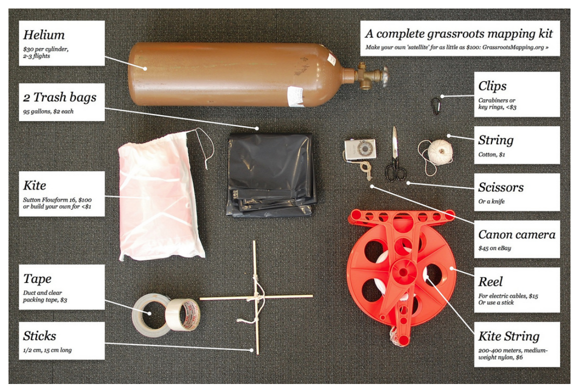
Chapter 6

The Grassroots Mapping tool chain

6.1 Balloon and Kite Aerial Mapping

As discussed in Section 5.4, prior works in kite and balloon mapping make it redundant to discuss the advantages of such techniques beyond to say that they are easier and less expensive than aircraft or satellite-based imagery sources. However, the particulars of the equipment desiged for Grassroots Mapping projects have emphasized yet lower cost, ease of use, and ease of reproduction than many existing designs, and a discussion of these decisions is relevant.



Due to the distinct compromises of each technique, I recommend that those attempting to capture aerial imagery equip themselves to use both balloons and kites. Luckily, the techniques share much of the same equipment, and it is possible in many places in the world to assemble a basic but complete kit for under $150. I have done so in surprisingly unlikely locales, such as the West Bank in Palestine, Lima, Peru, and Kutaisi, Georgia.

6.1.1 Balloon mapping

Helium is a limited and non-renewable resource, and obtaining it in the quantities necessary for aerial photography can prove challenging in the more remote parts of the world. 250 cubic foot tanks are most common, but are too heavy to carry without a wheeled dolly, and do not easily fit into cars or buses. They are also excessive, providing enough helium for between six and ten flights with a typical payload. If available, 80 or 120 cubic foot tanks are preferable, typically sold in the United States for $45 and $60, respectively. Those constructed from aluminum are especially convenient, being far lighter and easier to transport. Costs vary, depending on the distance from

Table 6.1: Comparison of balloon and kite mapping techniques. Despite the challenges and higher costs of balloon mapping, typical extents of a balloon map are far greater due to the higher altitude of flight, and due to a balloon's tendency to fly vertically in low winds, it is much easier to image the correct area. In the largest Grassroots Mapping project in the Gulf of Mexico, more than 60% of maps to datewere made with balloons, and kite flights have typically had a much lower success rate.

Type	Kite	Balloon
Altitude	300m	1400m
Extent	several hundred meters	>1km is common
Control	hard to target imagery - difficult in winds <45kph or <10kph	very fine control on windless days - difficult in winds >10kph
Payload	<2 kg	<300g
Time constraints	best winds in early afternoon	lowest winds at dawn
Portability	foil kites pack down to 1 liter size	helium tank and fragility of balloon limit portability, access
Tether angle	poor, camera altitude as low as 1/5 of tether length	in windless conditions, flies vertically; very sensitive to wind
Durability	excellent, no consumables	very poor; balloons pop regularly
Cost per flight	none	$15-35 per flight dependent on helium costs
Initial total cost of kit	$100-400 depending on kite and tether material	$150-500 depending on choice of balloon and tether material

Table 6.2: Comparison of balloon type options

Type	Cost	Typical # of uses	Permeability
5-foot polyurethane advertising balloon[1]	$140	hundreds?	Deflates 1-3% per day
8-foot[2] **latex weather balloon**	$25	up to 10 if careful	remains inflated for several hours; this weakens the balloon
Trash bags	$2	2-3	1-2 days if thicker (3 mil) plastic is used

[1] Available from Southern Balloon Works, southernballoonworks.com
[2] '8-foot' denotes burst diameter, actual filled diameter during use is approximately 4 feet

major helium sources such as the United States and Russia, but I have found large, 250 cubic foot tanks available for rental at approximately $250 each in Bethlehem, in the West Bank, and for approximately $300 in Lima, Peru, both at party stores. Gas supply vendors may offer somewhat lower prices, but sometimes require a permanent customer account, and can be reluctant to rent to non-industrial customers.

