From Geography to Physics: How does geography help students learn motion?

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Abstract. We have been developing modules for teaching graphicacy to middle and secondary school. In this paper we present the module that we have developed for teaching basic mechanics and physical geography at the secondary school level by using the Global Positioning System (GPS). The GPS units are presented as a powerful technology enabling students to learn basic ideas of motion, along with concepts of physical geography. We used the GPS units as data loggers to provide us spatial and temporal variables. The raw data thus obtained forms a good source for analysis of physical geography and basic mechanics. We provide some examples of the usage of such GPS units and resulting analysis that we have performed on the data. The use of technology in this way is a form of studio based education (close-to-life collaborative construction contexts). Such a context enables students to construct and analyze their own data, thus providing an opportunity to develop critical graphicacy along with the subject knowledge (physical geography and basic mechanics in this case). We also discuss the impact and significance of such studio based learning for science education.

1 Introduction

The concept of motion is introduced at an elementary level and forms much basis of the physics learning to come. The basic concepts in motion such as position, displacement, velocity, acceleration need to be understood in different contexts and representations. But numerous literature studies have shown that these concepts are prone to errors from students and even teachers. The comprehension of graphs of these dynamic quantities presents a formidable challenge to the students. Many studies mention the common problems that students encounter in visualizing these quantities [McDermott et al., 1987], [Beichner, 1994].

Understanding graphs presents a major challenge to the students, especially when given out of context. In *Critical Graphicacy* by Roth et al. [Roth et al., 2005] understanding of all forms of graphics is shown to be under In comprehension of graphs apart from the cognitive factors the design criteria also make a lot of difference. In this article we are reporting some activities that we have developed in context of motion with help of a low cost GPS unit along with rich geographical data in forms of maps and satellite images that are freely available on the internet. Such use of GPS devices has been reported by [Budisa and Planinsic, 2003], [Larson, 1998], [Biermann and Nelson, 2000]. The average cost of the GPS unit has come down considerably and technologies enabling the use of data obtained from the GPS have proliferated in computers, cars and mobile phones and other data collection devices. A lot of Free Software programs, along with proprietary ones are available which can interpret the GPS data meaningfully. The main programs that we have used in our study are Tango-GPS[1], which is a Free Software. Along with this we also have quite a number of Free Software libraries for geo-spatial tools like PROJ.4 and Free-GIS. Given the current trends the technology, the GPS may become a default feature in many of the electronic gadgets to come.

The use of GPS we think will also provide the students with idea about the magnitudes of the quantities involved. Also, use of GPS serves another purpose; that is of mapping the local area by students themselves. This will lead to collection of data for a Geographical Information System (GIS). Collection and collation of GIS data can lead to lot of other projects and activities by students.

In the rural areas in India most of the houses, road, villages are not mapped, the mapping itself will be of relevance in this area. We have done a few pilot studies for this in the Khalapur *taluka* of Raigad district near Mumbai. The preliminary results of this pilot activity are encouraging. The mapping of the local area can be an incentive for the students to work with the GPS units. Apart from the GIS data, the data logged in the GPS unit can be used to teach basic concepts of motion, connecting the it to real life situations. Teaching motion in such a context, where ideas from geography and physics and mathematics have been merged will present the students with good opportunity to make connections between the concepts which otherwise may remain disconnected. In this particular article we will be concentrating on aspect of teaching basic mechanics from the data that is collected.

2 The GPS technology

The Global Positioning System or the GPS technology was initially developed for military purposes, but it was then later released for civilian use. For the survey of GPS technology and its usage see the article by. Several technical monographs exists explaining the working of GPS and the interesting physics that is involved in its functioning. For a primer on the GPS technology please see [Cornwall, 2000]. But we need not be concerned here with the actual working of the GPS technology, but rather the use which can be made from data obtained. In spite of all the advanced technology involved in working of GPS technology,

[1] http://www.tangogps.org/

it offers the end user a very accurate determination of user's position on the Earth. The accuracy of the observations for the common hand-held GPS devices is about 5 meters, considering that the Earth is a sphere with radius of about 6400 km, this is an extremely accurate reading.

Some of the GPS units and now the smart phones come with their own maps and enable users to see their location on a base map, which can be Open Street Map, Google Maps or Google Satellite Maps. For the stand-alone units that we used in the pilot mapping studies, the data is stored on the device and can be retrieved on a computer. When this device is connected to a laptop, we can get a 'live' feed on the computer of our position, speed and direction in which we are heading. A lot of programs are available for this doing GPS/GIS related information.Tango-GPS is one of the programs that enables one to plot the GPS log files which are collected during a tracking.

