinates, all 27-deformation stations were processed with two reference stations and IITB permanent reference station. Here the coordinates of IITB and two reference stations were tightly constrained to their calculated values in step 1. The process data gives coordinates and base lines both in Cartesian rectangular and geodetic coordinate system. The geodetic coordinates were projected on to the UTM grid to give results in Northing (m) and Easting (m).

In order to monitor land subsidence over the area, other factors responsible for land subsidence like cumulative gas extraction, water level, pressure depletion, temperature changes over the reservoir fields were also collected and studied. The relation between elevation changes over the different campaigns and other parameters were established.

Analysis of the Results

The precision estimated for the coordinates obtained with GPS is 4 to 5 mm for height and 1 to 2 mm for latitude and longitude for this work. It is observed that the vertical component (Height) is comparatively less precise than horizontal components. But this precision is enough for measuring land subsidence (Mousavi et al. 2001). To monitor general trend over the study area, elevations of all deformation stations between two campaigns are compared. For land subsidence study only difference in heights between two campaigns are enough to monitor change in elevation. GPS derived heights are ellipsoidal, and enough to monitor land subsidence (Abidin et al. 2001). Hence for this study, ellipsoidal height has been used.

Results of all the nine campaigns show that, there is effect of seasons on the GPS derived elevations, so the elevations for the same season have been compared to get the real picture of land subsidence over the study area. The elevations of same seasons May 2004, May 2005 and May 2006 have been compared and shown Table 1. From Table 1 and Figure 3 and Figure 4, it is revealed that, average change in elevation for stations within reservoir boundary is significant than the points out side the reservoir boundary. Subsidence is found to be 81mm for stations within reservoir boundary while only 17 mm is found for stations out side the reservoir boundary. Thus it can be concluded that deformation stations within the reservoir boundary are showing significant vertical deformation compared to deformation of stations outside the reservoir boundary.

Table: 1 Ellipsoidal Height for Deformation Stations

Deformation Stations		**Ellipsoidal Height in m.**			**Difference in Elevation in m During May 04 and May 06**
		May-04	**May-05**	**May-06**	
1	Deformation Stations outside the Reservoir Boundary	-50.561	-50.616	-50.5927	-0.032
2		-50.23	-50.246	-50.2388	-0.009
3		-51.341	-51.359	-51.3478	-0.007
4		-50.983	-51.02	-51.0451	-0.062
5		-50.649	-50.686	-50.6802	-0.031
6		-51.56	-51.597	-51.593	-0.033
7		-52.939	-52.985	-52.943	-0.004
8		-49.311	-49.327	-49.2843	0.027
9		-48.224	-48.194	-48.2426	-0.019
10		-47.919	-47.911	-47.9067	0.012
11		-49.502	-49.477	-49.467	0.035
12		-49.779	-49.778	-49.8137	-0.035
13		-48.385	-48.393	-48.4165	-0.032
14		-49.569	-49.588	-49.6082	-0.039
15		-50.552	-50.552	-50.5687	-0.017
16		-48.133	-48.17	-48.1449	-0.012
17		-50.726	-50.705	-50.7525	-0.026
		Average Change in Elevation out side reservoir boundary			**-0.017**
R1	Deformation Stations within the Reservoir Boundary	-49.778	-49.816	-49.8643	-0.086
R2		-49.538	-49.61	-49.6667	-0.129
R3		-49.395	-49.422	-	
R4		-50.513	-50.568	-50.5708	-0.058
R5		-49.973	-50.037	-50.0342	-0.061
R6		-49.747	-49.784	-	
R7		-49.819	-49.863	-49.8039	
R8		-50.118	-50.174	-50.1801	-0.062
R9		-51.109	-51.154	-51.168	-0.059
R10		-50.183	-50.282	-50.2946	-0.112
		Average Change in Elevation within reservoir boundary			**-0.081**
		Average Change in Elevation over the study area			**-0.049**

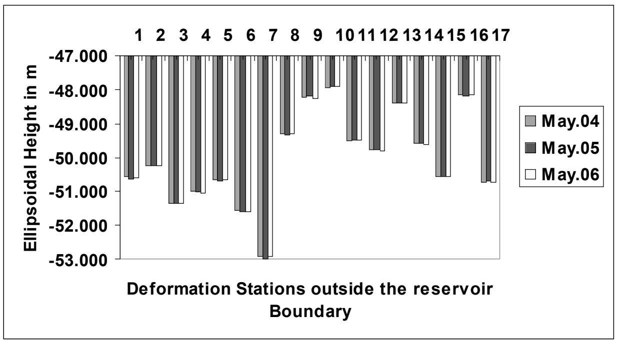


Fig: 3 Change in Elevation for Points outside Reservoir Boundary

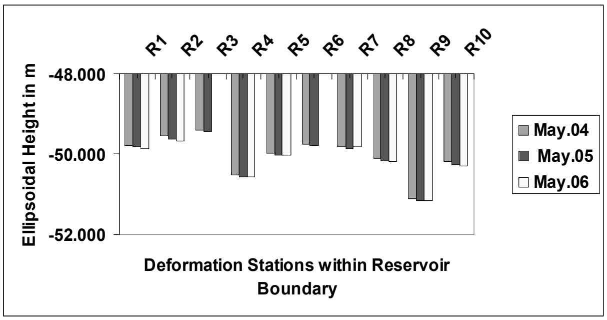


Fig: 4 Change in Elevation for Points within Reservoir Boundary

Effective (relative) subsidence is the difference between the average elevation difference of all deformation stations and average elevation difference of reference stations. Effective local subsidence is estimated during May 2004 to May 2005 is 41 ± 5 mm and 26 ± 5 mm during May 2005 to May 2006. The precision estimated for vertical height is 4 to 5 mm for this work. So the subsidence calculated may be erroneous by ± 5 mm. The change in elevations during May 2004 to May 2006 is found to be 67 ± 5 mm over reservoir boundary and overall subsidence including deformation stations outside the reservoir boundary is found to be 34 mm. This study was started in February 2004 and to study and monitor