To further reduce costs, it is possible to use large high density polyethelene trash bags, of the kind typical worldwide. Two extra-large ninety-nine gallon bags suffice to lift a small camera and string to thousands of feet. Bags may be sealed shut with tape and filled without modification, or cut open and reassembled into tetrahedral shapes to minimize the surface area to volume ratio and provide greater lift. In addition, trash bags may be left inflated for several days without stretching or damaging the plastic, unlike latex balloons. However, helium leaks slowly through the plastic, and even relatively thick 2.7 mil plastic bags will lose most of their lifting power after a day or two. Trash bags are available for less than a dollar anywhere in the world, as is the clear plastic packing tape which may be used to seal them closed.

Figure 6.1: Testing trash bag balloons with the Department of Play working group on the MIT campus in Cambridge, Massachusetts.

6.1.2 Kite mapping

Kites present an opportunity to loft cameras at near-zero cost — materials for making kites can be found for less than a dollar, or recycled from waste. However kites can be particularly challenging to fly stably and difficult wind conditions often make for a frustrating and exhausting day of attempted mapmaking. With this in mind, I have looked to the experience of KAP enthusiasts in choosing a respected standard in highly portable, reliable, and flexible flight: the Sutton Flowform. This 'sled kite' has no rigid spars and even its 16 square foot model can be packed down to fit in a small sack. Flowforms can be flown at a wide range of wind speeds and the Flowform 16 can lift tens of kilograms in ideal conditions. However, its $100 cost makes it somewhat beyond the means of many map makers. Therefore, whenever possible I have encouraged my collaborators to apply local traditional kite designs, often with great success. In Lima, Peru and Ramallah, Palestine, local designs were cheap and effective, the only issue being that they had to be scaled up to a size which could lift the approximately 300 gram payload. Kite building makes for an engaging and fun activity while reyling on local means of production for an aerial platform.

6.1.3 Camera and intervalometer

Throughout the design of the Grassroots Mapping Kit I have emphasized low cost; therefore, taking a note from the page of low-cost aerial photographers like Oliver Yeh of 1337arts.com, I recommend an inexpensive 'point-and-shoot' camera, ideally of Canon's A or SD lines (the SD series is sold under the brand IXUS in Europe). While these tend to be in the 7-12 megapixel range, they are typically only 200-300 grams and are durable and compact. Such cameras can be found second-hand on eBay.com for as low as $50. Despite resolution, lens choice and stabilization advantages of more expensive models, consumer-grade compact cameras of this sort are widely available, and their image quality is sufficiently high that they make a good balance of weight, image quality, and cost — the latter being of especially high importance since we have occasionally lost entire kits due to accidents such as improperly tied knots or sudden immersion in water.

Figure 6.2: César, a CEDRO student, completes a kite of his own design in Juan Pablo II.

Consumer-grade Canon cameras also benefit from the active open-source hacking community's efforts to provide an alternative firmware with advanced features such as scripting. The Canon Hacker Development Kit (CHDK), which is stored on the camera's SD memory card, makes possible a script which I have adapted to trigger image capture every 5-10 seconds. The script, referred to as an intervalometer, is available for download at `http://wiki.grassrootsmapping.org/show/BalloonAerialPhotography`. Alternatively, many participants have found it easier to set their camera to 'continuous mode' and hold down the trigger button with a rubber band. This captures an image must faster; typically once per second, filling up the memory card and using more battery power. However, it has the benefit of simplicity, and of working with almost any brand of camera.

