The NSF Industry-University Center at FIU has developed tools and expertise to assist in operational and analytical health informatics. The Center’s flagship project, TerraFly has applications in Integrated Vector Management, vaccine management, intelligent management of emerging diseases, cross-analysis of locations of patients and health providers and demographic and economic factors, and other geospatial and data-intensive applications. The Center’s other projects have applications in the analysis of electronic health records, affective social computing, and electronic health agents.

1. Background

According to the World Health Organization (WHO), vector-borne diseases are endemic in over 110 countries in the world and account for millions of deaths each year. Malaria alone, currently the most deadly vector-borne disease, accounts for over 1.2 million deaths per year, most of whom are children under the age of 5[1]. Health officials throughout the world are increasingly alarmed at the spread of the fastest growing vector-borne disease, Dengue Fever, and its more severe syndromes, Dengue Hemorrhagic Fever and Dengue Shock Syndrome. It is estimated that over 2.5 billion people, or 40% of the world’s population, are at risk of contracting this serious disease, with an estimated 50 million infections and 400,000 cases of Dengue Hemorrhagic Fever each year. It is now the leading cause of death for young children in several Asian countries [2;3].

To help overcome the spread of these devastating vector-borne diseases, WHO is advocating a policy of Integrated Vector Management (IVM). IVM is an evidence-based approach to intelligent planning, monitoring, evaluating and delivering vector-borne disease control measures that emphasize and integrate relationships between health and the environment, providing benefits to both [1;3;4]. Although the use of Integrated Vector Management has shown some positive results, much more work is needed. Effective implementation of the management of existing and emerging diseases involves a variety of approaches for rigorous and comprehensive surveillance, monitoring and evaluation of current data, including disease surveillance, vector surveillance and intervention impact monitoring and analysis. It also requires efficient and easy-to-understand means of dissemination and communication of effective interventions for mitigation and response to disease outbreaks [5].

There are some existing tools that can aid in the critical types of surveillance, monitoring and analysis needed for effective Integrated Vector Management. One very powerful modality is the use of Geographic Information Systems (GIS). Geospatial and remotely-sensed data, such as geo-referenced satellite imagery and aerial photography, combined with location-based map data, can provide particularly critical information that either is not available in other forms, or is not otherwise easily conveyed. Specifically, the monitoring and analysis of epidemiological data combined with geospatial data could provide a powerful analytics and easily understood visualization of results. A number of studies have documented the successful use of remotely sensed imaging technologies to track the environmental conditions that encourage the spread of malaria [6;7;8;9]. In these studies, predicted levels of malaria-vector mosquito populations based on remotely sensed imagery and GIS data approximated actual observed levels with upwards of 85% accuracy [10]. The analysis and
visualization of geospatial remotely sensed and related data could also effectively be used for other types of disease such as Dengue.

However, implementing the cutting-edge technology needed for these types of solutions is complex and challenging. Massive amounts of data are required, and this data is often heterogeneous, from divergent sources, and consists of both structured and unstructured data. Further, the tools available for these types of analyses, and the expertise currently needed to use those tools, can be very costly and out of reach for many affected communities [11;12;13;14;15]. Many victims of vector-borne diseases such as Dengue are located in resource-poor areas. In addition, with these limited resources, communicating and improving adherence to the needed interventions is also a major challenge. This makes it a major challenge to find easy-to-use and cost-effective solutions that can help both local and international public health officials’ work towards implementing and maintaining an Integrated Vector Management program.


Combining epidemiological data with remotely sensed imagery and map data would enable public health workers and epidemiologists to identify correlations between environmental and other risk-related data and the spread of diseases. It would also enhance the ability to evaluate the efficacy of various interventions, such as the introduction and continued use of new preventative vaccines, the management of at-risk and affected populations, including patients and potential patients, and the coordination of medical providers. There is an advanced yet easy to use technological solution that can be implemented to further the types of monitoring and analyses needed in Integrated Vector Management (IVM). The needs of IVM are very similar to the needs in other types of disaster mitigation, and one GIS system that is designed for use in disaster mitigation, TerraFly, can provide a powerful solution for IVM. TerraFly is a solution that efficiently and effectively deals with the challenges involved in handling and analysis of massive amounts of heterogeneous geospatial and related data, as well as with the challenges that users encounter when attempting to use traditional GIS tools.

Figure 1. TerraFly Landing Page

TerraFly is a technology and tools for visualization and querying of geospatial data. The visualization component of the system provides users with the experience of virtual “flight” over maps comprised of aerial and satellite imagery overlaid with geo-referenced data. The data drilling and querying component of the system allows the users to easily explore geospatial data, to create geospatial queries, and get instant answers supported by high-performance multidimensional search mechanisms. TerraFly’s server farm ingests, geo-locates, cleanses, mosaics, and cross-references over 40TB of basemap data and user-specific data streams. TerraFly’s Application Programming Interface allows rapid deployment of interactive Web applications to provide customized, innovative
solutions for many domains; it has been used to produce systems not only for disaster mitigation, but also for ecology, medical provider locating services, medical examiner data, crime, real estate, tourism, and municipal services. TerraFly’s Web-based client interface is accessible from anywhere via any standard Web browser, with no client software to install.