2.1 Our GPS Unit

Some years back ($\sim$ 2007) we had developed a stand alone GPS unit Fig. 1. This was done during a hackers meet on GIS/GPS systems in Homi Bhabha Centre for Science Education. Mostly this unit was used for the pilot studies that were mentioned above. Whereas the commercial stand-alone GPS units are available from 15,000 rupees, our unit costs about 7,500 rupees. One of the needs for developing such a unit was that in commercial units, the unit is more of a black box, with almost no information about the electronics inside the box. The unit that was developed was based completely on concept of *free software* and *hardware*. All the design and specifications of the unit are available on request from one of the main developers of the unit . This will enable the spread of the development work that we have done to others seamlessly. The use of Free software and hardware in education forms one of the mandate of our Lab.

3 Physics from GPS Units

The basic data that all the GPS units generate have at least the following, apart from other data :

- Latitude
- Longitude
- Altitude
- Time-stamp

Most of the GPS trackers that we have seen, and the one developed by us, have a time base of 1 second. So what we essentially observe is the position of the unit on the surface of Earth with an interval delay of 1 second. This, along with the final accuracy of about ± 5 meters, are the limitations to use of GPS for very small distances travelled, but when longer time and distance is involved the process smoothen s out. All other quantities like the direction of travel, position on the ground, velocity is derived from this data.

Fig. 1. The GPS unit developed by us.