Table 6.3: Balloon mapping kit pricing

Mid-range estimate		Minimum estimate	
8 ft diameter weather balloon	$30	2x100 gallon trash bags	$3
2000 ft. nylon string	$50	2000 ft. nylon string	$24
cotton string, duct tape, packing tape, rubber bands	$20	cotton string, duct tape, packing tape, rubber bands	$10
Soda bottle, cardboard	$2	Soda bottle, cardboard	$0
Scissors	$8	Scissors	$2
Camera	$80	Camera	$50
Clips etc.	$5	Helium	$55
Helium	$55		
Total	$250	Total	$144

Table 6.4: Kite mapping kit pricing

Mid-range estimate		Minimum estimate	
Sutton Flowform 16	$110	Trash bags & sticks	$3
1000 ft 200 lb dacron or spectra string	$50	1000 ft nylon string	$20
Kite reel	$20	Soda bottle, cardboard	$2
Soda bottle, cardboard	$2	Scissors	$2
Scissors	$8	Camera	$50
Camera	$80	Clips etc.	$5
Clips etc.	$5		
Total	$275	Total	$99

6.1.4 Enclosures and suspensions

In order to attach the camera to the balloon or kite, KAP enthusiasts typically make use of a 'Picavet suspension', an arrangement of one continuous string on a series of rings or pulleys. This has the exceptional ability to keep the camera level and relatively stable even in turbulent conditions. However, experience in Peru[1] showed that constructing a working Picavet and maintaining it without tangles can be difficult, especially under adverse conditions such as long crowded bus rides, limited construction materials, and excited young participants. In the light of these challenges I have developed a more basic but still serviceable alternative called the 'Soda Bottle Rig' which as an added feature protects the camera from light impacts. The basic design can be seen in Figure 6.1.4, and includes a pair of 'wings' placed approximately 30 degrees apart, which serve to stabilize the enclosure against the wind, reducing radial blurring in the aerial images.

The soda bottle rig is convenient to carry, and makes immediate visual sense to observers, unlike the confusing array of crossed strings in the Picavet. The additional swaying of the Soda Bottle Rig in fact results in greater extent in the resulting maps, though resolution drops dramatically as photographs become more oblique. This does allow map-makers to decide whether to sacrifice consistent resolution in favor of a larger extent, however. In addition, while it works well for the typically horizontal tether of a kite, the Picavet suspension is rendered largely useless on a vertical tether, as the two mounting points are placed inline, one above the other. The Soda Bottle Rig has been used through the BP oil spill mapping project described in Chapter 8. Still, experienced aerial photographers may achieve better results with the Picavet suspension in kite photography.

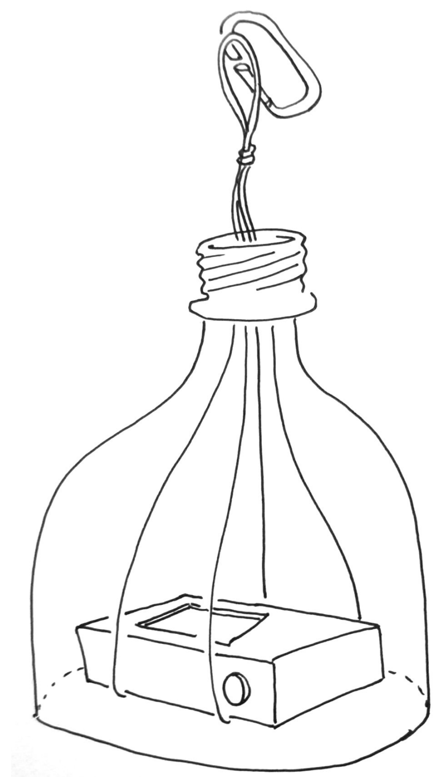


Figure 6.3: The Soda Bottle Rig

6.2 Map processing and publication

Once aerial imagery is captured, software must be used to distort or 'warp' the photos and combine them to fit a projection. This essentially maps every pixel of the source imagery to a corresponding position on the earth's surface, allowing for correlation to other maps and sources of geodata. As no existing tool has so far met all of the design requirements I had compiled from the pilot project in Lima, Peru — such as cost, ease of use, low barrier to entry, and performance (see Section 5.3) — I developed a unique tool and associated mapping framework with the goal of making DIY cartography simpler, cheaper, and more inclusive.