TerraFly has been covered by both popular and specialized media, including TV (e.g. Fox and Discovery), radio (NPR), newspapers (e.g. New York Times, USA Today), magazines (e.g. Science) and journals (e.g. Nature). The project’s primary sponsor is the National Science Foundation (NSF). Of the 53,000 NSF-funded projects in 2009, it chose 120, including TerraFly, for the NSF annual report to congress [16].

The TerraFly solution features portability, fly-over data-browsing technology, ability to integrate multiple sets of geospatial and local data into customizable, multi-layered products, and inclusion of powerful but easy to use visualization, querying and analysis tools. As can be seen on TerraFly’s landing page (see Figure 1) [17], users are able to easily select and explore any geographic area of interest. By streaming incremental imagery tiles, TerraFly enables users to engage in virtual flights (see Figure 2) where they maintain full control over flight speed, direction and altitude (spatial resolutions) via an intuitive navigation system.

![Figure 2. TerraFly Flight and Data Layers Control Layout](image)

Unlike most GIS applications [18], TerraFly eliminates the need for the end-user to deal with any technical aspects of the system. The tools available in TerraFly include user-friendly geospatial querying, data drill-down, interfaces with real-time data suppliers, demographic analysis, annotation, route dissemination via autopilots, customizable applications, production of aerial atlases, and an application programming interface (API) for web sites.

Users are able to easily query for data of interest, and have that data automatically visualized in the form of non-obstructing geo-referenced overlays, or data layers, combined with spatial imagery [19; 20; 21; 22]. Any data capable of being geo-referenced can be input into TerraFly and overlaid onto spatial imagery. The most popular types of overlaid data include NAVTEQ NAVSTREETS street vectors, World OpenStreetMaps, property parcels, Yellow pages, White pages, demographics, and Worldwide Geographic places. In addition to data overlays, TerraFly provide users with a drill-down detailed information page on a point or area (see Figure 3). For example, users can use TerraFly to “fly” to a specified address, and then request more specific information about that particular location with a click of the mouse. A preview page will pop up in the flight window that contains a summary of information about that location, along with links to more detailed location information.
A critical component of TerraFly is its data repository, and a major strength lies in its integration of heterogeneous data sources including relational and semantic databases and web sources with spatial data. TerraFly's data repository was one of the first GIS databases that were able to store heterogeneous data in one database [23;24;25;26;27;28]. As with other GIS tools, there are two main types of geo-referenced spatial data that TerraFly must handle: raster (satellite and aerial photography) and vector data (points, lines and polygons) [29]. TerraFly's data repository currently stores over 40TB of geospatial and related data.

![Figure 3. Sample of TerraFly's Data Drill Down](image)

### 2.1. Advanced Data Visualization Capabilities

One of TerraFly’s cornerstone capabilities lies in its empowerment of its users. TerraFly provides robust systems and tools that are very flexible and easy to use, so that end-users can focus on the work that they need to get done without having to worry about the technology behind the system they are using. Even non-technical users are able to very quickly and easily create complex queries that combine heterogeneous data without requiring database expertise. For example, for effective vaccine management, more than surveillance and analysis to track and predict outbreaks of disease is needed. Appropriate and efficient planning and dissemination of preventative and intervention vaccines is also needed. TerraFly can provide easy-to-access tools to aid in the planning and coordination needed for this type of work.

TerraFly is able to easily combine complex, medical-related queries with geospatial data to provide users with information such as the location, distribution and density of medical clinics in relation to population, or any other information of interest. With a few clicks of the mouse, this information is presented to users in both visual and textual forms. An example of this can be seen in Figure 4, which visualizes the following query: “Where are all of the medical clinics that do not have backup clinics nearby and are located in middle income areas within densely populated sprawl.” This type of query could easily be changed to accommodate the user's informational and analytical needs. It could, for example, help public health and other officials intelligently plan and coordinate the most effective interventions by looking at patient and population density combined with possible medical outreach location distribution.
Figure 4. All of the medical clinics that do not have backup clinics nearby and are located in middle income areas within densely populated sprawl.
A powerful capability of the system is the TerraFly TimeSeries application. This application has a unique ability to provide efficiently retrieve geospatial and remotely sensed imagery of the same geographic location that was acquired during different time periods. The system is then able to create an animated sequence over time to clearly show historical changes. The resulting time series can be quite dramatic and useful. This capability has been used in disaster mitigation, and would have similar, powerful applications in Integrated Vector Management. For example, TerraFly could be used to monitor changes in certain features or characteristics of a particular area that are considered risk factors for a disease such as Dengue, or be used to monitor the efficacy of new interventions such as the use of preventative vaccines.