The sample data file that we have obtained from our GPS units has the following format:

```
19.647364,73.475067,287.5,0.0,87.6,5.7,2010-11-13T04:39:15Z
19.647365,73.475065,287.4,0.2,79.1,5.7,2010-11-13T04:39:16Z
19.647364,73.475063,287.2,0.3,71.6,5.7,2010-11-13T04:39:17Z
19.647364,73.475062,287.1,0.2,64.3,5.7,2010-11-13T04:39:18Z
19.647362,73.475055,287.8,0.1,57.9,2.3,2010-11-13T04:39:19Z
19.647358,73.475054,288.1,0.0,56.5,2.3,2010-11-13T04:39:20Z
19.647354,73.475058,288.1,0.0,55.6,2.3,2010-11-13T04:39:21Z
19.647351,73.475057,288.4,0.0,58.8,2.3,2010-11-13T04:39:22Z
19.647349,73.475056,288.7,0.0,58.3,2.3,2010-11-13T04:39:23Z
19.647347,73.475055,288.8,0.2,52.0,2.3,2010-11-13T04:39:24Z
19.647350,73.475051,288.8,0.2,45.0,2.3,2010-11-13T04:39:25Z
19.647351,73.475051,288.9,0.4,45.9,2.3,2010-11-13T04:39:26Z
19.647350,73.475045,289.1,0.1,48.5,2.3,2010-11-13T04:39:27Z
19.647351,73.475040,289.2,0.1,49.6,2.3,2010-11-13T04:39:28Z
19.647351,73.475037,289.2,0.1,50.6,2.3,2010-11-13T04:39:29Z
19.647350,73.475033,289.4,0.0,52.2,2.3,2010-11-13T04:39:30Z
19.647349,73.475029,289.4,0.1,53.1,2.3,2010-11-13T04:39:31Z
19.647349,73.475025,289.5,0.2,46.8,2.3,2010-11-13T04:39:32Z
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The first three entries in each row are the latitude and longitude and altitude, whereas the last entry is the time stamp. These readings were taken near Kasara railway station near Mumbai. The data above can be plotted on in tangogps, and the result is as shown in Fig. 2.

The same track can be overlayed on a satellite map As is seen in Fig. 2 we see the full track of a vehicle with all the turns and twists. All the data required to analyze this path is available to us in terms of the log file of the track. When a GPS unit is attached and has a fix on the satellites, the TangoGPS interface provides us with our speed and heading (direction in terms of degrees with North being 0^o, and South being 180^o), altitude in meters.

How do we process this data? If seen from an analysis point of view each line of the file contains the data in following way.

$$(X, Y, Z, T) \tag{1}$$

Thus we have the data for the position as a function of time. But the format of X, Y are in degrees of latitude and longitude, so before it can be used for measuring quantities in terms of length units a simple conversion has to be done. The time difference between each measurement is 1 second.

The formula for conversion from one coordinate system to other are well-known.

For junior students this conversion may be directly given, whereas for the senior students they can be asked to analyze why this particular transformation

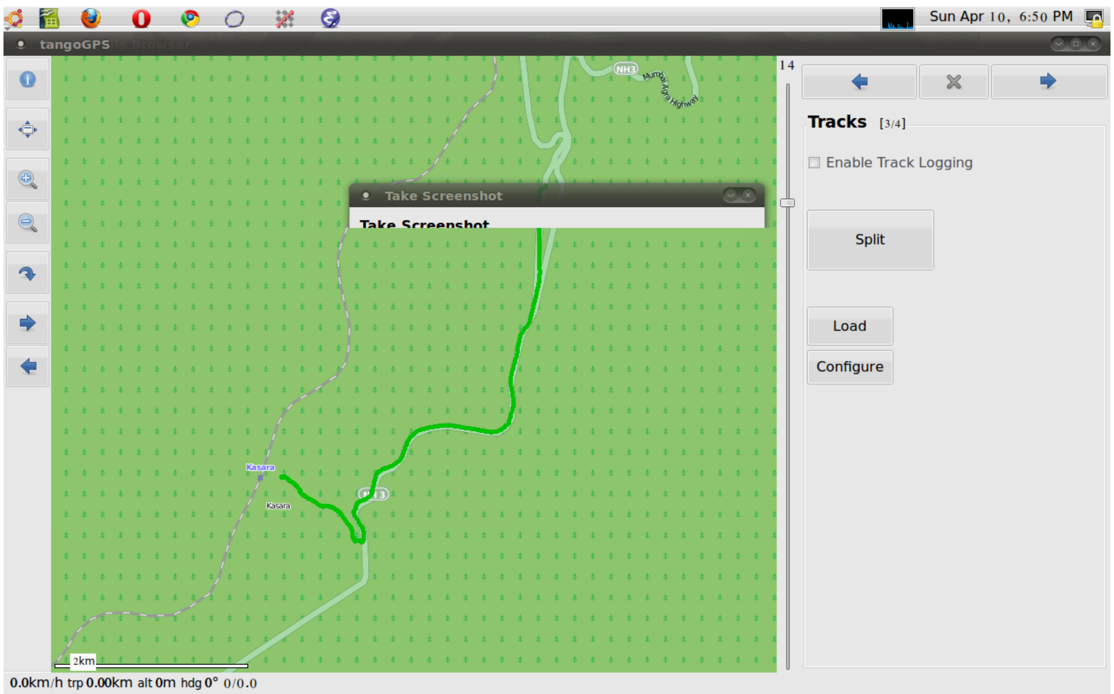

Fig. 2. A sample GPS track loaded in TangoGPS, taken near Kasara railway station. The background map is from Open Street Map (OSM)

Fig. 3. The same track as Fig. 2, but displayed with a satellite map of the surrounding.

was chosen. This can lead to further questions about the shape of Earth and the units that we use to measure it.

3.1 Processing the data

Once this conversion is done we have our data in meters instead of degrees of latitude and longitude. The altitude Z does not require a conversion as it is in already in meters. Thus we have the variables that we have mentioned

$$(X_i, Y_i, Z_i, T_i) \tag{2}$$

corresponding to each time the GPS device has taken a reading.

Thus we have the basic data of position as function of time for further analysis. From this deriving other quantities like velocity, acceleration, momentum and force [later two if the mass of the moving object is known] is simple. This we think is one of the best data-logging that is possible, in which the students can relate to the data obtained to their sense experience.

This can be done in two ways. One is that we ask the students to actually plot the graphs of displacement versus time, as they themselves have walked.

This particular activity will perhaps help to address one of the well know difficulty that children tend to associate the actual path taken to graph of position versus displacement. This particular difficulty has been reported widely in following studies [Beichner, 1994], [Leinhardt et al., 1990], [McDermott et al., 1987].

4 From Concrete to Abstract and back

According to stage theory of Piaget the transition from concrete operational to formal operational stage presents during the middle school level. In the concrete operational stage the child understands the world from experiences that are concrete, whereas in the formal operational stage they think more abstractly, logically and can reason from given situation. A concept may is linked to both concrete and formal operations. For example we can get distance and speed and forces as concrete sense experiences when we are moving from one place to another. The same experience can be represented on a graph, which would be very formal presentation of the experience. Only when we are able to make the transition between the concrete to formal and back again, we can say that we have learnt the concept. In case of motion this would mean that we should be able to translate our motion experiences to graphs, and in the other case we should be able to make sense of graphs of motion by knowing what kind of motion it would represent.

According to the constructionist theory as put forth by Seymour Papert in his book *Mindstorms: Children, Computers and Powerful Ideas* [Papert, 1980]. The difference between the *contructionist* as opposed to *constructivist* approach is Papert's own words is [Papert and Harel, 1991]:

> Constructionism–the N word as opposed to the V word–shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of the learning. It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe.