[1]See Chapter 7

6.2.1 Web-based orthorectification and warping

The collaborative mapmaking process conducted in Lima in January 2010 demonstrated that the primary barrier to producing map imagery was the orthorectification process. While in Lima, participants made use of Adobe Photoshop CS4 as well as the Map Warper software discussed in Subsection 5.3.1. Attempts were made to instruct residents in the use of these tools, but were met with limited success due to the limited availability of computers powerful enough to run Photoshop, latency in internet access, and most of all, the obscure interfaces which users were required to learn.[2]

6.2.2 Cartagen Knitter

The Cartagen Knitter software, developed in the months following the project in Lima, makes this possible. Using the Cartagen framework along with an HTML 5 distortion technique prototyped by Steven Wittens of http://acko.net [84], I created an interface for users to upload images as overlays on an existing base map, typically OpenStreetMap vector data or a source of existing satellite imagery. Users then manually distort an image by dragging the corners with the cursor. Tools for rotating, scaling, and adjusting the transparency of images were added, and the tool was tested and refined in a variety of workshops and mapping projects over several months.

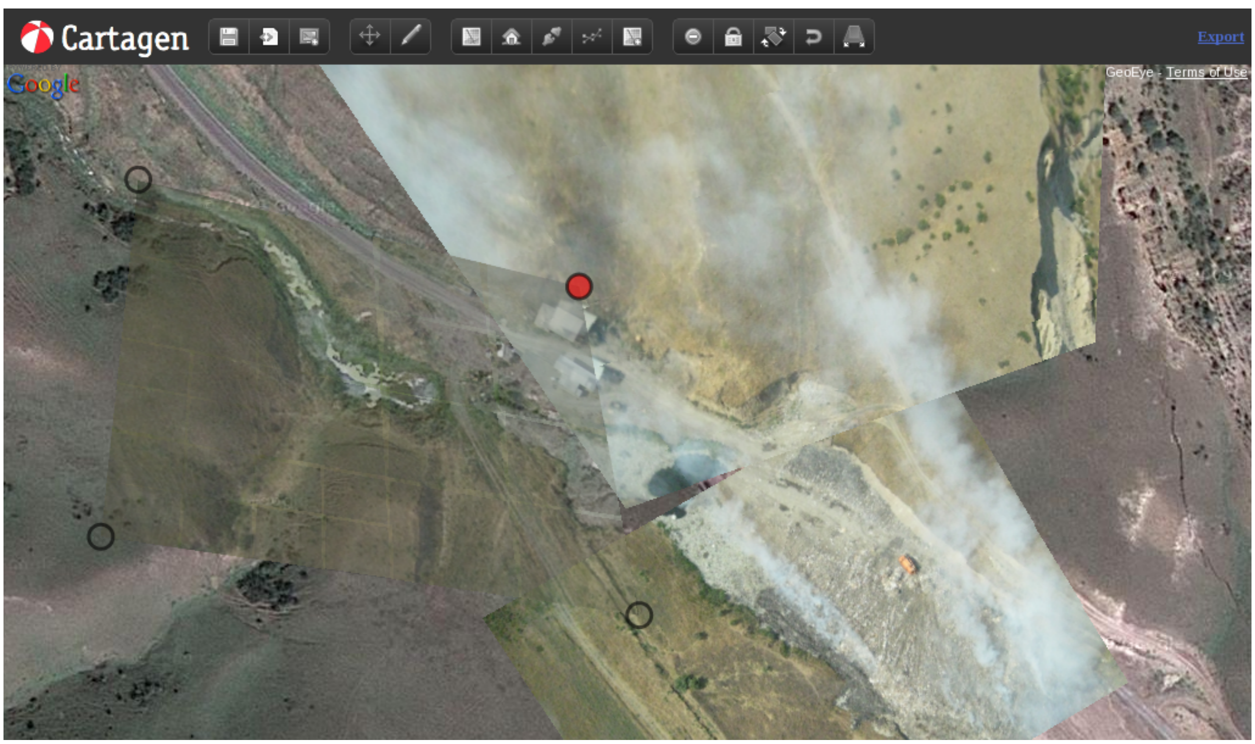


Figure 6.4: Warping aerial imagery over a base layer from Google Maps. The imagery was captured with students and OpenMapsCaucasus staff in Rustavi, Georgia, using kites. Note that imagery orthorectified against Google satellite data may be considered a derivative work; a base layer available under an open license is preferable.