The recent earthquakes and tsunami that hit Japan in March of 2011 provides an example of the power of this technology. As can be seen in Figure 5, the before, during and after geospatial images, respectively, of the tsunami are quite dramatic. In the image from April 4th, 2010, entire neighborhoods can clearly been seen as having been established and intact. The image from March 12th, 2011, the day after the tsunami hit, shows that water has rushed well inland, inundating those neighborhoods. The final image, from March 19th, 2011, shows the aftermath once the waters have finally receded. Those neighborhoods were completely decimated.

TerraFly includes autopilot technology that allows users to preplan and map out a customized flight path of interest. With this tool, end users can quickly and easily select specific destinations, and the system will automatically create that flight path at the speed and altitude (resolution) desired at will by the user. The user is able to determine which features will be displayed while traveling in the flight path. In essence, any feature or information that is possible to view when the user is in manual mode can be added as a component of the requested flight path. For example, public health officials could create coordinated autopilot flight paths over specific areas of interest to aid in monitoring and analysis of disease spread. They would not have to manually control movement over the area of interest and could, instead, just focus on gaining the information that they need. Further, this same
flight path could easily be used over and over as updates and new information come in, and its path can be annotated with voice clips, images, and data.

TerraFly also provides numerous data analysis and visualization tools for scientists in various domains. Figure 6 shows Hydrology data analysis tools in TerraFly. With this tool's intuitive interface, users are able to view and analyze data, and have results of their analyses displayed as imagery, charts and tables. Additional functionality found in TerraFly, such as time series data, key word searches, and layer control, is also available on this screen. For example, users are able to select a date range and view time series animation of changes, as well as graphs that plot these changes over time. As can be seen in Figure 7, very detailed geospatial temporal plots are available to users of this application. As with all TerraFly flight windows, locations are searchable by address, and more detailed data for specific points is available at the click of the mouse. For example, clicking on one of the stations provides information about that particular site. With TerraFly's flexible technology, interfaces and analytical capabilities can easily be customized for specific uses for Integrated Vector Management.
There are also numerous capabilities in TerraFly that individuals find useful in their day-to-day lives that could be useful for public health officials. Overlaying data from the White Pages, for example, improves its usability for many individuals (see Figure 8). Users are able to search for needed information in the White Pages not just by a person’s full name, but also by attributes such as address, phone number, or the names of other individuals in the home. Alternately, users can search the geospatial imagery visually to find a particular location, and related information.

![Figure 8. White Pages](image)

### 2.2. Summary

Through the implementation of innovative techniques and technologies, TerraFly provides users with GIS capabilities without the need to learn complex interfaces or deal with the technology behind the system. It is a robust, user-friendly system that has wide appeal to many different types of users, and application to many different domains. The use of TerraFly in Integrated Vector Management could provide public health officials and researchers with critical analysis and visualization tools that they otherwise would not have access to, increasing our capabilities to mitigate, and eventually eradicate, vector-borne diseases.

### 3. Affective Social Computing and e-Health Agents

Another critical part of Integrated Vector Management is on-the-ground interventions that require the aid of health care and other professionals, particularly when for the need to address behavioral health issues. It is economically impossible for medical and healthcare professionals to provide appropriate medical care and health education for the millions in need, particularly in areas that have limited resources. As a result, work on the design of patient-centered computer-based interventions could greatly improve our ability to provide rapid and effective interventions.

Research has shown that patient’s readiness to change is the single most powerful determinant of behavior change. A patient’s readiness to change is itself greatly influenced by a strong therapeutic alliance (i.e. the collaborative relationship between the patient and the health professional). This suggests that “how the doctor prescribes is actually more important than what the doctor prescribes!” However, physicians are often rushed and sometimes untrained to build a conducive patient-physician alliance. Further, in areas with limited resources, physicians may not be readily available at all times. To help provide more effective interventions, it is important to study how socially engaging and empathetic virtual characters can contribute to provide complementary e-health automation that is needed in order to address growing societal problems for a number of health issues.
Specifically, we **build e-health help agents**

- that users can access anytime (even when traveling),
- that users can actually use (and do not require technical sophistication),
- that users will actually use (non-threatening, supportive, culturally sensitive), and
- who are emotionally competent because these lifestyle issues are intensely emotional for the users.

![On-Demand Personal Health Counselor](image)

**Figure 8. On-Demand Personal Health Counselor**

Our approach involves designing and developing **dialog-based virtual characters** who can dynamically *adapt* their (repeatable) health promotion interventions to their patient’s needs and preferences, by using an *empathetic* style of motivational communication when addressing the desired behavior change. This is achieved by using motivational interviewing conversational techniques (e.g. asking non-threatening open questions), appropriate verbal and non-verbal multimodal expressions (e.g. choice of words, facial expressions), matching the character’s ethnic features and language to those of the patient, keeping track of the patient’s progress, fluctuating stage of change (readiness), in an updated user-model self-monitoring system, and increasing access to e-health for underserved population by developing help agents on different delivery platforms.
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