In a constructionist theory all the learning happens in context of a construction. The construction tasks that a learner has, can be different. Each construction opportunity will enhance the learners understanding of the concepts involved in that construction activity.

Experience with GPS device allows us to do this translation from concrete to abstract and back. Mapping of an area is a very concrete experience that students can have and this is something which directly relates to their sense experience. Mapping of an area with aid of GPS also allows students to see their local area in a much larger context. Once this data is put on a map, we can relate to our local experience to a global one.

5 Relating GPS/GIS to graphicacy

The use of GPS/GIS units can relate to different topics and subjects at different grades. Some of the concepts and the subjects that can be touched upon by the use of this technology are illustrated in Figure 4. Many of the concepts appear in different grades and in different subjects. All these concepts can be linked through the GPS technology. And this relation will not be a one way relation, but rather it will be mutually enhancing relation. By the use of GPS technology the transition between concrete and abstract will be reinforced. Also the linkages that the concepts have in different subjects will get enhanced by using.

This something that we wanted to be addressed in the larger study under which this particular activity was done.

In an earlier study we have reported an quantitative analysis of Indian textbooks, from grade 5 to grade 10 [Dhakulkar and Nagarjuna, 2011]. The subjects included textbooks of science, mathematics and social science. sample of textbooks that we had chosen for this study were the National Centre for Educational Research and Training (NCERT) textbooks. NCERT is the apex body for designing curriculum and textbooks in India. The NCERT textbooks provide a framework for all other textbooks that are produced in the country. In the analysis we found out that the graphs in the textbooks are under-represented and underused. The graphs when present were not linked with other subjects, even though many times there were ample opportunities to do so. Also we found that there were very little scope for students to collect and analyze the data collected by themselves.

Various different studies including the National Curriculum Framework (NCF) 2005 indicate that the students must be empowered to collect and analyze their own data []. If the subjects in the school education like science, mathematics, and humanities do not include a reflexive component that allows students to critically evaluate the knowledge claims, they will always be subject to some form of indoctrination [Roth et al., 2005]. As the NCF 2005 [NCF, 2005] puts: "Science education in India, even at its best, develops competence but does not encourage inventiveness and creativity . . . inquiry skills should be supported by language, design and qualitative skills. Schools should place much greater emphasis on co-curricular activities aimed at stimulating investigative ability, inventiveness and creativity, even if these are not part of the graduating exam." Education for a critical graphicacy would mean providing students with the opportunities to interrogate the different means of representing the world and to question the different power relations that are thereby constructed [Roth et al., 2005].

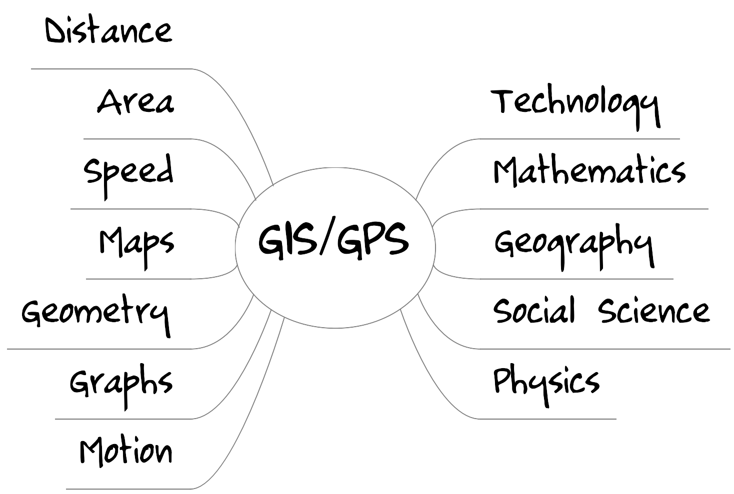

Fig. 4. Some of the concepts and subjects to which we can relate to by GPS/GIS technology.

6 Some of the suggested acitivities

From the few studies that have been reported we present some of the activities that can be performed by the students using the GPS units. These activities were

6.1 Mapping of the local area

6.2 Putting GIS information in the mapped area

6.3

The concept of vectors plays an important role in developing conceptual structures in regard to motion at the elementary grades. [Larson, 1998] gives an intersting example for use of GPS for activities in which one tries to measure the displacement vectors.

We had been inspired by the outdoor vector lab as suggested by [cite]. So we did some experiments with children in rural schools.

6.4 Walking, Jogging and Running

6.5 A view from the bicycles and motorcycles

6.6

6.7 Travelling the local train

6.8 Flight

7 Implications and Discussion

Science and mathematics education cannot ignore the existence of modern devices and technologies if we have to keep up to date with the changes that surround us. Use of such technolhogies will enable students to generate their own 'real' world data as has been suggested in NCF 2005 and other literature. What we have tried to emphasize in this article is how a technology like GPS/GIS can enable students to collect their own data, analyze the data, make connections from across subjects and across grades. It has been suggested by Monk that graphing must be repeatedly encountered by students as a means of communication and of generating understanding, as the students move across the grades [Monk, 2003]. The activities that have been suggested can be used to make linkages which would be otherwise difficult to make. Depending upon the grade of the students the activities can be concrete or abstract.This we think will enhance an aspect of *Critical Graphicacy* as suggested by Roth [Roth et al., 2005]. Using such technologies will enable students to learn the concepts involved in a much better way from what they will learn passively in the textbook.

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