[2]See further discussion in Section 7.2

Cartagen Knitter makes several unique choices about how users orthorectify imagery. The first is that it emphasises orthorectification of individual images against a base map, rather than initial stitching of images into a larger composite image and subsequent orthorectification and warping of that larger image. This decision was based on the relatively high computing resource requirements of manipulating a single higher-resolution image, given Knitter's emphasis on low-resource usage. Additionally, Eric Wolf of the US Geological Survey has found experimentally that the composite, or mosaic, technique suffers from a loss of accuracy. His analysis demonstrated a loss of accuracy of 'nearly 100% in both location and orientation'. [85]

The second design decision which may seem curious is the emphasis on a completely manual orthorectification interface: no automated interest point finding or matching is used, despite the availability of such software (i.e. Hugin, Photosynth, Vision Workbench, etc.). Even Map Warper automatically warps images using the **gdalwarp** utility, though it asks users to identify ground control points to determine how to perform the warping. In practice, however, the use of such automated techniques did not result in good mosaic images, nor was the process of stitching, warping, and orthorectifying easy to understand or troubleshoot for non-technical users. Hugin provides for rectilinear warping, which does not assume a fixed camera position, but in order to successfully apply this configuration in the graphical user interface requires a 'hack' and existing documentation is either unclear or obsolete. Additionally, desktop programs such as hugin or Photosynth may be difficult to install in an internet cafe, which users in Lima might find necessary.

6.2.3 Rubbersheeting

The manual orthorectification process is based on an interface paradigm known as 'rubbersheeting', due to its similarity to physically stretching rubber sheets over a reference map. The distortion used in Cartagen Knitter is technically known as a projective warp, unlike the polynomial 'affine warp' employed by Map Warper, or the simple stretching used by Google Earth. While considerably more computationally intensive than a first-order affine warp, the projective warp results in an exact mapping of four corners of the warped image to latitude/longitude coordinate positions. By contrast, Google Earth can only exaggerate the height and width of an image, while Map Warper attempts to find a best fit, accepting measurable inaccuracies in the placement of each point. While affine warping can compensate for spherical distortions such as lens effects, in practice, it was difficult and frustrating for users to place control points which did not actually bind a position in the warped image to a position in the base image. Many users attempted to compensate by placing deliberately incorrect control points. [9]

Direct placement of the four corners of an aerial photograph on a base map was a much more direct means to orthorectify images. While this does not allow for spherical or nonlinear distortions, future versions could accommodate further subdivision of an image into a triangulated mesh; this would allow for more subtle adjustments of the interior of an image without disturbing the positioning of the outer edges of the image. Additionally, known lens geometry, extrated from Exchangeable Image File Format (EXIF) data, could be used to reduce lens distortion automatically.

The resulting interface was both easy to explain to users and faster than alternatives. Non-technical uses and even children have used the Cartagen Knitter to produce large maps in just a few hours, and the export feature added recently has enabled finished maps to be saved in the GeoTIFF and TMS standards, and viewed in common tools such as JOSM, facilitating integration into existing workflows.

6.2.4 Cartagen: an alternative architecture for digital maps

Beyond the ability to orthorectify imagery, Cartagen is a fully-fledged cartographic scripting environment and renderer. It can draw vector data onto a pixel grid at over 10 frames per second on most computers, and follows the conventions of an animation framework rather than the more static assumptions of the typical mapping system. As the user interacts with a Cartagen map, features are updated and drawn continuously. This negates the need to cache or otherwise store raster representations of map data, and sidesteps many of the assumptions and limitations of the modern mapping software stack. This alternative geostack is one of the most unique aspects of the Grassroots Mapping tool chain, and is also what makes possible the rapid feedback loop of the Cartagen Knitter, as there is no 'render' or 'warp' step — the effect of the user's orthorectification is visible in real time.

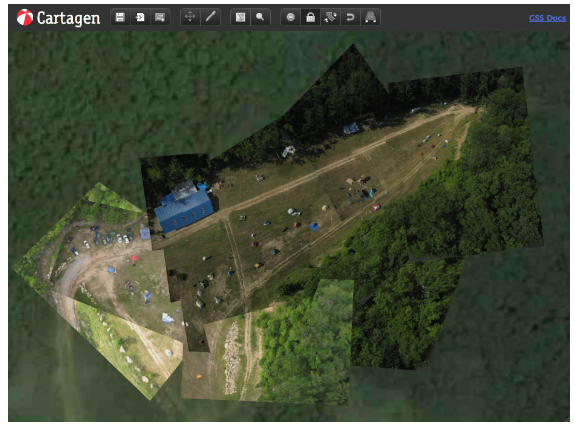


Figure 6.5: A map of Wiley's Last Resort in Kentucky, produced in Cartagen Knitter with imagery captured from a remote controlled aircraft by Stewart Long.

Dynamic local rendering

As discussed in Section 5.2, most digital maps today employ a server-side caching mechanism providing a tiled image collection. The tiles are assembled seamlessly in the user's browser, and zooming is accomplished by maintaining multiple tilesets — one for each zoom level. The resulting system scales predictably, as tiles do not vary dramatically in file size, and can be served using a standard web server such as Apache, or even stored locally for offline use. While this works well for a single dataset, it commits the map to a single representation. Multiple tile sets can be stacked, and polygons can be overlaid, but the end user cannot edit the tiles or manipulate the data they contain — the map is essentially static. Compressing data into tiles strips them of their metadata and authorship information in favor of scalability and consistency, but such a tradeoff may no longer be necessary. For companies such as Google or Yahoo, this represents a form of control over the map data; instead of distributing the source data, their use of tiles protects their intellectual property from re-use or adaptation.

I designed Cartagen to sidestep many of these requirements, and to allow users to participate as first-class citizens in the authoring of maps. Using new techniques made possible by widespread browser support for HTML5 and specifically the Canvas element, Cartagen can create maps which are not pre-rendered, but generated on-the-fly. This frees the map from a single projection or representation, and enables a more dynamic, interactive, and narrative cartographic style. Discrete vector data (made up of points, lines, and areas) is downloaded in JSON format just once, and displayed at any scale and in any style. HTML5 adoption in open-source web browser frameworks such as WebKit, along with recent dramatic increases in JavaScript execution speed makes this local rendering possible, and eliminates the need for browser plugins like Flash or Java. This makes dynamic mapping possible even on mobile devices such as on the iPhone, Android, and Windows Mobile platforms, many of which implement these new standards.

As an added advantage, Cartagen performs much of the computation of map rendering and display locally, reducing dependence on high-latency internet connectivity. It also allows users to easily download data and view or edit it offline. These features make it particularly appropriate for use in developing countries or in crisis situations. When multiple users access a map simultaneously, an additional benefit is that any number of users may edit simultaneously — a feature which has dramatically accelerated the speed of stitching a map in field tests.

Cartographic design with Geographic Stylesheets

Though other mapping frameworks such as OpenLayers have made use of the canvas element as well as other alternatives such as Scalable Vector Graphics (SVG), Cartagen was among the first to appropriate the 'content vs. style' paradigm of HTML/CSS, in order to allow users to style maps using a simple CSS-like syntax, known as GSS. This took advantage of Cartagen's live-rendering ability to render features in response to simply defined, tag-based style definitions. Cartagen is one of the most easily customizable map rendering frameworks, and is specifically designed to leverage widespread literacy in HTML/CSS, thereby lowering barriers for those interested in using geospatial design tools.

```
leisure: {
    fillStyle: "#2a2",
    lineWidth: 3,
    strokeStyle: "#181"
},
park: {
    fillStyle: "#2a2",
    lineWidth: 3,
    strokeStyle: "#181",
    pattern: "images/pattern-water.gif"
},
coastline: {
    strokeStyle: "#57d",
    lineWidth: 20
},
highway: {
    strokeStyle: "white",
    lineWidth: 7
}
```

Figure 6.6: An example GSS stylesheet, demonstrating the simple syntax it uses to specify map styles.

6.2.5 Architectural advantages of the Cartagen framework

As a fully scriptable cartographic environment, the Cartagen framework was uniquely suited for building an image orthorectification tool. The Canvas element is essentially a pixel raster, but because Cartagen's primitives are vector objects stored as points and polygons, it there is no need to resample source imagery while performing distortions or transforms. Resampling and compositing occurs only once a map is completed and exported, reducing data degradation due to repeated resampling. While in Photoshop, a powerful computer is required to store, manipulate, and export

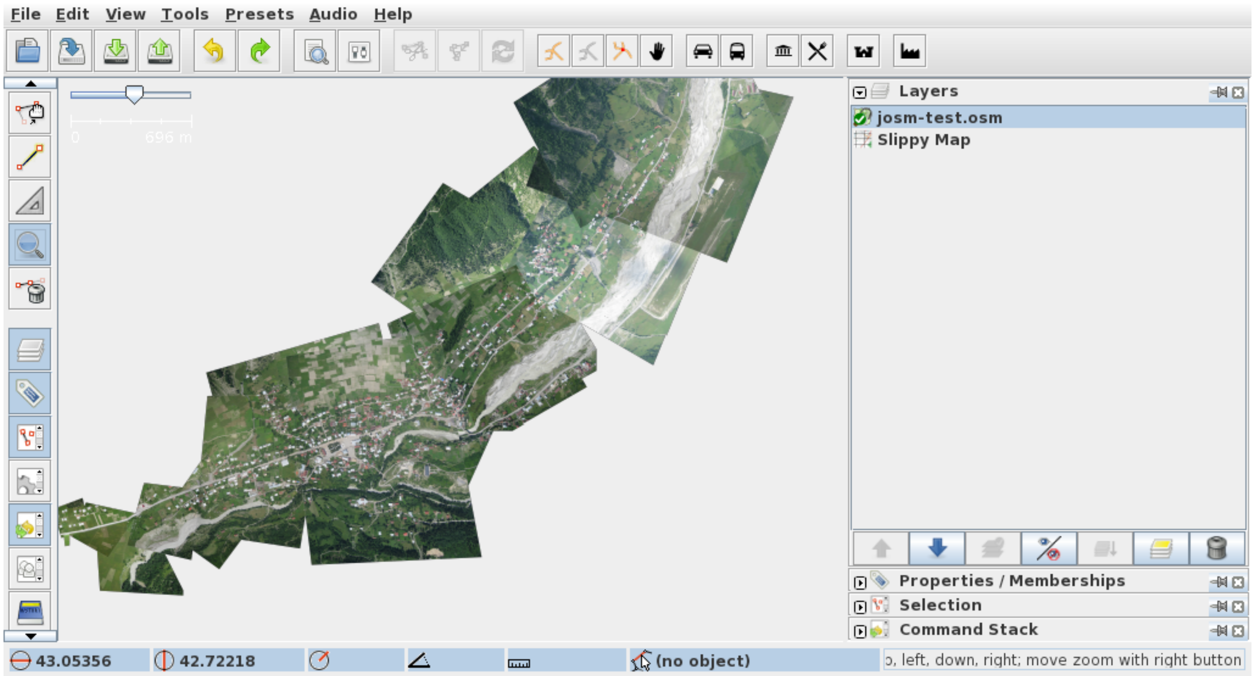


Figure 6.7: Viewing output from the Cartagen Knitter in JOSM for contribution to the OpenMap-Caucasus project in Georgia. Read more in Section 10.1.2

a map of any considerable size[3], Cartagen can be used to stitch maps using a laptop or even a low-power netbook. While editing, users see a lower-resolution preview rendered only at the size of their browser window. The final, high-resolution composite image is exported using ImageMagick on the server side. This lowers the cost of the equipment to process and orthorectify aerial imagery by thousands of dollars.

In a sense, rendering is at the heart of the argument for participatory cartography. If mapping is to be a means to advance an agenda, develop a narrative, or create a communal self-image, it must allow for diverse forms of representation. We have the divergent data and the means to collect, collate, and publish it what we lack is a way to represent it in layered, interactive, and radical new ways. Cartagen's unique architecture allows it to describe a constantly changing data set with both technical and epistemological consequences. Once maps are rendered in the browser window instead of by Google or Yahoo, users are empowered to design, interpret, manipulate, and publish that data in new and compelling ways.

6.3 An iterative and collaborative approach to tool design

In order to develop tools which respond well to user needs, I employed a collaborative process, testing various tools in a variety of contexts. Combinations of tools were tested with participants from Lima, New Orleans, and Rock Creek, West Virginia. Interviews and notes were used to develop new tools which built on the strengths of existing off-the-shelf systems such as Photoshop,

[3]Some maps produced during the BP oil spill project were over 50,000 px in each dimension

Hugin, and Map Warper. The same is true for the physical tools such as the balloon and kite kits, including the camera housing, reel construction, and auto-triggering setup.

In the case of the camera housing, Grassroots Mapping community members have iterated and improved upon the soda bottle enclosure, discussing and testing alternatives on the mailing list, and even posting videos of tests. Pat Coyle, a mailing list member, published a narrated demonstration of a soda bottle enclosure with improvements such as a window to access the camera controls and a small bungee cable to stabilize the camera against the inside of the bottle. In another example, Mathew Lippincott prototyped solar-powered hot air balloons constructed from painter's plastic sheeting, conducted pigmentation and lift tests to determine suitability for carrying cameras. The tests and builds were held at a public event in Portland, Oregon, and videos and instructions were posted online.

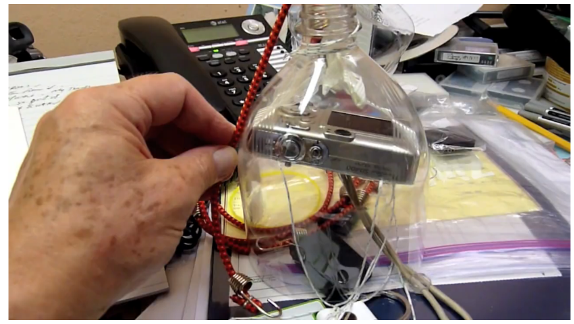


Figure 6.8: Still frame from Pat Coyle's demonstration on YouTube [20]

My own regular testing of new tools at the MIT campus, as well as repeated attempts to orthorectify the resulting imagery, grounded the software development in concrete usage and experience, and a workshop at the Google campus in Mountain View in April 2010 included a collaborative hacking session aimed at identifying and resolving bugs and adding new features in direct response to the day's mapping efforts. As development of the Cartagen Knitter software progressed, mailing list members with a variety of needs chipped in with suggestions, bug reports, and feature requests, including the ability to lock images when finished warping, revert to original image proportions, and use keyboard shortcuts for common commands. Combined with test flights and experimentation by active community members such as Pat Coyle and Mathew Lippincott, the tools have progressed from partially functioning prototypes to relatively mature technologies with understood abilities and limitations. It was the multiple deployments of the tools in the Lima, Peru and BP oil spill case studies, however, which put them to the test in real-world applications, and forced us to push the tools' abilities to their limits.

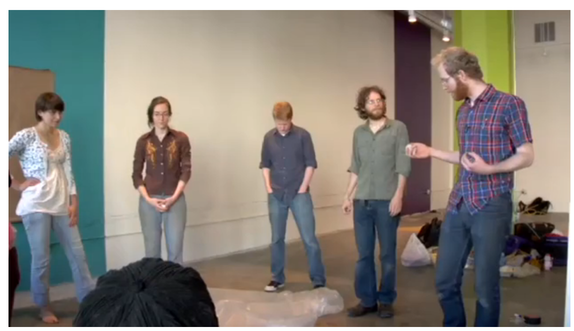


Figure 6.9: Mathew Lippincott leads a workshop entitled 'Grassroots Mapping PDX' where participants constructed and tested solar and helium balloons made of plastic sheeting, for use in the Gulf of Mexico.